5) Energy Conversion, Transmission, Storage and Power Technology

"Ego hac aestate occupabor in absolvendis tandem meis molendinis ventaneis, quae fodinis applico".[1] [=97] Leibniz to Ehrenfried Walther von Tschirnhaus, May 23, 1681.

Mining in the Harz Mountains

Leibniz's activities in the Harz mines after 1679 have in the past been described as coming in the wake of a period of two centuries of German ingenuity in the fields of mining and metallurgy, whereby the epochality of Leibniz's own contributions to engineering has been attributed more to his publications on differential and integral calculus in 1684 and 1686, respectively, than to new approaches taken in relation to energy conversion, transmission and storage, as well as power technology.[2] However, the concept of a power technology did have, even in Leibniz's time, a long tradition going back 400 years and more to the medieval exploration of mechanical power when a range of active minds – stimulated both by technological successes in their time and led on by a certain will-o'-the-wisp (or gleam in the eye) of a perpetual motion – began to generalize the concept of mechanical power and came to think of the cosmos as a vast reservoir of energies waiting to be tapped. The fantasies and imaginations of the power-conscious technicians and engineers of the Late Middle Ages were to be the foundation for the Early-Modern development of power technology in the Western World.[3] The present work pays particular attention to the latter aspects and seeks to provide a revised view of

[1] [Continuation = Footnote 96+1= 97] A III,3 N. 233, p. 428; Translation: I will be occupied this summer in completing at last my windmills which I am applying in the mines.

[2] [96+2= 98] cf. W. H. G. Armytage, *A social history of engineering*, London, 1961 and 1970, in particular chap. 7, pp. 60-66 (German miners and metallurgists, 1450-1650); D. S. L. Cardwell, "Power technologies and the advance of science, 1700-1825", *Technology and Culture*, vol. 6(2), (1965), pp. 188-207, and "Some factors in the early development of the concepts of power, work and energy", *British Journal for the History of Science*, vol. 3(3), (1967), pp. 209-224 (also published online by Cambridge University Press: 05 January 2009).

[3] [96+3= 99] cf. L. White Jr., *Medieval technology and social change*, London, Oxford, 1962, in particular pp.129-134 (The concept of a power technology) and notes; B. S. Hall, D. C. West (eds.), *On pre-modern technology and science*: *A volume of studies in honor of Lynn White Jr*., (*Humana civilitas*: *Sources and studies relating to the middle ages and the renaissance*), Malibu, 1976, in particular Introduction; S. A. Walton, *Fifty years of medieval technology and social change*, New York, London, 2019.

Leibniz's commitment to the development of energy and power technologies in the fields of mining, transport, and beyond.

Leibniz's published correspondence reveals that, following a first preparatory stay in the fall of 1679, he commenced his activity in ore mining in the Harz mountains in the summer of 1680. With the construction of windmills, he aimed to tap into a renewable energy and power source which, although known since medieval times, was surely an innovation as regards applications to operate the pumping and winding machinery in the mines.[4] Previously, water wheels had been employed in the Harz mining district in order to operate the pumping machinery for draining the mines. These water wheels were powered using rainwater collected in ponds or reservoirs. Thus, the operation of the ore mines had depended on the available quantity of rainwater and, in times of drought, ore production was considerably reduced. At first Leibniz anticipated relatively problem-free and rapid success with his plans to employ windmills, notwithstanding the protracted negotiations with the local mining authority and with duke Ernst August in Hanover. In the course of events, however, his commitment only ended in the summer of 1685 and then without a satisfactory outcome. Difficulties arose repeatedly forcing him to continually alter his plans. Thus, for example, an iron crankshaft was at first envisaged as part of the transmission system supplying energy to power the pumping machinery. Since, however, the requisite furnace was inoperative for a lengthy period, an alternative construction had to be devised, and the miller and master carpenter Hans Linsen informed him accordingly, on December 12, 1680. This temporary arrangement then led to further repair and maintenance work. Only in in the summer of 1682, did it become possible to install the crankshaft weighing 13 hundredweight, as is evident from Linsen's letter of August 2 of that year. Three weeks later, on August 24, Linsen informed him that, for the transport of an iron shaft in the hilly country, as many as 16 horses were required. To such extraneous influences, the prevailing weather conditions can be added. Operations had to be suspended during the winter months; on April 7, 1681, for

[4] cf. J. G. O'Hara, "Quellen zur Geschichte der Nutzung regenerierbarer Energiedargebote – Mühlen- und Maschinenbücher", pp. 95-111 in: G. Bayerl (ed.), *Wind-und Wasserkraft*: *Die Nutzung Regenerierbarer Energiequellen in der Geschichte*, (Series:Technikgeschichte in Einzeldarstellungen), Düsseldorf, 1989; U. Hasenöhrl, J.-H. Meyer, "The energy challenge in historical perspective", *Technology and Culture*, vol. 61(1), (2020), pp. 295-306, in particular, pp. 297-299 (The alternatives – Historicizing renewables).

example, Leibniz complained to Johann Daniel Crafft about the diabolic weather conditions that were holding up operations and causing him to lose time in the Harz mountains. In addition to such external factors, internal difficulties of Leibniz's own designs also played a role in the delays. The transfer ratio in the cog and rung internal transmission of the windmill – that is, between the cogs of the cogged wheel and the vertical staves of the lantern pinion – had to be altered several times in 1681-82 from its initial state in June 1680. Likewise, the success of a project involving power transmission by means of compressed air – referred to in letters to Linsen in September and October 1682 – proved not to be feasible with the materials available. In addition, the lack of cooperation on the part of the local mining authority, and the mining officials, added greatly to the difficulties. Thus, in an underhanded manner, the Harz project, that Leibniz had hoped to complete successfully in just one or two summers – as his remark to Tschirnhaus, on May 23, 1681, cited in the heading of this section, reveals – developed into a time-consuming preoccupation over several years.

In the 42 month period between January 1680 and June1683 Leibniz travelled fourteen times to the Harz district, and he spent a total of 18 months there. On the occasion of one of the few palpable successes, which however soon proved to be fleeting, Leibniz told Johann Daniel Crafft in retrospect, on March 26, 1682, that he could have ceded on a hundred occasions to the multifarious opposition forces he was confronted with, if he had not wanted to show that it was a core feature of his mindset not to let up until he had carried out what he had set out to do. Leibniz's unusual stubbornness here is remarkable and may perhaps be attributable to the fact that at stake was, not just the proof of the practicality of a theoretical idea, but also his reputation at court and his future influence on the new duke.

The correspondences relating to windmill construction in the early 1680s – namely those with Hans Linsen, Heinrich Schütz, Reinhart Pfeffer and Johann Hagen – include estimates of costs, design drawings, receipts concerning wages paid and smithy costs, reports of the master carpenter Linsen during Leibniz's absence as well as his instructions for Linsen. From these correspondences, as well as from that with duke Ernst August and the mining office, certain insights can be gained concerning Leibniz's plans, his visits to the mining district and the progress of operations. Naturally, Leibniz's commitment to his windmill venture, as well as his interest in discoveries and innovations in this area, are also reflected in a range of other correspondences. Thus, in a letter from the end of November or early December 1679, he informed Huygens about his windmill project for draining the mines that was intended to replace the water wheel-powered system that suffered especially in times of drought. He specified, for the depth at which the water lay in the mine, a value of the order of 100 mining measures of length ("jusqu'à 100 toises et plus"), and he requested the correspondent's opinion.

In his answer to this query, Huygens communicated his opinion in the closing paragraph of a letter of January 11, 1680. He proposed using a paternoster system, using chains and buckets, for lifting the water from the mine. Although technically possible for depths of 100 "Lachter" or "Berglachter" (about 180 meters), Huygens thought any investment in machinery ought to match the expected return. He recalled learning from a Scottish gentleman about such a chain and bucket pumping system, which had been successfully employed in coal mining, albeit using horse mills. In his reply, on February 5, 1680, Leibniz then elaborated on his Harz project. A special difficulty was the corrosiveness of the water in the pits, which would damage the metal components of a bucket and chain pumping system. Instead it was necessary to employ a score of pumps (having wooden cylinders) arranged in tiers, one above the other, which were powered by water wheels. His idea, Leibniz explained, was to avail of wind power to service and replenish the reservoirs, while retaining the existing system of pumps and tiers of pumps. There remained the difficulty that the wind supply was erratic, and he explained that he had thought of an arrangement, where the windmill sails might be rotated a little in order to remain in the direction of the wind, and where the inclination of the axis of the sails might be varied according to the strength of the wind.

Leibniz's collaborator Crafft appears to have informed him belatedly, but then frequently, about the state of the windmill enterprise. As an experienced project developer himself, Crafft realized at the outset (in September 1680) the complex essence of the matter, and he cautioned that, while Leibniz's ideas were good in theory, only time could tell if they would survive the test of practice and, a month later, he warned Leibniz that such things always prove more difficult than anticipated.

As regards Leibniz's interests in mining then, the years from 1680 to 1687 saw both a continuity, in the form of his pursuits of earlier interests, as well as a departure in the guise of the emergence of new applications or fields of activity. These efforts included, in particular, the multifarious proposals for the improvement of ore mining and, in addition, for the requisite water resources management in the Harz mountains.[5] Already in the fall of 1679, a contract between Leibniz and the local mining authority – the Board of Mines in Clausthal – had been ratified by duke Johann Friedrich. This was for a one-year trial of the use of windmills for draining the Dorothea Landskron colliery, an undertaking which was moved to the Catharina colliery in the spring of 1680. The plan was to raise the pit water from the mine by means of a pump assembly attached directly to a windmill, the so-called direct, or immediate, windmill ("immediate Windkunst") solution. In August of 1680, Leibniz then presented a new arrangement in the form of a plan, which had been first devised by a Dutchman, namely by the mining official Peter Hartsinck (or Hartzingk) who died in that year. This alternative plan – which Leibniz had previously rejected but now advocated – envisioned that the windmills would not be used to power the pumping machinery directly, but would rather form part of a pumped-storage system. The service water, which was used to drive water wheels attached to the pumping machinery, was to be returned from the collecting pond below the prime mover to its original storage pond above the water wheel by the use of wind power. This was the so-called indirect or 'mediate' windmill ("mediate Windkunst") solution. A commission then decided that the direct or "immediate" system should continue in operation at the Catharina colliery, while, simultaneously, the indirect or "mediate" system should be deployed at the Zellbach colliery, thus making use of two separate windmills.

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[5] cf. J. Gottschalk, "Theorie und Praxis bei Leibniz im Bereich der Technik, dargestellt am Beispiel der Wasserwirtschaft des Oberharzer Bergbaues", *Studia Leibnitiana*, Supplementary vol. 22, (1982), pp. 46-57; J. Gottschalk ,"Windmills and water-mills", pp. 108-128 in: K. Popp, E. Stein (eds.): *Gottfried Wilhelm Leibniz*: *The work of the great universal scholar as philosopher, mathematician, physicist, engineer*, Hanover, 2000; A. Wakefield, "Leibniz in the mines", *Osiris*: *Annual journal of the History of Science Society*, vol. 25, (2010), pp. 171-88; H. Hecht, J. Gottschalk, "The technology of mining and other technical innovations", chap. 30 (pp. 526-542) in: M. R. Antognazza (ed.), *The Oxford Hanbookof Leibniz*, Oxford, 2018.

