Green is the Colour: St. Petersburg's Chemical Laboratories and Competing Visions of Chemistry in the Eighteenth Century

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Abstract: Histories of chemistry in eighteenth-century Russia have often ignored or downplayed the scientific character of chemical sites outside the chemical laboratory of M. V. Lomonosov in St. Petersburg's Imperial Academy of Sciences. This essay surveys a variety of Russian medical, military, and academic chemical sites and suggests that dividing them up as scientific or non-scientific sites is unhelpful, as many were integrated and engaged in connected enterprises. A case study then shows how the setting of Russian court society provoked competition within the network of Russian chemical sites. Competition led Lomonosov to urge a sharp division of labour between chemical artisanry and chemical science, forging a distinction that historians of Russian chemical sites have often reproduced subsequently.

In the eighteenth century, the laboratory, insofar as it existed in Russia, was a site for doing chemistry.[1] Chemistry, or *khimiia*, a term introduced during the reign of Tsar Peter I (c. 1696-1725), might refer to a variety of things, taking in pursuits from alchemy and medicine to pyrotechny and metallurgy.[2] In his 1749 *Description of St. Petersburg*, the Russian author A. I. Bogdanov identified three types of laboratory (*laboratoriia*) in the Russian capital. These were the chemical laboratory of the Imperial Academy of Sciences, the fireworks laboratory of the Arsenal; and the laboratory of the Chief Apothecary (*Glavnaia Apteka*). Bogdanov noted “they have other laboratories in almost all the apothecaries, as many as may be found in Saint Petersburg, in which they make all sorts of medicaments.”[3] In recent times, historians have been more particular than Bogdanov in the way they characterise Russian chemical sites. Henry M. Leicester proposed that the chemical laboratory of the Imperial Academy of Sciences, founded by Mikhail Vasil'evich Lomonosov in 1748, was “the first in Russia”, ignoring the pyrotechnic and apothecary’s establishments.[4] In his numerous works on the Russian chemical industry the Soviet historian P. M. Luk'ianov alternatively identified Lomonosov’s laboratory as one among many others, but characterised it as the “first scientific research laboratory” in Russia. Of the other chemical sites in Russia, Luk'ianov noted, “we do not know of any scientific investigations which were carried out” in them.[5]

A wealth of literature on the famous Lomonosov has further emphasized the exclusivity of his laboratory as a site of chemical investigation.[6] This essay will remind us that Lomonosov’s laboratory was not the only place where chemical activities or investigations occurred in eighteenth-century Russia. There were a variety of locations where practitioners worked with, thought about, and experimented upon chemical substances, using techniques and approaches that have often subsequently been separated into distinct categories of the ‘industrial’, the ‘scientific’, the ‘military’ and so on.[7]

Here the focus will be on a variety of sites engaged in chemical labours, from academic laboratories to apothecary’s shops and artillery manufacturies. The stress will be on connectivity, interactions, and integration between different kinds of chemical institution in Russia, and between Russian and non-Russian sites of chemistry. Rather than offer a “nationalistic” history, it is here emphasized how Russia became part of a broader network of chemical sites spanning Europe in the eighteenth century. The first part of the paper explores some of the key chemical sites in eighteenth-century Russia. Although much more work would be needed than is possible here to obtain an exhaustive survey, this section will begin to trace some of the ways in which sites were connected and integrated, through exchanges and movements of personnel, materials, and apparatus. Turning to the chemical laboratory of Lomonosov, I shall suggest that the Russian chemist himself promoted the idea of dividing chemical sites up according to alleged degrees of theory versus practice, and did so as a strategy in efforts to exclude non-academic chemical sites from the map of legitimate chemistry. The second half of the essay then explores this theme through a competition among various chemical practitioners in the middle decades of the eighteenth century over the pyrotechnic effect of ‘green fire’. This will offer a context for making sense of Lomonosov’s divisive strategies, which have featured in the historiography of Russian chemistry ever since.

1. The Network of Russian Chemical Sites

Rather than try to distinguish laboratories in Russia by their contributions (or lack of them) to chemical theory, it might be better to emphasize their similarities.[8] All grew out of a particular historical context and the needs of the Russian monarchy and state to enhance its status as an empire and military power. Many chemical sites emerged as the Tsars sought to improve the health, wealth, and war-making capacity of the state. This began in the sixteenth century and accelerated during the reign of Peter the Great (1696-1725) who sought to expand Russia's military and civil service in the face of war with the Swedish empire of Charles X.

i. Apothecary's Laboratories

Imported foreign expertise was crucial to the development of Russian chemistry from at least the sixteenth century. In the case of pharmacy, English merchants and physicians enjoyed close collaboration with the Muscovite court through the trade of the Muscovy Company incorporated in 1555. English doctors and apothecaries served the Russian tsars for more than a century, and typically brought, indeed were expected to bring, chemical and medicinal materials and apparatus with them to Russia. In the sixteenth century one assumes these were mostly herbal ingredients. But by the end of the seventeenth century chemical medicaments were being imported. Samuel Collins, physician to Tsar Alexis from 1659 to 1676, furnished the Tsar with "pleasing and yet effectual Chymical Medicines" which were given to him in London for Alexis by Robert Boyle.[9]

Chemical activities accelerated during the reign of Peter the Great as the Tsar set about transforming the old Muscovite empire into a more European-looking and more up-to-date military power.[10] Peter expressed a fascination with foreign learning from his childhood and in 1697-98 undertook a Grand Embassy to western Europe to meet and hire experts in a range of technical skills for service in Russia. He visited Hermann Boerhaave in Leiden, the Oxford iatrochemist Moses Stringer in London, and witnessed chemical experiments by Etienne-François Geoffroy and Louis Lémery in Paris.[11] Among the foreigners who entered Russian service was Robert Erskine (Areskin in Russian) a Scot who soon became Peter's personal physician.[12] Also serving Peter was Jacob Bruce, born in Moscow to a Scottish father, and a close friend of Peter's from a young age. Bruce spent time in England and the Netherlands studying metallurgy, mathematics and natural philosophy before returning to Russia in 1699.[13]