The preferential trials of the direct system proved to be very protracted, due to a variety of circumstances. To begin with, the employment of new pumps proved to be controversial, as did the use of control mechanisms for a steadier, or more uniform operation, of the windmill and, in addition, the aforementioned system of power transmission using compressed air was contemplated. As a result, the costs increased to over 2000 Taler by the middle of the year 1683 and, on December 6 of that year, duke Ernst August ordered the suspension of payments by his court to the mining company until the efficiency of the windmills could finally be established. Leibniz, who previously had to contribute only a third of the costs, now agreed to the continuation of the trials for a further year entirely at his own expense. Two new test series, using the direct or "immediate" method, were carried out in 1684 in the absence of Leibniz himself at the Catharina colliery but, alas, with only partial success, mainly as a consequence of the erratic wind supply in the mountainous environment. Because of the varying strength and direction of the wind, Leibniz pursued simultaneously, from the beginning of 1684, his "mediate" or indirect project using horizontal windmill technology.[6] In this system, the vanes of the wind turbine rotated horizontally about a vertical axis which allowed the wind power to be better and more uniformly regulated. For the construction of such a horizontal windmill, which was considerably cheaper but also correspondingly less efficient in comparison to a conventional windmill, the duke had promised the payment of a sum of 200 Taler on January 31, 1684. This horizontal windmill operated presumably satisfactorily at the location of the lower Eschenbach pond, but not, however, under full-load conditions. An actual practice test with piston pumps, or an Archimedean water screw system, attached to raise water was probably never carried out. Finally, after a third test series – this time in Leibniz's presence at the beginning of 1685 – at the Catharina colliery with a directly-attached windmill failed to prove an unreserved success, the duke ordered the termination of the windmill trials, on April 14, 1685.

Notwithstanding this setback, Leibniz was unable to free himself from his commitment to the Harz undertaking. In September 1685, he presented a new proposal to the duke, this time for improvement of

[6] cf. for example, R. L. Hills, *Power from wind*: *A history of windmill technology*, Cambridge, 1994, in particular chap. 2 (The horizontal windmill).

the winding, or ore-hoisting, machinery in the ore mines using a closed-loop, or endless cable, to be powered by water wheels, and to be put to the test at three pits, owned by the duke, in the Thurm Rosenhofer mountain range. Scarcely a year later, Leibniz considered the practicability and advantage of this system to have been proven, but he nevertheless accepted (at least for the time being) the termination of the test series in the light of outstanding repair and maintenance work at the pits. At the end of the year 1686, Leibniz finally departed from the Harz mountains, where he had spent a considerable portion of the previous seven years. Almost another seven years were to intervene before (in 1693) the challenge of improving the Harz mining processes would once again capture his interest.

Leibniz's activity in the Harz mining district for the period from February 1684 to August 1686, *i.e.* during the time of the final three test series with the direct or "immediate" wind-mill technology at the Caterina colliery, as well as with the horizontal windmill technology and the ore-lifting techniques at the Thurm Rosenhof pit, is reflected above all in his general political and historical correspondence at this time. Leibniz's most important correspondent in relation to his mining interests was surely Jobst Dietrich Brandshagen, who supervised the trials and experiments during his absence and recorded the financial accounting in writing on his behalf. Leibniz's correspondence with Brandshagen (between 1677 and 1690) is spread between his general political and historical correspondence and his correspondence in mathematics, science and technology, for this period. On the other hand, reports, accounts and sundry communications, sent by the master carpenter Hans Linsen to Leibniz, belong to his correspondence in the area of engineering and technology and include, firstly, those from the summer and fall of 1683 relating to work on the direct or "immediate" windmill at the Catharina colliery, secondly, those relating to a probably failed effort in 1685 to secure an order or commission for the implementation of the horizontal windmill technology, and thirdly, those for the period between November 1685 and March 1686 during which the use of a closed-loop or endless cable in the winding machinery was being investigated at the Thurm Rosenhof mine. For his part, Linsen was, throughout the period in question, willing and in a position to assist

Leibniz in acquiring wooden models for his technical designs. In relation to this important correspondence with Linsen, stands a range of minor correspondences and communications with tradesmen, smiths and material suppliers, which document above all financial accounts and reveal expenditure for materials and labor.

Leibniz's knowledge of mining was not limited to his own practical experience in the Harz district. Contacts with persons from other mining districts in Germany and Europe frequently came to the fore. Early in 1687, for example, there developed an extended correspondence between Leibniz and the mining engineer Friedrich Heyn, who had recently returned from England. In a letter of November 30, 1686, to the Harz resident and apothecary, Johann Christian Wachsmuth, Heyn lauded the knowledge he had gained during his stay in England, referring among other things to Robert Boyle's process for making phosphorus, to a process for the desalination of sea water, and to a process employed by Prince Rupert of the Rhine for tempering iron, or for the production of the alloy named after him ('Prince Rupert's metal'). On the basis of his practical experience in English mining, and of his familiarity with English mineral ores, Heyn was in a position to introduce himself to Leibniz as a prospective assistant on February 6, 1687. In this letter from Lüneburg, he reported about a new powerful water wheel-powered pumping machine, with rod engine-like sectional components, that had been designed by Johann Joachim Becher and successfully deployed and operated, following Becher's untimely death in 1682, in the mining district of Cornwall. The new machine, Leibniz was told, incorporated neither a standard "suck and press" pumping-system, nor a scoop water wheel system, but consisted rather of a "Taschenkunst" or rag and chain pump (also known as a chain of beads, or paternoster pump) of a type previously used in Hungary and that had already been described by Georg Agricola in *De Re Metallica Libri XII* (1556). The novelty of the Cornish technology,[7] as Leibniz was told, was that it incorporated not just a single chain pump but rather a series of stages, comparable to the sections of a "Stangenkunst", or rod-engine transmission system, and involving pumps of a kind that might operate using several pipes of different

[7] cf. G. Hollister-Short , "Leads and lags in late seventeenth century English technology", *History of Technology*, vol. 1, (1976), pp. 159-183, and "The vocabulary of technology", *History of Technology*, vol. 2, (1977), pp. 125-155.

measure, in either perpendicular or inclined shafts, and at depths of up to 100 or more fathoms. The power supply could come from wind-power, water power, horse power or even manpower.

In a further letter of March 26, 1687, Heyn reported further, but now in a more cautionary fashion, about the new machine in Cornwall. The perfection of this machine had taken three years and had involved an investment of more than 15 thousand Taler. Once fully functional it had brought the operating company a monthly return on its investment of eleven hundred Taler, or two hundred and fifty pounds sterling. Alas, his most recent intelligence from England was that the machinery had, in the meantime, come to a complete standstill, as a consequence of the vein having been cut off and of a mining accident. And Heyn offered to reveal the details of the Cornish machine to Leibniz using a model of the device.

Heyn also provided Leibniz with further information about Becher's demise, his family situation, his legacy, and liabilities. He also informed him about Becher's writings – his chemical writings in particular – and specifically about the satirical work entitled *Närrische Weißheit und weise Narrheit* (foolish wisdom or wise foolery/ folly'ish wisdom or wise folly) of 1682, in which the author had ridiculed discoveries and projects of a range of contemporaries including Leibniz himself. Though not mentioned in Heyn's letter, the work in question contained, as an appendix, an additional work entitled *Dr. Bechers kurtzer doch gründlicher Bericht von Wasserwercken und Wasser=Künsten*, where an invention the author claimed – perhaps that referred to by Heyn in his letters to Leibniz – is alluded to. This was essentially a variant of the "Stangenkunst", or rod engine technology, involving a double rotary crank mechanism and an intervening double rod mechanism. Regarding the long-established German "Stangenkunst" technology, Becher explained that it was essentially a power transmission system connecting regular, or circular, motions at both ends by means of an irregular, or retrograde linear (or alternating), motion in between. It connected a prime mover – supplying wind power, water power or horse power – with a distant load like a flour mill. Becher's report on waterworks and water wheels is at all events a further instance of his activity as an engineer and discoverer.[8]

[8] cf. H. Breger, "Becher, Leibniz und die Rationalität", and U. Troitzsch, "Johann Joachim Becher als Techniker

In Heyn's next letter to Leibniz of July 1687 – which followed a meeting of the two in Lüneburg in late June or early July – the correspondent recalled that he had informed Leibniz during their meeting about yet another water mill near Ehrenfriedersdorf, in the Freiberg mining district of Saxony, that was likewise compared to the "Stangenkunst" or rod engine technology. The machine in question was most likely nothing other than a technically improved version of the so-called "Ehrenfriedersdorfer Radpumpe". This was essentially a piston-pump system, which consisted of several pump stages, arranged one above the other, and powered by a single prime mover. Just as with the machine of Becher's design in Cornwall, the focus in Heyn's account of the machine in Saxony was the mechanism which transmitted the power of a horse mill, or water wheel, to two or three such pump stages, arranged likewise one above the other. It had been employed – Leibniz was told – at a pit which had previously stood still for years due to a lack of adequate pumping machinery.

The piston-pumps with flap valves, just like the rag and chain, or paternoster pumps, represented a conventional technology which was, however, still capable of improvement through the reduction of friction losses, as for example in the leather packing or sealing of valve-pistons. While Heyn was convinced and excited about the possibilities for the use of machines like those in Cornwall or Saxony, Leibniz viewed the prospects in a more sober vein. The modification of a machine, like that in Ehrenfriedersdorf, would in Leibniz judgement – as he outlined in his reply to Heyn of mid-July 1687 – not lead to any increase in efficiency. He then presented the following simple calculation to illustrate the point. For a mine shaft with total lifting height requirement of a hundred lachters (about 200 meters), and a desired delivery volume of half a hundredweight of water from the mine for each revolution of the water wheel above ground, a head (equal to the diameter of the water wheel) of some 5 lachters (or 30 feet), and a volume of at least 10 hundredweights of water, would be required in order to power each such rotation of the wheel. In reality, however, one would require a great deal more to compensate for the considerable frictional losses in the transmission mechanism. With this train of thought, Leibniz broached the fundamental problem in all

und Erfinder", pp. 69-84 and pp. 85-102, respectively, in: G. Frühsorge, G. F. Strasser (eds.), *Johann Joachim Becher (1635-1682)*, Wiesbaden, 1993.

such mechanical power transmission systems, namely the enormous frictional losses between the constituent parts of the mechanism.

In his letters to Leibniz, Heyn also reported about his professional experience in salins, or salt works, and he enquired about a salt refinery being set up near the town of Einbeck. As Heyn's attempts to find employment at such salt works proved unsuccessful, he opted to accompany Leibniz on his research tour as far as Vienna. By the time of Leibniz's return from Italy, Heyn had become a mining official, a tax gatherer and inspector in Ilmenau. On June 6, 1690, he sent Leibniz, from Leipzig, mineral ores in which fossilized plants were to be seen. Then, in a subsequent letter from Ilmenau, on November 14, 1690, he expressed his pronounced interest in a new translation of A. A. Barba's work, entitled *Arte de los metales* (1640), which was then being prepared by Christoph Pratisius in Hanover.[9]

The apothecary Wachsmuth, who had brokered Heyn's role as Leibniz's companion on the first leg of the Italian journey, and who had even contemplated accompanying Leibniz himself to Italy, served him not only as a supplier of medication. He also provided Leibniz with important information about the Harz mining towns, and their administration, as well as about learned travelers in the Harz mountains such as, for example, in a letter of July 19, 1687, about the Swedish mining expert Eric Odelius who, while fulfilling a royal commission, was exploring the Harz district and who – having been provided with a letter or recommendation from Wachsmuth – then desired to meet Leibniz, in Hanover, on his return journey to Sweden.

On July 31, 1683, the Dutch mathematician Johann Jakob Ferguson reported to Leibniz about a technically interesting wind-powered water elevator, which he had seen during an inspection of the new fortifications of the town of Breda. The machines in use, the "Slang-molens", required a strong wind and their performance was apparently equivalent to that of three "Ketting-molens" or chain mills. Leibniz then informed the correspondent, on August 25, about his own horizontal windmill concept, and he even raised the possibility of introducing such systems in Holland. To this he added a query about the so-called "Slang-molen" or "Ketting-molen" designs. In his reply

[9] cf. J. P. Melero, "The scientific revolution and enlightenment in Spanish American mining and metallurgy", pp. 51-61 in: G. D. Rosenberg (ed.), *The revolution in geology from the renaissance to the enlightenment*, (*The Geological Society of America*, Memoir 203), Boulder, Colorado, 2009, and in particular pp. 55-57 (Álvaro Alonso Barba: The last in the alchemistic tradition).

from Amsterdam, on September 11, Ferguson compared the operation of the former to a rotating wooden spiral or helical staircase, *i.e.* an Archimedean screw,[10] and the latter to a chain elevator system in which the water was lifted by a system of troughs, which were attached to the chain and arranged one above the other.

While Leibniz's most important innovation in mining was no doubt the exploitation of wind power, he was also very much occupied with water-powered and water-raising machines, and in this regard too, he tried to obtain information about corresponding developments, and corresponding technologies, in other European countries. Thus, Noel Douceur (on December 20, 1680), Mariotte (in March-April 1681) and Brandshagen (on November 5, 1682) reported to Leibniz about new water-lifting machines in Paris and Copenhagen and, through the intercession of Ferguson, Leibniz received, in November 1682, accurate and detailed construction drawings of a Dutch windmill. Then, in July 1684, Leibniz himself requested information about relevant publications, and projects, of the Académie Royale des Sciences in Paris, in a letter to the secretary Jean-Baptiste Du Hamel. Leibniz enquired here specifically about the activities of Samuel Morland, who had been sent to France in early 1682, by the English king Charles II, in order to gain knowledge and experience for the further improvement of English waterworks and water-lifting machines. Morland's involvement was in the scheme, which Louis XIV had in hand, known as the Machine of Marley,[11] an installation that was planned and carried out between 1681 and 1683. In January 1685, Leibniz enquired once again about the scheme, this time in a letter to Claude Comiers.

Leibniz's involvement in mining continued until August 1685, when duke Ernst August ordered the cessation of his activities in the mines against his clearly formulated wishes. Nonetheless, by the middle of 1687 at the latest, Leibniz had come to terms with the fact that his involvement in Harz mining was not desired. Six years later, however, a proposal made by two moneyers, Johann Jacob Jenisch and Rudolf Bornemann, to increase the production in ore mining by

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[10] cf. G. J. Henderson, "Turn, turn, turn: The construction of the architectural spiral fluted column in the ancient mediterranean world", *Technology and Culture*, vol. 59(2), (2018), pp. 363-409, and in particular, regarding the origins and development of the water screw, pp. 376-385.

[11] cf. H. W. Dickinson, *Sir Samuel Morland*: *Diplomat and inventor, 1625-1695*, Cambridge, 1970, in particular pp. 74f.

employing a small number of horses to power the winding machinery, led to a revival of Leibniz's interest in the ore mines. When he learned of this undertaking, at the end of March 1693, the authorization procedure was already at an advanced stage. Accordingly, he immediately approached both the chamber in Hanover and his sovereign Ernst August – who ultimately had to grant approval for the proposed venture – claiming his own priority in the matter. Since the means of realizing a profit increase had not been clearly presented by Jenisch and Bornemann, Leibniz feared that his own idea of weight compensation using an endless rope or cable might actually be applied in the enterprise. In the summer of 1693, he finally succeeded in convincing Ernst August that his work on the history of the dynasty would not be retarded by a revival of the Harz project, since he would be able to delegate the execution and supervision of the work to others. Thus, the trial of Leibniz's proposals, at his own expense, received short-term approval until the end of the year 1693. The application of his rivals was then put on hold for the time being.

For the execution of the skilled manual work, Leibniz was able to obtain the services of Hans Linsen and fellow craftsmen or tradesmen and, for supervision and procurement of materials, Balthasar Ernst Reimers was engaged as his managing agent and, as a skilled pitman, the senior mining official from Clausthal, Daniel Flach, was to be present at operation trials of the winding machinery. Details of the allocated pit, as of its nature and condition, along with the difficulties encountered in the trials are revealed in Leibniz's extensive general political and administrative correspondence relating to his mining involvement in the years 1693-1696. As might have been expected, in light of the ill-fated series of trials of Leibniz's proposals for the improvement of engineering methods in the mines carried out during the first half of the previous decade, he once again greatly underestimated the operability and requisite time span for his undertaking and so, at the end of 1693, he found himself trudging through a mammoth task, whose end was not in sight and which would earn him more disappointment than recognition.

The years between 1693 and 1696 then marked Leibniz's second period of activity in the Harz mining district. The improvement of the mine-dewatering pumps, and an increase in the efficiency of the winding machinery for hoisting ore, were at the center of his interest at this point. He contemplated the possibility of replacing horse mills, as well as the overshot reversible water wheel, as power sources by using a rod-engine power transmission system from a remote water wheel to the pithead, and not just for operating the pumping machinery alone, as had previously been done, but also for the winding or hoisting machinery. In order for such a combined system to function properly, the overall power requirement needed to be significantly reduced, and Leibniz thought of achieving this, on the one hand, by employing an endless or closed-circle winding cable or chain. In addition, he conceived a tugging or towage device, having a switchable pinion gear mechanism, that would transform the above ground alternating linear motion, firstly, into the vertical alternating linear motion of the pump or piston rods, by employing a standard cross-shaped lever-system located at the pithead and, secondly, into the circular motion of the winding machinery, by means of a capstan or roller drive also at the pithead. Thus, in theory at least, the objective would be achieved of powering both the pumping machinery (vertical alternating linear motion) and the winding machinery (circular motion) using a single vertical water wheel,[12] with its rod-engine transmission system.

Progress towards the completion of the construction, and testing, of the requisite machines proved, however, to be very protracted. It was only in February 1694, that Leibniz was able to connect, for test purposes, the tugging system, being powered by the rod-engine transmission line, with the capstan or roller drive of the winding machinery at the pithead. Here the additional tugging system was mounted on a linkage along the transmission line, located at a switching point about halfway between the water wheel and the pithead. The system proved to be functional at first and was demonstrated, on February 18, 1694, in Leibniz's presence, to the mining officials. On the occasion of that demonstration, 4 tons of ore were hoisted in an hour before the machinery came to a standstill. In the course of later hoisting trials, further dysfunctions were experienced and there ensued contention and conflict with the Mining Office in Clausthal, a matter which was duly reported to the Chamber in Hanover.

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[12] cf. T. S. Reynolds, *Stronger than a hundred men*: *A history of the vertical water wheel*, Baltimore (Maryland), 1983, and in particular chap. 3, pp. 122-195 (Continuity: The traditional vertical water wheel at its pinnacle, c.1500 to c.1750).

Leibniz delegated the supervision of the trials at the pits to Balthasar Ernst Reimers during his absence, whereas the juror Zacharias Pöhler emerged as his main opponent or adversary in the undertaking. On April 16, 1694, Leibniz reported to Crafft about damage (perhaps even sabotage) to the rod-engine machinery, and about the opposition and obstruction being experienced from the jurors and engineering officials. He also included a sketch of the damaged rod engine system, illustrating the water wheel location, the pithead, the rod-engine transmission line and the point where the towage system, for the winding machinery, was connected to it, and he completely rejected any blame on his part for the damage incurred.

Crafft kept Leibniz informed und up-to-date about the matter, for example in his letter of May 20, 1694. The rival party, he was informed, had in the meantime conceded that Leibniz's combined system could function under certain favorable conditions as, for example, when the residual water level in the mine was low. However, in the event of the quantity of water in the pit being considerable, the entire power of the prime mover would have to be applied in order to operate the pumps alone.

According to Crafft's report, the senior mining official, Otto Arthur von Ditfurdt, was attempting to bring the rival factions to their senses by pointing out that, in the event of a continuation of the trials, one of the parties would in the end have to bear the costs. The Chamber president and privy counsellor, Albrecht Philipp von dem Bussche, too had advocated the suspension of the trials. And even Crafft himself could not exclude the possibility that the juror Pöhler might indeed be vindicated in the end. And so, after the situation for Leibniz's efforts to improve the ore-hoisting methods had considerably deteriorated, he reverted to the mine pumping machinery in the knowledge that his idea could only be successful in the long-run, if he were to succeed first in constructing energy-saving pumps. Instead of using leather obturator rings, he wanted to provide the pump cylinders with valves in order that the previously existing friction losses might be reduced. The task of fabrication of the pumps, Leibniz once again entrusted to Reimers, who in turn kept him informed about the progress of the work in hand. In September 1694, the new pump was ready for use, but the testing and trials were drawn out into the year 1695, in particular because of lack of cooperation on the part of the mining office and the mining officials. Reimers' letter, from early February 1695, in which the correspondent reported about the preparation of the trial operation, contains the final report about Leibniz's efforts at the time for improvement of the pumping machinery.

Transportation

To the field of power technology belong certain themes from the area of transportation technology, and which also arose occasionally in Leibniz's correspondence. In September 1683, Georg Mohr reported about Nicolaas Witsen's tract on ancient and contemporary shipbuilding, entitled *Aeloude en hedendaegsche Scheeps-Bouw* (1671), a work that also attracted Leibniz's interest and from which he made extracts. In preparing his Italian journey, Leibniz established contact with a certain G[-] S[-] Schmid from Sulbeck, near the town of Einbeck, concerning the improvement of coaches and carriages. However, in the sole surviving item of this correspondence, dated July 17, 1687, Schmid had to admit his inability to complete the fabrication of his "Schese rolandte", but he did include a detailed drawing of such a carriage or coach. Leibniz's vision of a stage (or post) coach that could travel from Hanover to Amsterdam in six hours was reported, perhaps inadvertently, by Johann Daniel Crafft to Johann Joachim Becher, and it was ridiculed by the latter in his satirical work *Närrische Weißheit und weise Narrheit* (1682). Five years later, this was referred to, not only by Heyn (in his letter of March 26, 1687) but also by Friedrich Meurs von Blauenstein in a letter he wrote from Dresden, on February 28 of that year.