Bruce and Erksine played important roles in developing chemical endeavours during Peter's reign. These were largely prompted by war, as Peter fought first the Ottoman Turks in the 1690s and then Sweden in the Great Northern War (1700-1721). To win these campaigns Peter strove to re-engineer first the Russian army and then civilian society on a European model. War prompted significant growth in medical production, much of it overseen by Erskine. The production of medicines increased, as Peter insisted officers should receive free medications. Peter himself was fascinated with medical chemistry, and owned a personal field apothecary's cabinet.[14] While Moscow remained the capital city, the large-scale production of medicines took place under the auspices of the Apothecary's Chancery (*Aptekarskii prikaz;* from 1707 *Aptekarskaia kantselariia*), overseen by Erskine from 1706, and eight small liscenced apothecary's shops in the city.[15] The Dutch traveler Cornelius Le Bruyn described the Chancery building located on the east side of the Kremlin as a "dispensatory for medicines" containing two halls, "one of which serves for a laboratory, and the other for a library, wherein extraordinary plants and animals are likewise preserved."[16]

After St. Petersburg became the capital in 1713, the focus of medical chemistry was the Chief Apothecary (*Glavnaia apteka*) and its associated laboratory, the one identified by Bogdanov, and again overseen by Erksine. From about 1704, these laboratories were located in a bastion of the Peter and Paul Fortress, one of the first buildings to be constructed in the new city, but from c. 1731-2, they were relocated to Millionaia ulitsa ("Millionaire's Street") near what is now the Winter Palace.[17] In Peter's reign, the laboratory, also known as the "court apothecary" (*pridvornaia apteka*), produced medicines for the imperial family, the armed forces and nobility, stocked smaller apothecaries in the city, and carried out duties assaying chemical products sent from factories and mines across the empire.

The scale of this institution is notable. Visitors noted the busy chemical labors of the *Glavnaia apteka* on Millionaia, and also viewed the building as a form of exhibit, containing rarities.

> This apothecary is remarkable not only for its great and broad building, the multitude of servants and almost unbelievable quantity of medications, daily prepared within it and sent to the army, but also for its valuables – in it may be found jugs and vases of the most delicate Chinese porcelain.[18]

Another laboratory was subsequently established beside the Apothecaries' garden on the appropriately-named Apothecaries' Island in the north of St. Petersburg. Here again large quantities of medicine were produced for the armed forces.[19] Military medicine led to further new chemical sites, because from 1735, a decree ordered that military hospitals must also include a laboratory "for making all sorts of medications."[20] The Admiralty similarly maintained its own apothecary.[21] There were other, smaller crown apothecaries in the city, and as Bogdanov noted many of these contained laboratories.[22] A network of medical-chemical sites thus covered the city, linked through the supply of medications from the central state apothecaries.

ii. Assaying Laboratories

Another area where Peter introduced new chemical practices was in assaying. Peter wanted to expand Russia's war-making capacity and set about creating manufacturies to produce ordnance, gunpowder and ammunition. This in turn stimulated the growth of mining in the Ural mountains and Siberia to provide more metal. To pay for his reforms, Peter also reorganized the coinage in Russia and built new mints. All of these institutions demanded skills in metallurgy and assaying to test and improve the quality of metals and other chemical substances, prompting the foundation of numerous assaying laboratories in Petersburg, Moscow, and in the mining provinces of the empire.

Peter was personally interested in assaying, and at one point on campaign in Riga he ordered an assaying furnace to be sent to him.[23] The key figure in this work, however, was Jacob Bruce, chief of the Russian artillery, president of the Board of Mining from 1717, and director of St. Petersburg's mint from 1720. Bruce maintained a chemical laboratory at his Glinka estate near Moscow and a cabinet of curiosities containing mostly metals and minerals. Peter Collis has proposed that Bruce was interested in alchemy, though no direct evidence of alchemical pursuits remains besides numerous works in his library by figures such as Johann Kunckel, Basil Valentine, and Paracelsus.[24] Certainly Bruce inaugurated numerous chemical sites in Peter's reign.

A permanent crown assaying laboratory was constructed for the College of Mines (*Berg-kollegiia*) in 1720, close to the St. Petersburg Foundry court (*Liteiny dvor*) where Bruce resided and cannon were cast for the artillery. The Russian artillery evidently supplied materials for the new laboratory, which was built of brick and cost a thousand rubles to construct.[25] A wooden assaying laboratory was built on the fifth line (i.e. street) of Vasilevskii Island fifteen years later, but soon fell into disrepair.[26] Consequently the College of Mines established further laboratories on Vasilevskii Island, first in the Pskov townhouse on the twenty-fourth line, and then, after this building also fell into disrepair, from 1772 on the ground floor of a building belonging to the vice-president of the chancery, Kherasov. These laboratories appear to have been both residences and working places for officers and students employed by the College of Mines.[27] More laboratories were created for several new Russian Mints (*monetnye dvory*) established under Peter and Bruce, first in Moscow in Kitai-Gorod (Chinatown) and Red Square (1696-7) and then in the Trubetskoi bastion of the Peter and Paul Fortress of St. Petersburg (1725) and in the mining town of Ekaterinburg (1720-25). These mints produced a new European-style coinage for

Russia, with circular coins, Latin inscriptions, and images of Peter as "Imperator" or Emperor, rather than Tsar, of Russia.[28]

Elsewhere in the empire, mining enterprises expanded rapidly in the course of the eighteenth century. As South American mines suffered a crisis, Russia became a key global supplier of precious metals, and this led to rapid growth of mines in the Ural mountains and Siberia.[29] New mining works typically included an assaying laboratory. The works of Ekaterinburg (Sverdlovsk) included an assaying hut or house (*probirnaia izba*) with an area of a hundred square feet from c. 1730. By the end of the century, this laboratory was known for specializing in the assaying of gold and silver. There were six workers in it, with annual salaries of 227 rubles a year.[30] The assayer Johann Wilhelm (Ivan Andreevich) Schlatter recorded the appearance of an assaying laboratory in the Iaguzhinskii copper-smelting works in Perm c. 1760, showing assayers at work with furnaces and scales in a large room.[31] Other assaying laboratories existed at Polevskoi, Barnaul, Nerchinsk and Solikamsk, most being founded towards the end of the eighteenth century.[32]