The Steam Pump and Steam Engine

By mid-1696, the second period of Leibniz's involvement in mining in the Harz mountains had by and large come to an end. Power technology continued, nonetheless, to be an important topic in his correspondence after 1696, above all in the context of the exchange of ideas with Papin about his steam pump as well as about the possibility of using steam, and other vapors, to power a machine or a vehicle. The starting point was Leibniz's conjecture, in his letter to Papin of

November 18, 1697, that the explosive effect of gunpowder could be attributed to the compression pressure of the air. As is clear from Papin's reply, on December 5, this line of thought reawakened memories for him of his earlier work *Nouvelles experiences du vuide, avec la description des machines qui servent à les faire* (1674), from the time when he was assistant to Huygens in Paris, and perhaps also of his more recent article "Excerpta … ex Litteris …de Novo Pulveris Pyrii Usu", in the *Acta Eruditorum* of September 1688. On the basis of his calculations carried out while in Paris, he had concluded that the air contained in gunpowder causes the force released in gunfire. In order to be able to make more advanced pronouncements here, he explained to Leibniz that he would need to carry out further research on the powder and its constituent parts. Then, a week later, on December 12, 1697, Leibniz greeted their mutual agreement about the nature and power of gunpowder on the basis of experiment.

On April 20, 1698, Papin then reported that the landgrave, Charles of Hesse-Kassel (Karl von Hessen-Kassel), had charged him with the determination of the origin of the salt contained in salt or brine wells. In connection with this, he had carried out experiments on lifting water from a depth using the power of fire, or of steam. In addition, he announced that he had conceived far more important applications for the new power source than pumping water from a depth. Thereupon, on April 24, Leibniz enquired, as to whether Papin had made use of a principle of dilation, or of expansion, in raising water by means of the power of fire or steam. This was indeed a matter, which he himself had also contemplated and, concerning the realization of which, he now wished to consult the correspondent. Then, on August 4, Papin confirmed that he had in fact employed the expansion of steam, but in such a way that he could exploit both the suction and compressive effects. Referring to his article "Nova Methodus ad Vires Motrices validissimas levi pretio Comparandas", in the *Acta Eruditorum* of August 1690, in which he first published the principle of the atmospheric steam engine, he expressed the conviction that the power of fire or steam might indeed find other applications besides the raising of water. Papin related that he had constructed a model of a vehicle, powered by steam, that operated on water in a pan or pot. However, he doubted that this form of propulsion would be suitable for normal wagons or carriages on land, above all because of the imperfections of existing roadways. On the other hand, he believed that he himself possessed the competence to build a marine vehicle powered by steam.

Leibniz, replying four days later, on August 8, concurred with the view that the expansion of steam could produce a greater effect than the atmospheric pressure accompanying the condensation of steam. The expansion of steam had the same effect as the explosive power of gunpowder in a receptacle, whereby water had the advantage of not behaving so explosively on ignition. Like Papin, he had also contemplated the possibility of employing the expansion of other liquors or vapors in place of water vapor or steam. Water was, however, more practical as it was freely and plentifully available everywhere, he told the correspondent. Furthermore, he greeted the fact that experiments, which he himself had contemplated – but had been unable to carry out due to a lack of resources in Hanover – in order to test the superiority of a steam engine over a pneumatic engine, had now been carried out by Papin. He himself, just like Papin, had previously contemplated the use of such an engine to power a vehicle and to facilitate transport. Then, Leibniz outlined his own ideas about the use of pneumatic machines, referring to a device he had contemplated, which would use mercury for sealing or making airtight the contact between a piston and a pump cylinder. This idea came no doubt from his practical experience in the Harz mining district, where wooden rather than metal pumps were being employed. In the highly corrosive environment there, water was used for making the contact between the piston and the cylinder airtight. The idea, which he now presented to Papin, was that mercury could balance (or equalize) the air pressure inside the cylinder produced following the expansion of water vapor. At first, he had contemplated such machines for improving transportation, but then he had become skeptical regarding their aptitude (or suitability) for the purpose.

Following further experiments, Papin reported, on August 28, that he had been able to pump water only to a height of 70 feet using steam power. His recently gained knowledge included ascertainment of the fact that a small increase in the degree of heat would lead to greater effect. He believed one could achieve – through the further development of such machines and the use of higher degrees of heat – that a pound of water would produce a greater effect than a pound of gunpowder. As regards Leibniz's ideas for the improvement of transportation, Papin underlined their importance and urged Leibniz, in the event of him being unable to implement these in practice, to at least make them available to posterity through publication.

However, Papin cast doubt on the functionality of Leibniz's mercury-pump idea, primarily because it contained three interlaced tubes. The alternating movement of the tubes, and the mercury, would inevitably lead to considerable resistance losses. Furthermore, he had, through experimentation, gained the insight that the effect of gunpowder increases with the resistance to be overcome. It appeared that gunpowder would then set off its charge more completely and, accordingly, provide a greater effect or yield when confronted with a high resistance, for example in raising a column of water. Finally, he insisted that the means to control the expansion of the exploding gunpowder conglomerate would need to be researched, and found, in order to obtain the greatest benefit.

As regards the connection between the strength of the expansion force, and the height attained in lifting a body by means of steam power, Leibniz argued – in his reply on September 7 – that consideration ought to be given to the circumstance that force was actually being lost through the cooling of the steam during expansion, that is, that energy was being transferred to the surroundings not only as work, a premonition perhaps of what was later to become known in thermodynamics, or the science of heat,[13] as an adiabatic process. Leibniz wanted to organize his thoughts concerning transport or transportation and, accordingly, passed over the matter in this letter. As regards Papin's objection to his mercury pump idea, he responded that, the greater the length of the pump cylinder (and accordingly of the stroke of the piston), the smaller the friction would be in relation to the performance of the pump, since the friction increased in relation to the cylinder diameter while the performance grew in proportion to the square of the diameter.

As Papin was not able or willing to communicate any further details of his research on the steam pump – as he made clear in his letter of October 9, 1698 – the considerations regarding the matter ended at this juncture. Papin, however, did report to Leibniz, on June

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[13] cf. D. S. L. Cardwell, *From Watt to Clausius*: *The rise of thermodynamics in the early industrial age*, Ithaca (NY), 1971 and Ames (Iowa),1989, in particular chap. 1, pp. 1-31 (The origins of the science of heat).

18, 1699, about the steam pump constructed by Thomas Savery,[14] and the patent granted to him by the English parliament for the invention.[15] However, the pump had failed to live up to the expectations raised by its inventor, Leibniz was told. Alas, Papin was not in a position to provide him with a design description. Savery's tract *The miners friend: or, an engine to raise water by fire* appeared in 1702 and, in the year 1704, he was (no doubt with Leibniz's knowledge) invited to provide a description of his steam pump, and to demonstrate his invention, at the Court in Hanover. The visit to Hanover never did materialize, however, and Savery's letter of October 7, 1704, marks the end of Leibniz's indirect correspondence with him. As regards Papin, he sent (in the year 1707) a monograph to the Royal Society, in which he described a design of an engine which he had developed on high-pressure principles and, in the following year, he returned to London to seek support for his invention. Whereas Leibniz had admired it, and suggested refinements, Newton turned it down, and Savery criticized it most severely, even accusing Papin of poaching his ideas.[16]

Other Enginery

Some other discoveries of Papin were also discussed in correspondence with Leibniz. Thus, in his letter of September 21, 1699, the correspondent reported how, in a coal mine, he had successfully employed the centrifugal pump of whose merits he had long sung the praises, namely the so-called 'Hesse pump', together with a long air conduction pipe made from wood and serving as a

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[14] cf. for example C. Matschoss, *Geschichte der Dampfmaschine*: *Ihre kulturelle Bedeutung, technische Entwicklung und ihre großen Männer*, Berlin, 1901and Hildesheim, 1983, in particular part "B. Die technische Entwicklung der Dampfmaschine", pp. 32-43; H. W. Dickinson, *A short history of the steam engine*, Cambridge, 1939 (reprinted 2010 in the Cambridge Library Collection, Books of enduring scholarly value), in particular Part I, chap. II, pp. 18-28 (Savery and his fire engine), and (facing p. 22) plate I; D. S. L. Cardwell, *Steam power in the eighteenth century*: *A case study in the application of science*, London, 1963; R. L. Hills, *Power from steam*: *A history of the stationary steam engine*, Cambridge, 1989 and 1993 (reprinted 1995, 1997), in particular chap. 2, pp.13-30 (The impellant force of fire; The first steam engines, Savery, Newcomen (1600-1730)).

[15] cf. S. Bottomley, *The British patent system during the industrial revolution 1700-1852*: *From privilege to property*, Cambridge, 2014, in particular chap. 8, pp. 231-240.

[16] cf. their remarks accompanying a translation from the French of Papin's monograph and transcripts of his propsals in: A. Smith, "A new way of raising water by fire: Denis Papin's treatise of 1707 and its reception by contemporaries", *History of Technology*, vol. 20, (1998), pp. [139]-181, and also A. Smith, "'Engines moved by fire and water': The contributions of fellows of the Royal Society to the development of steam power, 1675-1733", *Transactions of the Newcomen Society*, vol. 66, (1995), pp.1-25; D. P. Miller, "A new perspective on the natural philosophy of steams and its relation to the steam engine", *Technology and Culture*, vol. 61(4), (2020), pp. 1129-1148, and in particular pp. 1132-1134 (Steam and the natural philosophy of the vacuum).

mine aeration or ventilation system. In his reply, on October 30, Leibniz referred to the connection between breathing difficulties and the extinguishing of lamp flames in the pits, both of which he attributed to inadequate air circulation. Already in the year 1692, the Hesse pump had been employed for the air exchange in Papin's submergible vehicle, during its trials on the river Fulda. It was now also to be the key element of a machine, for seawater desalination, and with which fuel use might be economized. Papin sent Leibniz a detailed report, on December 3, 1699, about the first successful experiments with the machine, and about the role played by the Hesse pump.

Leibniz, as he informed Papin, on March 10, 1700, was acquainted with a new process, for transporting earth, used by renowned French military engineer, Sébastien Le Prestre de Vauban, between 1699 and 1703 on the construction site of the fortification works at Neuf-Brisach (Neu-Breisack).[17] Here new machines, which were driven using manpower and horsepower, were in operation. In Leibniz's view the discovery was "pas fort considerable" but, nevertheless, he sent Papin a sketch or drawing as a sign of respect for the landgrave. Here Leibniz also referred to a news report in the *Gazette d'Amsterdam*, of February 25, 1700, with information about a new machine with the help of which one could transport a large quantity of sand from one location to another.