The personnel who worked in these various medical, metallurgical, and military institutions were diverse, a mixture of Russians and foreigners, often of German origin - indeed, apothecaries' apprentices in Russia were known as "gezeli" from the German *Geselle* for journeyman.[33] Little is known about these workers, but once again, we can stress their international character and the integration of Russian and European chemical sites by tracking some of the people who moved through them. Students, for example, were sent from provincial mines in Siberia and Kazan to the assaying laboratory in Moscow, where they were educated by the German chief assayer Johann Gottlieb Lehmann.[34] Assayers also had links to the Imperial Academy of Sciences, founded in St. Petersburg shortly after Peter's death in 1725. Peter's Scots physician Erskine and his successor as head of the Medical Chancery Lavrentii Blumentrost oversaw Russia's first scientific Academy in its early years, which remained connected to apothecaries throughout the eighteenth century.[35] One of the first corresponding members (from 1756) was the Chief Apothecary Johann Georg Model, a prolific author who previously worked in Württemberg and whose diverse "Oeconomic-Physical-Chemical Treatises" testify to the hybrid nature of Russian institutions.[36]

After the Academy began operations, it did not include a chemical laboratory, perhaps because there were already several in the city, nor did it have a professor of chemistry, since the first invited, Michael Burger of Courland, died shortly after arriving in Russia.[37] Nevertheless, a number of people close to the Academy were physicians or had connections to the laboratories of the Mining and Medical Chanceries. Besides Erskine and Blumentrost, professor of physics Georg Wolfgang Krafft and the Swiss professor of botany Johann Amman advised the College of Mines on assaying.[38] Mining ventures were also assisted by academic expeditions to Siberia, which charted the region, while mining officials such as Vasily Nikitich Tatishchev and the Dutch engineer Wilhelm de Hennin supplied the academy with ethnographic and geographical information based on surveys undertaken to establish new mines and smelting works.[39] Though it would need more research, there was evidently a network of intelligence and expertise linking sites of chemical investigation, academic scholarship, and state-sponsored industry across the Russian empire.

Laboratories were also connected through their material culture, as machinery and glass, metal and ceramic-ware were supplied by works outside the capitals and in the provinces. The Foundry Court (*Liteinyi dvor*) of the Russian Artillery provided materials to build the College of Mines' assaying laboratory in Petersburg, while glass and metal works at Iamburg and Olonets supplied the College of Mines with chemical apparatus. Provincial works sent samples of ores and other products to the capital's assaying laboratories for testing. The first assaying laboratory in Moscow tested sulphur produced by the Afonchikov factory in 1735 in the Medynskii region.[40] In the 1720s, the laboratory of the Chief Apothecary tested samples of aqua fortis, vitriol, and rosin made in the Savelov and Tomilinii factories, sent by the College of Mines.[41] Chemical substances, construction materials and apparatus thus prompted exchanges between different chemical sites.

iii. Pyrotechnic Laboratories

Of course while there was integration and exchange among chemical institutions, there were also distinctions. Laboratories had specialized functions, serving particular institutions and employing personel with particular expertise and experience. The labors of the apothecary and the assayer centered on the furnace, and the use of heat to distill liquids and melt metals. It served these laboratories to be situated relatively close together in urban centers, and personnel and materials seem to have moved between them regularly. The third type of laboratory identified by Bogdanov was different. Pyrotechnic laboratories, which used gunpowder to manufacture fireworks and ammunition, necessarily had no furnaces, and while they were at first located in city centres, typically in castle bastions, they gradually moved out to the edge of the city by the end of the eighteenth century in order to minimize the damage an explosion might cause.

“Liaboratorium”, an early Russian term for “laboratory” first appeared in what was probably a reference to a pyrotechnic laboratory in Riga in 1710.[42] As in the case of medicine and assaying, Peter the Great was an enthusiast for fireworks, composing recipes and setting off displays himself. Fireworks were used in Russia in the sixteenth century, but displays staged by the court for military triumphs, royal occasions and new year only became regular events in Peter’s reign.[43] A pyrotechnic laboratory existed in Moscow in the 1690s, before a new one was built in the Peter and Paul Fortress in 1705.[44] In the early 1730s, however, the head of the War College Burchard Christoph von Münnich oversaw the construction of a new laboratory situated in St. Petersburg’s Arsenal on the Moscow side, to the west of the Fontanka canal. In his autobiography, the Russian artillerist Mikhail Danilov described the laboratory as,

> a large square room, one side of which measured 30 arshins [70 feet]. There were a great number of people in this [room], all kinds of masters, some composing plans, others filling fountains [fireworks]... in addition, a few persons from the bombardiers of the Preobrazhenskii regiment worked under instruction [and] carpenters, turners, and mechanics were located in the corners of this room.[45]

'Plans' were large brightly-painted boards with pictures and mottos laid out in tracework that would be illuminated with a gunpowder mixture during a display. Other fireworks produced included rockets, various balls packed with stars and projected with mortars, and candles.[46] Artillerists seem to have recognized the hazards posed by working with gunpowder, since this laboratory was relatively distant from the centre of town, backing on to the Neva river past the canal, which supplied water in case of fire and an uninhabited area in case of explosions. However, the Preobrazhenskii regiment had barracks nearby, and the building closest to the laboratory was a military hospital (*lazaret*), so precautions only went so far, and were minor compared to later pyrotechnic laboratories. Indeed there were serious accidents from time to time. Danilov reported in 1757 how,

> As soon as I left [the laboratory], a fire occurred there from carelessness. The whole huge room was seized by flames and by powdery, mercurial smoke, which caused the people there a sudden, great confusion. Many, from fear and despair, unable to cry out, tried to save themselves in a headlong rush for the single door. One after the other was crushed... many were seized by the smoke and stopped breathing, and no longer able to run, they fell to the ground unconscious.[47]

The single exit is again a notable feature, and suggests that safety provisions in the pyrotechnic laboratory were limited.

While the pyrotechnic laboratory was relatively distant from other chemical sites, there were nevertheless links between them. Chemical substances – gunpowder, not least – had to be purchased and brought to the arsenal from elsewhere; accidents landed fireworkers in hospital or demanded medicines; and the production of ammunition connected the fireworks laboratory to the foundries and assaying laboratories responsible for producing ordnance. The Academy of Sciences provided another link, since the Academy's professors were responsible for designing fireworks 'plans', which they submitted to the laboratory for production and performance.[48]

Academicians appear to have been less than enthusiastic about collaborating with artillerist fireworkers, however. In a court society fireworks and illuminations provided opportunities for academicians to distinguish their labors from those of other chemical workers. Eighteenth-century Russia was a hierarchical society in which social advancement depended entirely on the achievement of rank (*chin*) in a formal Table of Ranks. Rank was awarded by the crown, and so there was much incentive to impress the court and monarch. While chemical sites might share techniques, materials, and personnel, exactly this proximity could engender rivalries. One occasion for such rivalry was the courtly fireworks display. When the Academy of Sciences designed fireworks scenery, it produced a printed brochure, rather like a theater program, which was distributed to noble and elite members of the audience.[49] Partly a means to educate Russians in unfamiliar European and classical iconography and emblems, the descriptions also served a valuable function for the Academy. Professors very rarely mentioned the fireworks in displays and focused almost exclusively on explaining the iconography – that is, the part that they were responsible for. This is notable because audiences typically remarked on how spectacular the fireworks were at Russian displays, and almost never discussed the scenery – and when they did they usually misinterpreted it. Printed descriptions thus served as a way to draw audiences' attention away from the visceral experience of ingenious pyrotechnic effects and hence diminish the potential for artillerists to receive the credit of the court for displays. Academicians rather emphasized the more intellectual, emblematic dimension of fireworks, and hence sought to drive a wedge between the fireworks laboratory and the Academy's contributions to displays.[50]

Chemical sites in Russia thus overlapped, but their contiguities could lead to competition among practitioners. Academics sought to divide the intellectual from the practical elements of chemical practice in order to obscure the contributions of rivals in a social order based on obtaining rank and rewards from the monarch and courtiers. The same strategy is evident in the work of the Academy of Sciences' first professor of chemistry, Mikhail Vasil'evich Lomonosov. Turning to Lomonosov's chemical laboratory, it will be seen how, in the 1750s, Lomonosov sought to distinguish his chemical work as distinctively theoretical, in order to offset the successes of rival chemists. He did so during efforts to claim precedence over a controversial new phenomenon – "green fire".

2. Repositioning Chemistry: the Case of Green Fire

Laboratories were critical sites of chemical manufactures in eighteenth-century Russia, but there were also sites of chemical performance, in theatres, opera-houses, and at fireworks displays. Both kinds of space brought together expertise from the empire and abroad, figures such as the assayers Schlatter and Lehmann, and the physician Erskine. Another foreign expert appeared in Moscow in the 1750s.

Giuseppe Sarti was a Bolognese pyrotechnist and associate of the most famous fireworkers of the age, the Ruggieri brothers of Paris. Nothing more is known of Sarti except that he had performed in London in 1749 with the Ruggieri, and seems to have remained in Russia until 1760.[51] He first appeared presenting fireworks to the imperial family at the Moscow opera house, before moving on to St. Petersburg to show further displays. The court found the performance extraordinary. It took place, according to Danilov,

> after a tragedy, to the great pleasure of all the spectators; it consisted of various changing figures, burning one after the other with great order and accuracy, the figures made up of rockets of white fire, with moving wheels and fountains.[52]

Sarti was rewarded with a position in the Russian artillery, but his success prompted competition from Russian fireworkers, keen to secure advancement in the Table of Ranks. After seeing his Moscow performances, Mikhail Vasil'evich Danilov and his colleague *ober-feierverker* Matvei Martynov resolved to imitate Sarti's techniques. But as Danilov explained,

> I must confess that we had not a little difficulty in making fires and sparks similar to his, which by their great size appeared excellent; and on hearing praise for this Sarti from many courtiers, we resolved not only to make a firework similar to Sarti's, but also to show something still better of another kind. Martynov asked if it was possible for us to show a firework in the same opera house. We applied all our strength to the invention of all sorts of rarities

> for presentation to the spectators; however we would not have been victorious if an unexpected event had not led me to try to make a trial of green fire, which had never been found in all the world… I took Venetian *iar*, dissolved it in alcohol, soaked gun cotton with it, set it alight and saw that it burned with a very green flame. I continued to make many trials with this, and succeeded in making it burn having made figures from it.[53]

Pyrotechnic competition thus led to novel chemical experimentation among practitioners outside the Academy of Sciences. Although it is not stated that Danilov's trials occurred in the Fireworks Laboratory, evidently chemical investigations were not restricted to Lomonosov's laboratory. Neither was this a trivial contribution, because Russian green fire would later come to be seen as a forerunner of all coloured fires in pyrotechny. Nineteenth-century writers suggested that the search for a green fire was the "desideratum" of previous pyrotechny.[54] Little evidence of this remains, but Danilov was certainly not the first European to propose methods for colouring fireworks green. Many sixteenth and seventeenth-century treatises included lists of ingredients for tinting flames green by using verdigris (copper acetate) or sal-ammoniac (ammonium chloride).[55] In 1739, the Italian Raimondo de Sangro, Prince of San Severo, claimed to have made a green fire, and in 1743, a similar claim was put forward for Count Friedrich August Rutowski, illegitimate son of Augustus the Strong of Saxony.[56] The Russians had also made green fire before, with fireworks in St. Petersburg in 1710 showing "beautiful light blue and green fires, invented by the Tsar himself" and another display in 1737 included "palm trees made with white and green fire."[57] Probably these colours were only pale, and later writers suggested that the intense fires of nitre and sulfur in gunpowder destroyed any colour produced by additives in these displays.[58] It was easy to tint flames green, but very hard to make a gunpowder mixture that burned with the same intense colour. It is not clear what Danilov's method added to these compositions, but it appeared to surpass available recipes.

Certainly Danilov and Martynov's green fire was a sensation, and appeared in many displays for the court for several decades, though as Danilov noted, the artillerists received no reward for the discovery. One person who recognized the significance of this development was Lomonosov, the Academy's professor of chemistry, and also, between 1751 and 1755, the Academy's principal designer of fireworks scenery and iconography, a role he took from the professor of rhetoric and poetry Jacob Stählin.[59]

Perhaps as a means to distinguish himself above his competitor Stählin Lomonosov's pyrotechnic designs included not only suggestions for scenery and emblems but also references to novel fireworks such as "spiraling rockets, invented by myself and demonstrated in tests."[60] The place where Lomonosov worked on these rockets was his chemical laboratory, located in the botanical garden of the Academy very near Lomonosov's residence between the first and second lines of Vasilevskii Island (now no. 45 on 2nd line and 52 on 1st line). Constructed in 1748 to Lomonosov's design, it consisted of a single building forty-six feet long, thirty-four feet wide and sixteen feet high. This contained three rooms with a hearth in the center, acting as a foundation on which furnaces of different kinds could be set up.[61] Here Lomonosov engaged in metallurgy, physical and industrial chemistry, and in particular the manufacture of porcelain and coloured glass for mosaics, both of which led Lomonosov into industrial ventures to produce these on a large scale.[62]

Here Lomonosov also tried to replicate Danilov and Martynov's green fire. Lomonosov's notebook for December 1755 recorded that, "Today, under my direction, Klementev the laboratory assistant is investigating how to make high-reaching green stars for the fireworks."[63] However, no further experiments on fireworks by Lomonosov are known. His efforts evidently failed. But this did not stop Lomonosov from attempting to appropriate the fireworkers' invention. He did so by arguing that artisans could not create legitimate chemical innovations without an understanding of chemical theory.