In Leibniz's correspondence between 1699 and 1701 with other correspondents, like Magnus Gabriel Block, other recent developments in technology and engineering were discussed. Thus, on January 10, 1699, Block informed Leibniz, about machines of the Swedish engineer Christopher Polhammar (later called Polhem),[18] which were being used for quarrying out stone. Polhammar had developed a conveyor system, with special conveying machinery, for the 'King Charles XI mineshaft' at Falun, where he had been head of the mining machinery operations since 1698 and where, at the beginning of 1700, he was elected to the position of senior mining engineer ("Kunstmeister"). As Block wrote to Leibniz, on June 24, 1699, Polhammar's machine was particularly suitable for inclined or slanting pits. Leibniz, replying on September 8, was able to point out

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[17] cf. J.-D. G. G. Lepage, *Vauban and the French military under Louis XIV*: *An illustrated history of fortifications and strategies*, Jefferson (North Carolina), 2010, in particular p. 23.

[18] cf. W. A. Johnson (trans.), *Christopher Polhem*: *The father of Swedish technology*, Hartford, Conn.,1963.

– indeed from his personal experience – that the mine pits in the Harz mountains were not only slanting but that, in addition, their slope varied along the veins.

6) Engineering

"Mais je estimeray peu tout cecy, si je ne voyois moyen de reduire les problemes de Mechanique aux termes de la pure geometrie, et de mettre les machines en calcul tout comme les figures".[19]
Leibniz to François de la Chaise, April-May 1680.

Ballistae – Military Engines and Engineering

At the beginning of the reign of duke Ernst August in 1680, there arose a contentious dispute about the Douceur cast-iron process, referred to above in the context of Leibniz's biography. He had purchased from the French engineer, Noel Douceur, during the reign of Johann Friedrich and with his mandate, a process for the ostensible production of malleable cast iron, a process that was alleged to render cast iron malleable and had an obvious military significance, in particular for improvement in the production of canons. Once in possession of the Douceur process, Leibniz could at least pride himself with the achievement in various places, such as at the Danish court. On July 6, 1683, Brandshagen reported from Copenhagen that he had spoken to king Christian V about, among other matters, the cast iron process and had read aloud to the monarch, on that occasion, the postscript of a letter from Leibniz. The full technical details of this process were, on the occasion of its original communication in 1679, kept a secret from all except duke Johann Friedrich. However, Leibniz had been informed to the extent that, in a text intended for duke Ernst August entitled "Bedencken betreffend eine Proposition von verbeßerung der Eisen Stuck und ander Eisen-manufacturen" (Thoughts concerning a proposition for the improvement of [cast] iron and other iron manufactory processes) from June 23, 1684, he was able to describe the Douceur roasting or annealing process.

[19] A III,3 N. 61, p. 192; Translation: But I would esteem all of this very little, if I did not see the means of reducing the problems of mechanics to the terms of pure mathematics, and of rendering machines as machine-equivalent figures for calculation.

A similar process, one comparable to that of Douceur, was the production of quality damascene steel, which had been a subject of interest at European courts since the late middle ages.[20] The matter arose in the letters of Brandshagen and Martin Elers sent to Leibniz from Copenhagen, in August or September 1683 and August 1684, respectively. Elers also enquired on this occasion about a military bridge which, according to reports, had been tested by the duke of Celle. He claimed to have made a similar discovery himself. Military technologies were likewise the subject of Leibniz's correspondence with Brandshagen in Denmark. On July 6, 1683, Leibniz was informed about the correspondent's activities with the Danish artillery. Four years later (on July 23, 1687), after he had quit Danish service, Brandshagen reported to Leibniz about a meeting in Hamburg with a former lieutenant of the Danish artillery. The latter had revealed to him the layout of French ballistic mortars, intelligence which Brandshagen was willing to make available to Leibniz. In the following letter to Leibniz, on August 27, he enquired about a possible trial of such a mortar. In addition, he offered Leibniz plans or layouts of Danish howitzers, and of grenade or artillery shell launchers.

On September 24, 1686, Friedrick Meurs von Blauenstein reported from Dresden about his investigations of iron and steel production, which he had undertaken with a particular focus on military applications. On February 28, 1687, in reply to a query from Leibniz, the same correspondent referred to the production of damascene blades, and to a smelting furnace for the mass production of steel in Saxony. However, most of his innovations, referred to in this letter, served exclusively military purposes as, for example, a light armor, halberds, grenade throwers and copper coatings for canon muzzles.

Civil Engineering: Urban Water Supply, Garden Design and Architecture

Leibniz, and his correspondents, also contemplated the use and improvement of pumps, and pumping machinery, outside of mining in

[20] cf. A. Williams, *The knight and the blast furnace*: *A history of the metallurgy of armour in the middle ages & in the early modern period*, Leiden and Boston, 2003, in particular Sect.1, Appendix 2, pp. 14f., and *The sword and the crucible*: *A history of the metallurgy of European swords up to the 16th century*, Leiden and Boston, 2012, specifically chap. 3, pp. 36-38.

his correspondence during the 1690s. Crafft, for example, in a letter from Amsterdam on June 14, 1695, professed his interest in a type of pump with a four-sided, or rectangular, section that had been referred to by Leibniz in a no-longer extant letter of May 1695. Crafft had read the description of such a pump with pyramidal form, in the *Journal des Sçavans* from the year 1679, and he was hoping to obtain further information from Leibniz, as is to be seen from his letter of February 23, 1696. The new pumps, which were also to be employed for pumping water into elevated reservoirs and which in turn would serve as a reserve supply for the watermills, were intended to overcome above all the unreliability of the traditional fluvial water mills. In his reply, on March 2, Leibniz then generally elaborated the mode of operation of such flour mills, which could be powered by wind, water or horse power. Even four-sided, or rectangular, pumps could be employed, he maintained, having established himself the advantages of pumps of this kind by means of an experiment with a pump assembly, having a quadrangular cross section of 8-inch width, a 4-foot length and a 3½-foot piston stroke length.

Leibniz's involvement in the design of waterworks, like cascades, waterfalls and ornamental fountains, for the electoral gardens at Herrenhausen (in Hanover) commenced in mid-1696.[21] This involvement, and commitment, is reflected above all in his correspondence with the military engineer, Andreas Du Mont. The draft of Leibniz's letter to Du Mont, of July 21, 1696, reveals that Leibniz had received a commission, from the elector Ernst August, to work for the provision of the waterworks and fountains at the gardens in Herrenhausen. In this matter, Leibniz sought the expert advice of authorities like Du Mont. In his letter to this correspondent, Leibniz elaborated three options for the development of the waterworks and fountains. The first option envisaged the construction of a vertical water wheel on the river Leine flowing through Hanover, directly opposite the gardens at Herrenhausen, with which water could be raised into a tower tank. From there, it would pass through pipes, either directly to the fountains in the gardens, or into a reservoir. Alternatively, the water wheel might be erected on a branch of the river, in the vicinity of Hanover's new town district (the "Neustadt"),

[21] cf. K. Popp, E. Stein (eds.): *Gottfried Wilhelm Leibniz*: *The work of the great universal scholar as philospoher, mathematician, physicist, engineer*, Hanover, 2000, in particular pp. 133-137 (Herrenhausen Waterworks).

and be used additionally for urban water-supply there. This option had a disadvantage, namely that the water for the fountains would have to be delivered, through a lengthy system of wooden pipes, from the town to the remote gardens.

The third – and in Leibniz's view the best – possibility would involve the construction of a canal passing through the gardens. From a location on the river, it would pass in a straight line to the gardens, before veering back to another location further along the course of the river. The costs, Leibniz claimed, would be moderate as long as the only function was to supply water for the fountains. The exploitation of the canal for other purposes, such as navigation, would of course lead to additional expense. Because of the considerable head of water it could provide, the canal might also be used to supply water mills along its course. The engineering hydraulics works, along the canal, would be less exposed to dangers than any alternative engineering works, along the main river, and would entail no impairment of shipping traffic along the course of the river. The water could be raised into a tower tank, and from there be directed to fountains in the immediate vicinity, or alternatively be conducted by means of a ditch or a hydraulic flume supported on stands – like those used in mining in the Harz district – to other locations in the gardens. Gondolas might even be used on the canal for transportation and would represent an added attraction, he thought. The water supply to Hanover's new town district – and perhaps the establishment there of a 'water network', like in London,[22] or of a 'water supply piping network' of the type that had been developed in German, and other, cities throughout Europe,[23] in the fifteenth and sixteenth centuries – would then have to be realized independently of the plans for the gardens at Herrenhausen.

In his expert's report, which was attached to a letter of July 30, 1696, Du Mont also argued in favor the construction of a canal between the river and the gardens. In addition, he recommended using the earth, obtained in the excavation works, to build a dike as a protective measure against flooding, specifically on the side facing the town. A lock should be built at the location, where the canal and river would meet, in order to keep the water level of the canal constant, and

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[22] cf. L. Tomory, "London's water supply before 1800 and the roots of the networked city", *Technology and Culture*, vol. 56(3), (2015), pp. 704-737.

[23] cf. C. Shulman, "The groundbreaking water supply systems of central and eastern European cities, 1300-1580", *Technology and Culture*, vol. 60(3), (2019), pp. 726-769.

to regulate the quantity of water for the operation of the water wheel. Such a canal might serve as a waterway for gondolas operating between Hanover and Herrenhausen. For the return flow of the water into the river, a cascade would have to be built. This would also allow for the canal to be drained on occasions in order to undertake cleaning operations. The second suggestion of Leibniz – namely that of combining the water supply of Hanover's new town district with that for the garden fountains at Herrenhausen, by means of an extended system of water pipes – was rejected by Du Mont as being impractical. While the proposal for the construction of a canal, as envisaged by Leibniz, found the support of Du Mont in principle, he pointed out that a number of difficulties would arise, like the task of dealing with the sandy and swampy ground near the river. To avoid an erosion of the sides of the canal, the cladding of its walls would be necessary and this would greatly add to the costs. Furthermore, a lock would be required – as in the case of the first proposal – in order to regulate the water flow and to protect the canal and garden.

Du Mont failed to meet Leibniz during a visit to Hanover in mid-August 1696. As is evident from entries in Leibniz's diary, for August 13 and 14, consultations were taking place at that time, at the court in Hanover, about the planned water-fountain system at Herrenhausen. On that occasion, the decision was taken to build the facility in accordance with Leibniz's first proposal and to forgo the construction of the canal because of the costs involved. Accordingly, Leibniz reported to Du Mont, on August 20, 1696, that a Persian or scoop wheel, of 50-foot diameter, was to be built on the river opposite Herrenhausen and, furthermore, that it was to be combined with a mill to help offset the costs. The water would pass through pipes to a reservoir, which would then supply the fountains. Leibniz regretted the rejection of his proposed plan to build a canal and he cast doubt on the calculation of the costs involved. He believed that extensive and costly hydraulic construction measures, on the main river, would be necessary and that such expense might have been avoided by the provision of a canal. Furthermore, since the canal would have been connected with an arm of the river, it would have been protected from the current and from ice formation on the main river. In contrast, the planned scoop wheel and mill, at their respective locations on the river, would be exposed to all the forces of nature. From Du Mont's final letter to Leibniz, from the last week of August 1696, it is clear that he shared Leibniz's skepticism about the durability of a scoop wheel on the main river. He likewise continued to adhere to his view, namely that the construction of a canal with a dike would be the best option. The construction of such a canal, projected and favored both by Leibniz and Du Mont, was however never realized during their lifetimes.