The occasion for this claim was one of the Academy of Sciences' public assemblies, a site for chemical and other scientific lectures held before members of the imperial family every year. In July 1756, Lomonosov presented an "Oration on the Origins of Light, presenting a new theory of colours".[64] By this time, Martynov and Danilov's green fire had been appearing regularly in courtly fireworks for more than a year, displayed on decorations of royal monograms, laurel crowns, and palm trees.[65]

Lomonosov used his public oration to undercut his rivals, a tactic he had employed before. When Stählin sought to build up a cohort of fine artists at the Academy in 1751, Lomonosov gave an "Oration on the Use of Chemistry" in which he claimed that "painting… depends entirely upon chemistry. Should we take away the means for preparing pigments, we would be deprived of the pleasures of portraiture."[66] Any artistic endeavours in the Academy must depend on Lomonosov's particular skills. Lomonosov used the same tactics in his oration on the origin of light. Here Lomonosov described his ideas on the origins of colour, following a corpuscular theory in which different mixtures and motions of ether particles produced different colours. Experience in the chemical laboratory was presented as vital to this theory, since experiments with fireworks and glass mosaics were claimed to reveal three primary colours corresponding with three chemical principles of salt, mercury, and sulfur.[67] Changing recipes produced different colours. Antimony, "a body rich in mercury" yielded a yellow-tinted firework, showing that mercury was the ether particle giving all yellow bodies their colour. Furthermore,

> A flame of green colour, though shown by many burning bodies, comes most of all from copper… when this melts, the whole flame becomes green when fresh cold charcoal is thrown on it… the heat of the flame is decreased by the cold charcoal, the acid material of the hot copper loses its rotary motion force while the inflammable and mercurious materials [sulfur and mercury] are heated enough by the weak heat for motion. Thus without motion of the red ether [produced by salt], the yellow and blue present green to the sense of vision.[68]

Lomonosov thus provided a chemical explanation for the production of green flames using copper and charcoal, though he did not explain how to *make* a green firework, in which these chemical constituents would have to burn with gunpowder to produce the colour – the problem that makers of green fire always faced and which Lomonosov himself seems to have failed to resolve. Nevertheless, Lomonosov was quite specific about the importance of such a chemical theory of light. At the conclusion of the oration, he declared that since Nature functioned chemically to produce colour, knowledge of chemical theory was fundamental to any legitimate site of chemistry,

> those who, because they turn their praise to chemical practice alone, do not venture to raise their heads above soot and ashes in order to seek the reason and nature of primary particles composing bodies... are to be considered vain and sophistical. For knowledge of the primary particles is as necessary in physics as the primary particles themselves are necessary for composing sensible bodies.[69]

In particular, Lomonosov sought to distinguish himself from those who made "simple discoveries without any supporting evidence and without enough work to justify them."[70] Perhaps Lomonosov's criticisms were aimed at Danilov and Martynov, who had recently produced a remarkable new invention with no chemical education. Lomonosov, unable to replicate their green fire, then asserted the necessity of theoretical knowledge in chemical innovations. Only the trained chemist could legitimately offer novel inventions in the realm of colour.

In the context of the competition over green fire, Lomonosov claimed that theory *must* be included in practice. Such claims diverted attention away from Danilov and Martynov in an institution that had a tradition of obscuring the ingenuity of artillerist-fireworkers. Yet Lomonosov did not discover Danilov's secret and it was another fireworker who figured out the recipe for green fire and replicated it. This officer's activities provide a final example of how integrated chemical sites and labors, experiments and industry, theory and practice were in eighteenth-century Russia, contra Lomonosov's efforts to distinguish his laboratory as an exclusively legitimate site of chemistry.

Around 1759, a young officer of the Noble Cadet Corps, Petr Ivanovich Melissino, began studying pyrotechnics with Sarti, and earned a position at the Arsenal's fireworks laboratory alongside the Italian.[71] Melissino then employed the skills of another chemist, St. Petersburg's chief apothecary Johann Georg Model, the early corresponding member of the Academy of Sciences, to successfully divine the recipe for green fire.[72] Thereafter, during the final years of Elizabeth Petrovna's reign, Sarti, Martynov, and Melissino shared the responsibility of executing fireworks, which now incorporated a variety of impressive colour compositions.[73] These were created through experimental investigations at the fireworks laboratory, and, presumably, at the apothecary's laboratory where Model worked. Hence the artillery major Mikhail Alekseevich Nemov, who executed fireworks in the 1770s, was "noted for his experience in chemical labors" to produce bright colours, including green and a "gold brilliance".[74] These coloured fires became internationally famous. In 1766 Antoine Lavoisier tried to produce a green flame for fireworks but like Lomonosov, he failed. In the nineteenth century, when new chemicals enabled the production of a range of coloured fireworks, green continued to be known as "Russian fire".[75]

Conclusion

Lissa Roberts and Rina Knoeff have observed that eighteenth-century chemistry was "a dynamic field whose terrain extended from the lecture hall to the manufacturer's workshop, from the dissecting table to the sociocultural pretensions of apothecaries."[76] This was certainly true in Russia, where diverse forms of laboratory engaged in chemical labors across the capitals and provinces of the empire. This essay has emphasized some of the connections between different kinds of laboratories, tracing material, personal, and technical exchanges and circulation between apothecaries, academics, assayers, and fireworkers. To follow a point made by Ursula Klein and Emma Spary, Russian chemical sites were typically "hybrid spaces", linking skills, apparatus and materials from medical, military, scholarly and industrial practices in multiple countries.[77] In all probability their architecture also shared many features: certainly the fireworks laboratory, the Kherasov mansion assaying laboratory and Lomonosov's chemical laboratory all consisted of a single floor, at ground level, no doubt to make water supply and material transportation easier.[78]

There were also divisions, based on specialized tasks and personnel, and different institutional and geographical locations. But for most there was not a strong distinction between practical and investigative or theoretical or scientific spaces. Artillerists did experiments to replicate or surpass their rivals' pyrotechnics. Apothecaries were included in the Academy of Sciences, and divined recipes for fireworks. Even Lomonosov's work clearly mixed industrial, academic and pyrotechnic goals. But in a court society, where rank was obtained through competitions for honor, the integrated nature of chemical sites could prompt rivalries and competition that led to the assertion of divisions of labour serving the interests of different chemical practitioners. Lomonosov thus insisted that sites were only chemical if their laborers had a proper appreciation of chemical theory. Other sites were reduced to the status of mere workshops. Although Lomonsov did not win the secret of green fire, the division of labour he asserted proved more successful, contributing to a vision of chemistry that helped to obscure the diverse terrain of chemical sites in eighteenth-century Russia from subsequent historians' accounts.