In the spring of 1697, Leibniz's correspondence with the miller and master carpenter Hans Linsen enjoyed a resurgence. Linsen – who worked at the Heyersum salt works, near the town of Hildesheim – had apparently been entrusted by Leibniz with the task of producing and testing a piston for a water pump. Furthermore, as is evident from a note of May 23, 1697, to Leibniz, Linsen had also been engaged by Leibniz to work on a model for a carriage. Linsen's water pump was possibly intended for the waterworks at Herrenhausen; at all events, Linsen offered Leibniz his services for the undertaking on this occasion.

In August 1697, the master builder Leonhard Christoph Sturm – the son of the renowned astronomer and mathematician, Johann Christoph Sturm[24] – having been appointed professor at the military academy in Wolfenbüttel, in succession to Johann Balthasar Lauterbach,[25] commenced a correspondence with Leibniz. Sturm had edited, and posthumously published, the chief civil-engineering work of Nicolai Goldmann (1611-1665) with the title *Vollständige Anweisung zu der Civil Bau-Kunst* (1696). In a letter of October 12, 1697, Sturm enquired about the possibility of his being appointed master builder in Hanover and, in a further letter of January 3, 1698, he presented himself as a master builder, a mathematics professor and a prospective preceptor at the court in Hanover. Finally, in a letter of February 3, 1698 – written just one day after the death of Leibniz's sovereign Ernst August – Sturm additionally offered his services as draughtsman, architect, poet and polymath for the design of a "castrum doloris", or castle of grief, in honor of the deceased elector. Following journeys to the Netherlands (in 1697), and to France (in

[24] cf. S. Kratochwil, "Johann Christoph Sturm und Gottfried Wilhelm Leibniz", pp. 104-118 in: H. Gaab, P. Leich, G. Löffladt (eds.), *Johann Christoph Sturm (1635-1703)*, (*Acta Historica Astronimiae*, vol. 22), Frankfurt am Main, 2004.

[25] cf. H.-H. Grote, *Johann Balthasar Lauterbach (1663-1694)*: *Professor für Mathematik, Landbaumeister und Ingenieur am Wolfenbütteler Fürstenhof*, Braunschweig, 1995.

1699), Sturm finally obtained an appointment as mathematics professor in Frankfurt an der Oder, in 1702.

The British architect John Smeaton (1724-1792) may well have been the first person to call himself a ‘civil engineer’ in English, a term that would come to refer to one who designs and constructs roads, bridges, water-supply and sanitation systems, or other other publicly funded and utilized projects, whereas in France the term ‘ingénieur civil’ (with a broader meaning than ‘civil engineer’) first appeared in the early 1800s. Overall the emergence of the civil engineer, as distinct from the military engineer, was a manifestation of a development which saw the continuing attenuation of the age-old connection between engineer and soldier in the period between the seventeenth and nineteenth centuries.[26] Leibniz’s correspondence with Leonhard Christoph Sturm, in 1697 and 1698, reveals at all events that the term “Civil Bau-Kunst” (or the art of civil engineering) was already well established in Germany at the end of the seventeenth century. Before his death in 1719, Leonhard Christoph himself witnessed the publication of his father Johann Christoph’s posthumous work *Kurtzgefasste Mathesis Oder Erste Anleitung zu Mathematischen Wissenschafften* (1717), whose 12 chapters or sections included those on military engineering (“Der Kriegs=Bau=Kunst”), and on civil engineering (“Der bürgerlichen=Bau=Kunst”), as well as his own *Architectura Civili-Militaris* (1719).

Engineering Manufactories

In the fields of engineering and technology (as in natural philosophy and physics), Leibniz’s correspondence with Papin was the most important from the mid-1690s. From his letter of August 30, 1696, Papin’s inventive genius and richness of ideas, but also his frustration, are evident; here he explained to Leibniz that he had conceived numerous new machines of which he could hope to realize

[26] cf. for example C. Mitcham, “Engineering as a productive activity: Philosophical remarks”, pp. 80-117 in: P. T. Durbin (ed.), *Critical perspectives on nonacademic science and engineering*, (*Research in Technology Studies*, vol. 4), Bethlehem (PA), London, Toronto, 1991, in particular pp. 82ff. (Where engineering comes from); A. W. Skempton, M. M. Chrimes, R. C. Cox, P. S. M. Cross-Rudkin, R. W. Rennison, E. C. Ruddock (eds.), *Biographical dictionary of civil engineers in Great Britain and Ireland. Volume 1: 1500 to 1830*, (*The Institution of Civil Engineers*), London, 2002, in particular pp. xvii-xxxiv (The practice of civil engineering 1500-1830).

not even half during his lifetime. Leibniz, in his reply on September 24, encouraged the correspondent to continue to dedicate himself to the progress of technology and he promised him his support in the endeavor. In this context, Leibniz too complained that he was not in a position to realize his own engineering discoveries. He specifically mentioned, in this context, his calculating machine which, even after 24 years of development, still had not been completed, principally due to lack of time and assistance.

In the fall of 1696, Papin submitted a petition for his release from the service of landgrave Charles of Hesse-Kassel, a copy of which he sent to Leibniz on October 4. In this petition, Papin emphasized the importance of his centrifugal ‘Hesse pump’ of 1689 (called the “Rotalis Suctor et Pressor Hessiacus”), especially for shipping and navigation. He desired to return to England, because navigation had a special significance there. Leibniz expressed his skepticism, and he was relieved when Papin’s petition to the landgrave was rejected, as he learned from a letter of January 14, 1697. Four months later, on May 13, Papin was able to report that, while his main objective in submitting the petition had not been achieved, he had been successful in having some of his demands met. Thus, he was given better conditions for certain research activities that were concerned with glass-kiln development, in particular for the improvement both of a process for glass melting, using his ‘Hesse pump’, and of a newly-developed oven. His efforts were directed, first of all, to testing and bringing to perfection a scaled-down version of the process. The realization on a large scale, however, was to be subject to a directive of the landgrave. Replying on May 25, Leibniz stressed the importance of glass melting for optics and recalled Tschirnhaus’ research on concave mirrors and convex lenses.

Papin was then able to report, on June 19, that his trials on small-scale glass melting had, in the meantime, been successfully concluded. He was confident that a scaled-up version of the process would also work. The landgrave had observed Papin’s experiment, and he had given instructions for the construction of a laboratory for the continuation of the series of experiments. Nonetheless, Papin had to show patience since, to begin with, a new oven had to be constructed. Then, on April 20, 1698, he could report to Leibniz that construction was under way. The new melting furnace – a key element of which was Papin's own 'Hesse pump' – was, however, not intended for the production of polished sheet or mirror glass, but solely of iron retorts or alembics. Finally, on October 9, 1698, Papin sent Leibniz a detailed description and a drawing of his new blast furnace.

In this blast furnace, the air was passed both above and below the burning wood using a centrifugal pump. The flames were blown by the ventilator pump in the direction of the melting crucible, and were simultaneously drawn to there by the suction effect of the smokestack. Through openings in the upper oven wall, a heating plate could be introduced and used for the extraction of the glass melt. This could also be carried out using a machine, the correspondent reported. The blast and suction air regulation would prevent the flames from rising through the openings (and thus impairing the servicing of the melting crucible, or even causing the curtailment of the fire). Papin informed Leibniz that the glass melt produced in the oven could be used for various product applications, such as mirrors, window glass or hollow cylinders. Furthermore, the oven could also be used for the production of iron products, by virtue of the great heat impact of the fire. Papin conceded, however, that he had not been able to realize the full potential of his invention, since his blast furnace was not large enough. In particular, the height of the smokestack was restricted to two feet.

In his reply from the third week of October, 1698, Leibniz recalled his own earlier experiments with melting furnaces, especially those carried out, in the summer of 1679, at the time of his cooperation with the discoverer of phosphorus, Heinrich Brand, as well as the ovens built by Johann Daniel Crafft. All these experiments had, however, not been undertaken using a blast furnace. Leibniz, although impressed by Papin's innovation, was of the opinion that, to begin with, ordinary bellows might be employed. Since the fire could now be regulated, the use of a heating plate for the removal of the molten glass seemed to him to be superfluous. The melting operations could be carried out entirely on such a plate, provided the intensity of the fire was not so great as to be able to damage the plate. Leibniz acknowledged that he himself had often contemplated the process of glass melting, and he continued to have the ambition to develop new ideas regarding it.

Papin, writing on November 17, emphasized the superiority of his method in comparison with the normal process, especially as regards the production of plate or mirror glass. In the conventional process, the glass melt was drawn from the oven and then polished. With the new process, the molten glass was to be drawn onto oven plates. To begin with, he wanted to test this, using smaller plates. However, the key innovation in his new oven was that the flame passed both above and below the material to be heated. Leibniz, for his part, as he wrote in his reply of November 28, was not really convinced that Papin's process was entirely new. In his view, such oven plates were already being used in the production of mirror glass. However, like Papin, he considered it worthwhile to render the polishing of the plate superfluous. Papin's final letter of the year 1698, written on December 11, contained a request to Leibniz for additional information regarding the normal process of producing plate or mirror glass. Papin confessed that his own knowledge was based on observations made on the island Murano, near Venice, in the year 1681. There, parts of a hollow cylinder were moved on a large stone into an oven. The molten glass was then spread out over the stone with the help of a draw-plate, or drawing die, before the whole was again removed from the oven.

Magnus Gabriel Block, in a letter of June 24, 1699, to Leibniz, described (with the help of a sketch) a smelting process of Francesco Maria Levanto, who was one of a number of foreign smelters and chemists who attempted to improve copper smelting at the Falun mine in Sweden.[27] Leibniz had already asked correspondents on a number of occasions about this process as, for example, on January 16, 1694, in a letter to Gustav Daniel Schmidt, and on July 23, 1697, in letters to Lorenz Hertel and to Johann Gabriel Sparwenfeld. At the heart of the process was a reverberatory furnace – or, one that isolates the material being processed from contact with the fuel, but not from contact with combustion gases – for roasting, or calcination, that could be fueled with twigs or branches. The roasted blende, or the ore produced by calcination, was then to be melted in an air furnace but was, however, carried away by the wind. As the desired success failed to materialize, Levanto was out of pocket following the trials of the process. This fate

[27] cf. H. Fors, *The limits of matter*: *Chemistry, mining and enlightenment*, Chicago and London, 2015, and in particular chap. 3, pp. 43-75 (Chemists in the mining business), and specifically (regarding Levanto) p. 66.

Levanto shared with Johann Kunckel von Löwenstern, who subsequently tried out the process, according to Block's report. Leibniz proposed operating the roasting furnace, and the air furnace, in a different way. He wrote to Block, on September 8, 1699, that one ought to leave the material longer in the roasting oven, in order that it becomes thicker, and to power up the air furnace slowly in dependence on the consistency of the material.

Reverberatory furnaces (alongside blast and cementation furnaces) were also employed in the eighteenth century Britain and Europe,[28] for tempering and annealing bar or rod iron, as well as for china or porcelain ovens,[29] and for glass ovens in manufactories, and presumably also in Tschirnhaus' new glass making plant, about which he informed Leibniz, in letters on May 18 and October 16, 1700, respectively. He had even set up a grindery, or grinding shop, for precious stones and jewels. The second of these communications provided details about his new glass-making plant and his plans for the production of convex lenses for telescopes and burning glasses. While Tschirnhaus lauded his lenses, in particular in his letters to Leibniz, the latter obtained technical details about Tschirnhaus' laboratories from Wagner. While on an exploratory tour through Saxony – having been spurred on to undertake it by Leibniz – Wagner visited Tschirnhaus in Dresden. His host showed him the glassworks, or glass kiln, regarding which Wagner sent a drawing and a detailed description to Leibniz. As regards the ingredients used to manufacture glass, Wagner learned little or nothing, other than the fact that arsenic and borax were not being used, since they would give glass a dark color. The visit to Tschirnhaus' laboratory for precious stones proved to be even more secretive. The king of Saxony – or, more precisely, the elector of Saxony, Friedrich August I (and king August II of Poland) – had forbidden visits by strangers, as well as the issue of materials from there. In spite of this, Wagner was able to take a quick look inside and to take a sample away with him. He had, however, to abandon any hope of visiting Tschirnhaus' private laboratory on his

[28] cf. C. MacLeod, "The European origins of British technological predominance", pp. 111-126 in: L. P. de la Escosura (ed.), *Exceptionalism and industrialisation*: *Britain and its European rivals, 1688-1815*, Cambridge, 2004; C. Evans, A. Withey, "An enlightenment in steel? Innovation in the steel trades of eighteenth-century Britain", *Technology and Culture*, vol. 53(3), (2012), pp. 533-560.

[29] cf. the following volume of the terminated Tschirnhaus Edition: E. Knobloch, C. Krautz, M. Ullmann (eds.), *Johann Friedrich Böttgers Tätigkeit am Dresdner Hof*: *Ehrenfried Walther von Tschirnhaus Gesamtausgabe,* Series II (Official Writings), Leipzig, Stuttgart, 2000.

estate in Kieslingswalde, since his host had proved very secretive in the matter. Wagner, in letters on June 26 and July 21, 1700, revealed to Leibniz the tricks with which he tried to elicit as much information as possible from his conversation partners. He also went to see the architect Johann Heinrich Gengenbach, during which visit he was able make numerous drawings of a fortification model, and of other discoveries and curiosities as, for example, a pull-out or fold-out table, an Italian andiron, as well as carriages and lanterns, as he reported to Leibniz on August 1 of that year.

Previously – on the occasion of the discussion of the failed trials of Levanto – Leibniz, in a letter to Block on September 8, 1699, pointed to the general difficulties in the realization and implementation of such engineering innovations. Large-scale trials often proved expensive. But these were necessary, not only for testing discoveries but also in order to establish trust in them, and so to counter the widespread skepticism towards innovations. Late in 1699, Jobst Heinrich Voigt – the head bailiff, or administrator, of the location Aerzen in the Weser Uplands – presented to Leibniz a drawing of a a threshing-machine of his design. This was attached to a letter, of November 28, sent to Leibniz by another official, Cord Plato von Gehlen, in which it was claimed that the machine in question could be operated by a single person, do the work of fifteen others and, accordingly, reduce costs considerably.[30]

Leibniz, in his reply in mid-December 1699, expressed his appreciation of the new machine, but he did make a proposal for the optimization of the threshing-machine transmission system, namely by replacing a three cogged wheel-lantern pinion element – a central cogged wheel in a vertical plane engaging the horizontal staves of a lantern pinion on each side – with a two-wheel pulley system and, accordingly, reducing resistance. Leibniz reacted not only by proposing technical improvements like this. He also expressed his opinion regarding the widely-held view, namely that such machines actually deny the poor of potential earnings. In this context, he recalled a further instance of social change accompanying technological progress, namely that which led to the proscription of the ribbon-loom (“die strumpf und bandmuhlen”) in the year 1685 by

[30] Regarding technology and social change, cf. L. White Jr. (note 3 above = note 99). Regarding the threshing machine, cf. T. S. Reynolds (note 12 above = note 108), and in particular p. 138 (Figure 3-5, showing a water-powered threshing machine from the year 1735).

the emperor, Leopold I, following a recommendation of the Imperial Diet at Regensburg in 1681. Leibniz rejected such concerns regarding the loss of employment though mechanization. Even if there were to be such lay-offs, there would be enough other useful occupations for those affected. At most there would be readjustment difficulties at the beginning. Leibniz also referred to Voigt's threshing-machine, in a letter to him from the second half of January 1700. Again his basic opinion on the matter, expressed in this letter, was that one ought not to refuse the assistance of machines, or the art of engineering, on the grounds of such a pretext. Besides, there would be an infinity of alternative occupations for the hands set free by mechanization. He also referred here to a similar threshing-machine being developed at the location Linden (near Hanover) by count Franz Ernst von Platen and of which he subsequently made a drawing. The drawing of Voigt's threshing machine reveals a human operator turning a camshaft to operate the thresher-cylinders. The carriage, to which the threshers were attached, was moved or pedaled along the threshing-floor by means of a rack and pinion gear mechanism. To deal with the faineance of workers, Leibniz proposed remuneration of the operatives on the basis of performance, namely in terms of recorded tours or working shifts. Leibniz also contemplated here the use of water and wind as alternatives to manpower as a prime mover for the threshing-machine. The former option, he found, would require the availability of a water raceway. On the other hand, in order to avail of wind power, a pumped-storage system involving the use of a windmill and a water reservoir system – similar to that contemplated for use in the Harz mining district – would be required, in order to ensure operation of the machinery throughout the autumn and for part of the winter, he told the correspondent.

Process or Chemical Engineering

Further key aspects of the correspondence between Leibniz and Papin, in the late 1690s, included chemical or process engineering, and techniques for the conservation of foodstuffs. On June 19, 1697, Papin indicated that he was working on a discovery of practical importance, through which chemical processes could be carried out in fresh air, and he promised to keep Leibniz informed. A little later, on

August 5, he reported that he had achieved a breakthrough. For the distillation of sulfur, he had developed distillation equipment consisting of six alembics, or retorts, in series. The outlet of the final distillation flask led into the open air, and in this retort a considerably greater quantity of spirit of sulfur, or oil of sulfur, was liquefied in comparison with the first retort. By the use of additional retorts, a complete liquefaction could be achieved without having acid fumes escape into the air. Papin stressed here that his method might also be used with other combustible materials and could provide insights into other chemical processes. And, in a later letter of October 24, he continued this line of thought, referring to flowers of niter purified by sublimation, and to the extraction or production of sulfuric acid.

Leibniz recognized at once the importance of Papin's new process for the production of the strong acids, like oil of vitriol (sulfuric acid), aqua fortis, spirit of niter or saltpeter acid (nitric acid), and spirit of salt (hydrochloric acid), as is evident from his letter to Papin of November 18. Papin in turn, in his letter of December 5, 1697, emphasized the importance of spirit of sulfur, particularly for chemistry and medicine, but also for the conservation of meat. And, as he explained in his first letter to Leibniz of 1698, on January 6, the spirit of sulfur, when diluted with water, could serve as a conservation fluid for foodstuffs. He had, himself, successfully conserved pears, raspberries, apples, and plums, as well as several types of meat and vegetables. In addition, he intended investigating the conservation of fish and he offered to make such conserved products available to Leibniz. In addition, in letters of December 12, 1697, and January 6, 1698, respectively, Leibniz and Papin discussed certain medical benefits in connection with the conservation of meats, fish and fruit, like, for example, the application of the spirit of sulfur as a remedy for scurvy.

Engineering Science: Mechanics of Fluids

Leibniz's meetings in Italy, in 1689-1690, with major figures of the second generation of Galileo's disciples included the renowned physician Bernardino Ramazzini, who was also interested in problems of hydraulics and hydromechanics, and these topics then became central issues in his correspondence with Leibniz in the year 1690.

Included in their epistolary exchanges were fundamental considerations in fluid mechanics, which involved, for example, the beginnings of the theory of streamlines.[31] The starting point here was the intelligence Leibniz received that Domenico Guglielmini – a physician, mathematician and engineer with whom he would correspond over several years – intended to treat fundamental questions of fluid mechanics in a tract, with the title *Aquarum fluentium mensura nova methodo inquisita* (1690-1691). In addition to this, Leibniz was interested in a work, planned by Ramazzini, on the springs or wells of Modena, and which duly appeared in 1691 under the title *De fontium Mutinensium admiranda scaturigine tractatus physico-hydrostaticus*, a work that was also to have an impact on Leibniz's ideas on earth history, which appeared in his posthumously-published *Protogaea*.[32] In the discussions Leibniz had with Ramazzini in Modena, between December 30, 1689, and February 2, 1690, he had learned that his vis-à-vis wanted to experimentally investigate the flow of water around an obstacle in a stream. From discussions with Guglielmini, whose acquaintance he had made in Bologna about a week before his arrival in Modena, he also knew of the latter's plans to write a tract about the laws of fluid motion in open channels. Although, Galileo's disciple, Benedetto Castelli (1578-1643), had formulated one of the fundamental laws of fluid mechanics, namely the continuity law, in his book *Della misura dell'acque correnti* (1628), several other basic questions had remained unanswered as, for example, about the vertical velocity distribution in a stream. Even in the third edition of Castelli's book of 1660, the corresponding proposition – which postulated a linear velocity distribution increasing from the river bed to the water surface – had proved to be unsatisfactory. Motivated by this, Guglielmini sought to place the laws of open-channel flow on a new foundation. When, on February 25, 1690, Leibniz enquired of Ramazzini about the progress of Gugliemini's undertaking, the correspondent – in his reply of April 15 – reported instead about another planned work, entitled *De motu*

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[31] cf. C. S. Maffioli, *Out of Galileo*: *The science of waters 1628-1718*, (*Nieuwe Nederlandse Bijdragen tot de Geschiedenis der Geneeskunde en der Natuurwetenschappen*, no. 49), Rotterdam, 1994; J. G. O'Hara, "The mathematician as engineer in the seventeenth century: Leibniz and engineering hydraulics", pp. [77]-89 in: M. C. Duffy (ed.), *Engineering and engineers*: *Proceedings of the XXth International Congress of History of Science (Liège, 20-26 July 1997)*, vol. XVII, Turnhout, 2002.

[32] cf. C. Hodoba-Eric, "Artificial apertures: The archaeology of Ramazzini's *De fontium* in 17th-century earth historiography", *Centaurus*, vol. 62(3), (2020), pp. 522-541.

mechanic, by yet another engineer of Modena, namely Giovanni Baptista Boccabadati whom Leibniz had also met during his stay in that city.