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[1] Ursula Klein, "The Laboratory Challenge: Some Revisions of the Standard View of Early Modern Experimentation," *Isis* 99 (2008): 769-782; Pamela H. Smith, "Laboratories," in *The Cambridge History of Science*, Vol. 3: *Early Modern Science*, ed. Katharine Park and Lorraine Daston (Cambridge: Cambridge University Press, 2006), 290–305.

[2] For the etymology of *khimiia*, see Max Fasmer, *Etimelogicheskii slovar' russkogo iazyka*, 4 vols. (Moscow: Progress, 1973), vol. 4, 237. See also vol. 1, 73 on the use of the term *alkhimiia* in Russia.

[3] A. I. Bogdanov, *Opisanie Sanktpeterburga, 1749–1751* (St. Petersburg, 1776; reprint, St. Petersburg: TOO Katriona, 1997), 149.

[4] Henry M. Leicester, "The History of Chemistry in Russia prior to 1900," *Journal of Chemical Education* (December 1947): 438-443; Henry M. Leicester, ed. *Lomonosov on the Corpuscular Theory* (Cambridge, MA: Harvard University Press, 1970), 9.

[5] P. M. Luk'yanov, "The first chemical laboratories in Russia," *Chymia* 9 (1964): 59-69, on 65; P. M. Luk'yanov, *Istoriia khimicheskikh promyslov i khimicheskoi promyshlennosti Rossii do kontsa XIX veka*, 6 vols. (Moscow: Nauka, 1948-1965), vol. 1, 412-480.

[6] See e.g. Nathan M. Brooks, "Chemistry Laboratories in Russia: 1700-1917," *Historia scientiarum. International Journal of the History of Science Society of Japan* 14 (2004): 89-100; "B. N. Menschutkin, A Russian Physical Chemist of the Eighteenth Century," *Journal of Chemical Education* 4 (1927): 1079-1087, on 1083; B. N. Menshutkin, *Russia's Lomonosov: Chemist, Courtier, Physicist, Poet*

(Princeton, NJ: Princeton University Press, 1952), 47, 130; Alexander Vucinich, *Science in Russian Culture: a History to 1860* (Stanford, CA: Stanford University Press, 1963), 112; Loren R. Graham, *Science in Russia and the Soviet Union: A Short History* (Cambridge: Cambridge University Press, 1993), 21-22; N. M. Raskin, *Khimicheskaia laboratoriia M. V. Lomonosova* (Moscow-Leningrad: Izdatel'stvo Akademii nauk SSSR, 1962) maintains Lomonosov's was the first "scientific-investigative" laboratory, but provides a survey of other chemical sites on 19-37; on the tendency to make Lomonosov first in everything, see Steven Usitalo, "Russia's "First" Scientist: The (Self-)Fashioning of Mikhail Lomonosov," In: *Russian and Soviet History: From the Time of Troubles to the Collapse of the Soviet Union*, Steven Usitalo and William B. Whisenhut, eds. (New York, Toronto: Rowman & Littlefield, 2008), 51-65.

[7] For a general discussion of this phenomenon, see Peter Dear, Lissa Roberts, and Simon Schaffer, eds., *The Mindful Hand: Inquiry and Invention from the Late Renaissance to Early Industrialisation* (Amsterdam and Chicago: Edita; University of Chicago Press, 2007); Ian Inkster, Lissa Roberts, eds., *History of Technology Volume 29* (London: Continuum, 2009); Margaret C. Jacob, Larry Stewart, *Practical Matter: Newton's Science in the Service of Industry and Empire, 1687-1851* (Cambridge, MA: Harvard University Press, 2005).

[8] As Ursula Klein suggests, chemical sites formed a "loosely coherent culture" of overlapping techniques and knowledge in the eighteenth century. Ursula Klein, "Blending Technical Innovation and Learned Natural Knowledge: The Making of Ethers," in Ursula Klein and Emma Spary, eds., *Materials and expertise in early modern Europe: between market and laboratory* (Chicago: University of Chicago Press, 2010), 125-157, on 126; see also Klein, "The Laboratory Challenge," 773-

[9] Quoted in John H. Appleby, "Ivan the Terrible to Peter the Great: British Formative Influence on Russia's Medico-Apothecary System," *Medical History* 27 (1983): 289-304, on 296; see also N. A. Figurovskii, "The History of Chemistry in Ancient Russia," *Chymia* 11 (1966): 45-79; the Tsars' personal physicians also engaged in alchemy. See N. A. Figurovski, "The Alchemist and Physician Arthur Dee (Artemii Ivanovich Dii): An Episode in the History of Chemistry and Medicine in Russia," *Ambix* 13 (1965): 35-51; John H. Appleby, "Arthur Dee and Johannes Banfi Hunyades: Further Information on their Alchemical and Professional Activities," *Ambix* 24 (1977): 96-109.

[10] On Petrine reforms, see James Cracraft, *The Petrine Revolution in Russian Culture* (Cambridge, MA: Harvard University Press, 2004); Lindsey Hughes, *Russia in the Age of Peter the Great* (New Haven, CT: Yale University Press, 1998).

[11] On these visits see Robert Collis, *The Petrine Instauration: Religion, Esotericism and Science at the Court of Peter the Great, 1689–1725* (Leiden: Brill, 2012), 485-494.

[12] On Erskine, see J. H. Appleby, "Robert Erskine - Scottish Pioneer of Russian Natural History," *Archives of Natural History* 10 (1982): 377-98; Collis, *Petrine Instauration*, 121-207.

[13] On Bruce, see Collis, *Petrine Instauration*, 49-119; A. N. Filimon, *Iakov Brius* (Moscow: Chistye vody, 2003).

[14] Brigitte Buberl and Michael Dückershoff, eds., *Palast des Wissens: die Kunst- und Wunderkammer Zar Peters des Großen*, 2 vols. (Munich, 2003), vol. 1, 59.

[15] Cracraft, *Petrine Revolution*, 242-3.

[16] Cornelius Le Bruyn, *Travels into Muscovy, Persia, and Parts of the East-Indies* (London, 1737) vol. 2, 179; Collis, *Petrine Instauration*, 145.

[17] Bogdanov, *Opisanie*, 191-2.

[18] Peder von Haven, "Puteshestvie v Rossiiu," in *Peterburg Anny Ioannovny v inostrannykh opisaniakh*, ed. Iu. N. Bespiatykh (St. Petersburg: Russko-Baltiiskii informatsionnyi tsentr, 1997), 303-384, on 357.

[19] On Apothecaries' Island, see O. Stapf, "The Imperial Botanic Garden of Peter the Great of St. Petersburg," *Journal of the New York Botanical Garden* 14 (1913): 195-209.

[20] Luk'yanov, *Istoriia khimicheskikh promyslov*, 459; V. I. Lipskii, *Istoricheskii ocherk Imperatorskago S. Peterburgskago Botanicheskago Sada* (St. Petersburg, 1913); I. G. Georgi, *Opisanie rossiisko-imperatorskogo stolichnogo goroda Sankt-Petersburga* (St. Petersburg, 1794; reprint: St. Petersburg: Liga, 1996), 230.

[21] Bogdanov, *Opisanie*, 191-2.

[22] Bogdanov, *Opisanie*, 149; Private apothecaries appeared first in the reign of Catherine II. William Tooke claimed that there were three main and four other crown apothecaries in Petersburg and ten private ones. A private apothecary could expect to earn 6750 rubles a year. William Tooke, *View of the Russian empire, during the reign of Catharine the Second, and to the close of the eighteenth century*, 3 vols. (London, 1800), vol. 1, 564.

[23] Luki'ianov, "The first chemical laboratories," 62.

[24] On Bruce's chemical endeavours, see Collis, *Petrine Instauration*, 97-109.

[25] Luk'yanov, *Istoriia khimicheskikh promyslov*, 425.

[26] Luk'yanov, *Istoriia khimicheskikh promyslov*, 429.

[27] Luk'yanov, *Isotriia khimicheskykh promyslov*, 430-31.

28 I. G. Spasskii, *Peterburgskii Monetnyi dvor ot voznikoveniia do nachala XIX veka* (Leningrad: Izdatel'stvo God. Ermitazha, 1949); Hughes, *Russia in the Age of Peter*, 142-44.

29 See Ian Blanchard, *Russia's Age of Silver: Precious-Metal Production and Economic Growth in the Eighteenth Century* (London: Routledge, 1989).

30 Luk'yanov, *Isotriia khimicheskykh promyslov*, 435, 456.

31 See Raskin, *Khimicheskaia laboratoriia*, 22-24.

32 The Alum works at Tambovsk contained a laboratory from 1797; the Yugovsk Copper foundry had a laboratory in the 1780s; Luk'yanov, *Isotriia khimicheskykh promyslov*, 435,
456-59.

33 Luk'yanov, *Isotriia khimicheskykh promyslov*, 415.

34 Luk'yanov, *Isotriia khimicheskykh promyslov*, 458.

35 On Blumentrost, see P. P. Pekarskii, *Istoriia Imperatorskoi Akademii nauk v Peterburge*, 2 vols. (St. Petersburg, 1870-73), vol. 1, 1-15.

36 Johann Georg Model, *Kleine Schriften, bestehend in Oeconomisch-Physicalisch-Chymischen Abhandlungen* (St. Petersburg, 1773); on Model, see Raskin, *Khimicheskaia laboratoriia*, 253-258.

37 Pekarskii, *Istoriia Imperatorskoi Akademii nauk*, vol. 1, 172-4.

38 Bespiatykh, *Peterburg Anny Ioannovny*, 211.

39 Rudolph L. Daniels, *V. N. Tatishchev, Guardian of the Petrine Revolution* (Philadelphia: Franklin Publishing Company, 1973); A. I. Iukht, *Gosudarstvennaia deiatel'nost' V. N. Tatishcheva v 20-kh-nachale 30-kh godov XVIII v* (Moscow: Nauka, 1985); Luk'yanov, *Isotriia khimicheskykh promyslov*, 456.

40 Luk'yanov, *Isotriia khimicheskykh promyslov* 432.

[41] Luk'yanov, *Istoriia khimicheskikh promyslov*, 435.

[42] P. Ia. Chernykh, *Istoriko-etimologicheskii slovar' sovremennogo russkogo iazyka*, 2 vols. (Moscow: Russkii iazyk, 1993), vol. 1, 461.

[43] Simon Werrett, *Fireworks: Pyrotechnic Arts and Sciences in European History* (Chicago: University of Chicago Press, 2010), chapter 4; D A. Rovinskii, *Obozrenie ikonopisaniia v Rossii do kontsa XVII veka. Opisanie feierverkov i illuminatsii* (St. Petersburg: A. S. Suvorina, 1903); V. N. Vasil'iev, *Starinnye feierverki v Rossii (XVII- pervaia chetvert' XVIII veka)* (Leningrad: Izdatel'stvo Gos. Ermitazha, 1960); Luk'yanov, *Istoriia khimicheskikh promyslov*, vol. 5, 85-90.

[44] Rovinskii, *Obozrenie ikonopisaniia*, 95.

[45] M. V. Danilov, "Zapiski M. V. Danilova," ed. Pavel Stroev. *Russkii Arkhiv* 21, pt. 3 (1883):1–67, on 46-47. All translations are my own, except where indicated.

[46] Danilov published a manual on pyrotechnics in 1777 listing ingredients and types of fireworks presumably similar to those made in the laboratory in St. Petersburg. Mikhail Vasil'evich Danilov, *Dovol'noe i iasnoe pokazanie po kotoromu Vsiakoi sam soboiu liuzhet prigotovliat' i delat' vsiakie feierverki i raznyia illuminatsii* (Moscow, 1777). Compositions used sulphur, nitre, antimony, charcoal, copper, and camphor.

[47] Danilov, "Zapiski," 47.

[48] Werrett, *Fireworks*, 112-119.

[49] Horst Röhling, "Illustrated Publications on Fireworks and Illuminations in Eighteenth Century Russia." In *Russia and the West in the Eighteenth Century*, ed. A. G. Cross (Newtonville, MA: Oriental Research Partners, 1983), 94–100.

[50] Werrett, *Fireworks*, 118-119.

[51] Stählin, "Kratkaia istoriia iskusstva feierverkov v Rossii." In *Zapiski Iakoba Shtelina ob iziash-chnykh iskusstvakh v Rossii*, 2 vols. (Moscow: Iskusstvo, 1990),

vol. 1, 238–66, briefly mentions Sarti on 259-61, who should not be confused with the musician and *Kapellmeister* of the same name who later worked in Russia.

[52] Danilov, "Zapiski," 37.

[53] Danilov, "Zapiski," 37-8.

[54] "Green fire," *The Museum of Foreign Literature, Science, and Art* 1 (1822): 568.

[55] For discussion, see Werrett, *Fireworks*, 161.

[56] See Raimondo de Sangro, Prince of San Severo, *Lettera apologetica dell'Esercitato accademico della Crusca [pseud.] contenente la difesa del libro intitolato Lettere d'una peruana, per rispetto alla supposizione de'quipu scritta alla duchessa di S**** e dalla medesima fatta pubblicare* (Naples, 1750), 215; see also "Extrait d'une lettre de Madame la Duchesse de S… contenant l'éloge & le dénombrement des découvertes dans les Sçiences & dans les Arts de D. Raimond de Sangro, Prince de S. Severo, Napolitain," *Journal Oeconomique* (April 1757): 175-9, continued June 1757, 137-146, on 138; Thanks to Lucia Dacome for pointing out De Sangro's interest in fireworks.

[57] Rovinskii, *Obozrenie ikonopisaniia*, 186-7; *Sankt-Peterburgskie vedemosti*, no. 9 (January 31, 1737): 70.

[58] Anon., *Encyclopédie methodique: arts et métiérs méchaniques* (Paris, 1782), 119.

[59] On Lomonosov's pyrotechnic designs, see G. E. Pavlova, "Proekty illiuminatsii Lomonosova," in *Lomonosov: sbornik statei i materialov*, eds. A. I. Andreev and L. B. Modzalevskii, 8 vols. (Moscow-Leningrad: Izdatel'stvo Akademii nauk SSSR; Nauka, 1940- 1983), vol. 4 (Moscow-Leningrad: Izdatel'stvo Akademii nauk SSSR, 1960), 219-237; Mikhail Vasil'evich Lomonosov, *Polnoe sobranie sochineniia*, 11 vols. (Moscow-Leningrad: Izdatel'stvo Akademii nauk SSSR, 1950-1983), vol. 8; see also Werrett, *Fireworks*, 158-9.

[60] M. V. Lomonosov, *Polnoe sobranie sochinenii*, vol. 8, 528, 552.

[61] For more details see Menshutkin, *Russia's Lomonosov*, 46-7; Raskin, *Khimicheskaia laboratoriia M. V. Lomonosova*.

[62] On Lomonosov's mosaics, see Henry M. Leicester, "Mikhail Lomonosov and the Manufacturing of Glass and Mosaics," *Journal of Chemical Education* 46 (1969): 295-298; Menshutkin, *Russia's Lomonosov*, 93-106; on porcelain, see Galina Dmitrievna Agarkova, Nataliia Petrova, *Lomonosov Porcelain Manufacture St. Petersburg, 1744-1994* (London: I. B. Tauris, 1994), 5-15.

[63] S. Biliarskii, *Materialii dlia biografii Lomonosova* (St. Petersburg, 1865), 313.

[64] M. V. Lomonosov, "Oration on the Origin of Light. A New Theory of Color," trans. Henry M. Leicester, in Leicester, *Lomonosov on the Corpuscular Theory*, 247-269.

[65] Rovinskii, *Obozrenie ikonopisaniia*, 246-7 255, 263; *Opisanie allegoricheskago izobrazheniia v' zakliucheniu velikol'epnykh' torzhestv', po sovershenii koronatsii Eiia Velichestva Ekateriny vtoryia… V' imperatorskom' rezidentsii Moskve protiv' Kremlia, sentiabr 1762 goda* (Moscow, 1762), n. p.

[66] M. V. Lomonosov, "Oration on the Use of Chemistry. Presented in a Public Session of the Imperial Academy of Sciences, September 6th 1751," trans. Henry M. Leicester, in Leicester, *Lomonosov on the Corpuscular Theory*, 186-202, on 198-9.

[67] Other chemists drew on arts such as textile-dyeing for new theories of light in the eighteenth century, though Lomonosov's reliance on mosaics and fireworks was unique. Alan Shapiro, *Fits, Passions and Paroxysms: Physics, method, and chemistry and Newton's theories of colored bodies and fits of easy reflection* (Cambridge: Cambridge University Press, 1993), 242-267.

[68] Lomonosov, "Oration on the Origin of Light," 264.

[69] Lomonosov, "Oration on the Origin of Light," 268.

[70] Lomonosov, "Oration on the Origin of Light," 269.

[71] On Melissino, see A. K. Makovskaia, "Melissino I. (1726-1797)," in *Zabytye imena i pamiatniki russkoi kul'tury: tezisy dokladov koferentsii k 60-letiiu Otdela istorii russkoi kul'tury*, ed. M. N. Diatlova (St. Petersburg: State Hermitage, 2001), 38-43; Stählin, "Kratkaia istoriia," 261, 263; Danilov, "Zapiski," 39.

[72] Stählin, "Kratkaia istoriia," 261.

[73] For example all three presented fireworks at New Year 1760. See Alexandr Sumarokov, *Opisanie ognennago predstavleniia v pervyi vecher' novago goda 1760* (St. Petersburg, 1759); Rovinskii, *Obozrenie ikonopisaniia*, 263-5.

[74] Stählin, "Kratkaia istoriia," 264.

[75] Werrett, *Fireworks*, 220-221, 231.

[76] Lissa Roberts and Rina Knoeff, "Introduction: The Places of Chemistry in Eighteenth-century Great Britain and The Netherlands," *Ambix* 53 (2006): 197-200, on 197.

[77] Klein and Spary, *Materials and Expertise*, 6.

[78] Kelin, "The Laboratory Challenge," 776-77, notes this as a common feature of eighteenth-century chemical laboratories.