Boccabadati had been concerned above all with the problem of flooding along the Po tributaries, Panaro and Secchia, and, during the recent inundations, at the beginning of April 1690, he had undertaken observations and measurements along these rivers, an activity about which Ramazzini reported to Leibniz in this letter of April 15. In commenting on Boccabadati's practical experience, Leibniz, in his reply of July 16, then brought up Castelli's theorem about the vertical velocity distribution in a stream. Leibniz doubted that an exact rule for this velocity distribution in natural waters could be given, and he posed an additional question, namely concerning the increase of the velocity of flow downstream from a point where the channel depth suddenly increased, having in mind perhaps a structure at a bend or turn in the stream (like an earth wall, levee or dam), similar to that built in the river Tiber by the Dutch hydraulic engineer, Cornelis Meyer (1640-1694), and about which Tschirnhaus had previously informed him in a letter from Rome, on April 10, 1678. Meyer was a member of the 'Accamemia fisico-mathematica romana' and author of a tract on the fluvial navigation of the river Tiber, entitled *L'arte di restituire a Roma la tralasciata navigazione del suo Tevere* (1683). Leibniz's conviction was that, at a greater distance from such a point, the velocity increase of the stream would be negligible.

Then, following his return to Hanover, he received several reports about Boccabadati, and about the planned work of his on mechanics that was to be founded on the practical experience of the author in the floodplain, or flood zone, around Modena. Thus, Ramazzini referred, on April 15, 1690, to an interruption of Boccabadati's efforts on his planned mechanics tract, that was to based entirely on restoration efforts along the Po tributaries Panaro and Secchia, and two years later, on March 30, 1692, Ramazzini reported about a further delay in the completion of the work, which, alas, was still unpublished at the time of Boccabadati's death in 1696.

As regards Guglielmini's forthcoming tract, Leibniz, in his letter of July 16, 1690, to Ramazzini, expressed his skepticism about whether an exact rule to supersede Castelli's might be formulated, but he did express his pleasure at the prospect of the appearance of

Ramazzini's own tract on the springs, or wells, of Modena. Leibniz learned about the appearance of the first part of Guglielmini's tract from a letter of Bodenhausen, of September 16, 1690, and in his reply of November 5, he immediately requested that the correspondent send him information about the most important propositions in Guglielmini's work and their foundation. Then, in the first half of November, Leibniz received a review copy of the work from Otto Mencke and, a little time later, on November 17, he sent a first opinion about Guglielmini's book to Bodenhausen. At the center of Leibniz's interest was Guglielmini's postulated parabolic velocity increase from the water surface to the river or canal bed. This "scala fallacy", as it was later called, was based of the false assumption of the applicability and validity of Torricelli's efflux law in an open stream.[33] Whether Leibniz immediately recognized, that the mistake in Guglielmini's proposition was rooted in an inadmissible application of the Torricelli law, is not clear. In any event, he emphatically asserted that the velocity distribution postulated by Guglielmini could have no validity in real rivers and canals. However, in his anonymous review of the first part of Guglielmini's *Aquarum fluentium mensura nova methodo inquisita*, in the *Acta Eruditorum* of February 1691, Leibniz desisted from any kind of criticism and restricted himself to an account of the basic tenets of the work.

Guglielmini's treatment of fundamental questions of fluid flow in open channels, in his *Aquarum fluentium mensura* (1690-1691), instigated Papin to publish a critique, entitled "Observationes quaedam circa materias ad hydraulicam spectantes", in the May 1691 number of the *Acta Eruditorum*. This in turn provoked a réplique from Guglielmini in the form of two open letters, one addressed to Antonio Magliabechi, and the other, dated December 24, 1691, addressed to Leibniz, which were published with the title *Epistolae duae hydrostaticae* (1692). The dispute was essentially concerned with the issues of whether Galileo's laws of falling bodies were valid in fluid flow, whether the velocity in the upper layers of a stream was influenced by the movement of the lower layers, and how the efflux

[33] cf. S. Leliavsky Bey, "Historic development of the theory of the flow of water in canals and rivers", *The Engineer*, vol. 191, (1951), pp. 466-567, specifically p. 466, p. 498, p. 533, p. 565, and pp. 601-603; J. C. I. Dooge, "Historical development of concepts in open channel flow", pp. 205-229 in: G. Garbrecht (ed.), *Hydraulics and hydraulic research*, Rotterdam, Boston, 1987; L. Boschiero, "Machines, motion, mechanics: Philosophers engineering the fountains of Versailles", *Technology and Culture*, vol. 61(4), (2020), pp. 1108-1128, and in particular pp. 1111-1114 (Hydrostatics in the seventeenth century: From Galileo to Pascal).

velocities of a fluid out of an orifice, near the bottom of a cylindrical container, compared with that from an orifice of the same diameter in the bottom itself, under the same pressure head. Papin's response to Guglielmini's *Epistolae duae hydrostaticae* only appeared in 1695 in the form of two open letters, addressed to Huygens, with the titles "Lettre, touchant la mesure des eaux courantes" and "Epistola … de fluentium aquarum mensura", respectively, as part of Papin's bilingual miscellany entitled *Recueil de diverses pieces touchant quelques nouvelles machines* and *Fasciculus dissertationum de novis quibusdam machinis*, respectively. Here Papin repeated his objections in greater detail than in his "Observationes quaedam" of 1691. In doing so, he desisted from using mathematical or technical proofs and restricted himself to the consideration of analogies or differences between solid bodies and fluids. In this way, he believed he had refuted, or made superfluous, the objections of Guglielmini.

Papin's *Recueil* was reviewed (probably by Leibniz) in the August 1695 number of the *Acta Eruditorum*, and thus became known to Guglielmini. However, on June 22, 1696 – when Guglielmini commenced his correspondence with Leibniz – he still did not have Papin's work to hand and, accordingly, he did not feel obliged to provide a response, or a rejoinder. He did, however, request Leibniz's help in acquiring a copy of the work. A month later Papin had two copies of his *Recueil* sent to Leibniz, one of which, although forwarded by Leibniz, never did reach its intended addressee in Italy. Subsequently (on January 7, 1697), Leibniz sent Guglielmini hand-written extracts from the work. For his réplique to Papin's criticisms in 1697, Guglielmini once again chose the form of two open letters, addressed to Leibniz and Magliabechi, respectively. However, the publication of Guglielmini's letter (of June 5, 1697) to Leibniz in the *Acta Eruditorum* was refused, in view of its length, and so the long-aspired to publication was finally procured by Leibniz himself only thirteen years later – namely in the first volume of the *Miscellanea Berolinensia* (1710) – thus bringing the dispute to a conclusion in the year of Guglielmini's death.

Guglielmini's letter of June 5, 1697, was concerned, among other things, with his postulated parabolic velocity distribution and increase from the water surface to the canal bed on the basis of Torricelli's efflux law, the applicability of Torricelli's theorem to open-channel water flow (over both horizontal and inclined canal beds), and the general validity of Galileo's laws of falling bodies in fluvial mechanics. According to Guglielmini's *Aquarum fluentium mensura* (of 1690-1691), the laws of fluid flow were to be explained exclusively by the fall (or head) of the channel, the slope or inclination of the water surface, and the pressure of the water. Neither gravitation nor resistance forces were taken into account. This abstract mathematical approach could not, of course, be automatically applied to conditions prevailing in real rivers and canals. However, in his letter of June 22, 1696, Guglielmini informed Leibniz that he was preparing a new tract, which would not be subject to such restrictions. Leibniz delighted in the new knowledge emerging in the context of Guglielmini's fluvial mechanics, including that about the nature of curl or vorticity flows, as his letter of January 7, 1697, to Guglielmini reveals. And so with the appearance (in 1697) of Guglielmini's main work – that was based on actual engineering practice rather than mathematical abstraction – entitled *Della natura de' fiumi trattato fisico-mathematico*, the academic dispute with Papin about the fundamentals of fluid mechanics lost its importance to a great extent.

7) Projects

"Solcher sterilitat nun zu hülffe zu kommen habe ich den vorschlag gethan gehabt, wie man unzahlbare neue und nüzliche anmerckungen die schohn unter den leuten sind, nur daß sie den gelehrten nicht bekand, herfür geben könne".[34]
Leibniz to Sebastian Scheffer, Mid-April 1682.

The world of projects and of projectors, at the end of the seventeenth century, was symbolized by an interaction of artisans and practitioners with the world of learning. It was the lack of such interaction in Nuremberg that Leibniz complained so bitterly about in his letter to Scheffer cited here. In contrast, this interaction is clearly evident, for example, in Leibniz's correspondence in relation to his calculating machine.

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[34] A III,3 N. 342, pp. 588f.; Translation: To counter such sterility, I had made a proposal regarding how the countless new and useful annotative expressions prevalent in the population, although unknown among the learned, might be used to this end.

Projects: Calculating Machines

The history of Leibniz's calculating machine can be traced back to the years of his sojourn in Paris, between 1672 and 1676.[35] Following early designs, dating from his time in Mainz before his stay in Paris, he had presented a wooden three-place demonstration model to the Royal Society on the occasion of his first London visit in 1673. The presentation, on February 1 of that year, was recalled by Oldenburg in a letter to him on February 9. Subsequently, an improved version of the machine, made of metal and with six entry and twelve result positions (powers of ten), came into being in Paris and it was presented to the Académie des Sciences early in 1675. It was referred to, in an entry of January 9, 1675, in the Procès-verbaux of the Académie. However, the final version of this first metallic model still remained to be presented at the time of Leibniz's departure from Paris in 1676. Accordingly, he attempted in the years that followed to entice the Parisian clockmaker Ollivier, who had been entrusted with the construction of the machine, to come to Hanover, and the clockmaker may possibly have arrived in Hanover at the end of 1679, or in early 1680, although there is no clear proof that he actually did. At all events, when the model was finally completed, in the mid-1680s, Leibniz commissioned a larger machine with eight entry and twelve result positions. The work on this so-called 'older machine' was finally brought to a conclusion by the Hanover clockmaker Georg Heinrich Kölbing, in 1694, following a construction period of almost ten years.

Leibniz's efforts for the completion of his four-function (*viz*. addition, subtraction, multiplication, division) calculating machine, from between 1680 and the mid-1690s, can be traced in his correspondence in this period. His efforts to develop his calculating machine – about which he informed various correspondents in the

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[35] cf. L. von Mackensen, *Die Vorgeschichte und die Entstehung der 4-Spezies-Rechenmaschine von Gottfried Wilhelm Leibniz, nach bisher unerschlossenen Manuskripten und Zeichnungen mit einem Quellenanhang der Hauptdokumente*, Doctoral Dissertation (TU Munich), 1968; M. R. Williams, *A history of computing technology*, Englewood Cliffs, N.J.,1985 (and Los Alamitos, CA, 1997), in particular chap. 3, pp. 122-158 (Mechanical calculating machines); L. von Mackensen, "Calculating machines", pp. [84]-107 in: K. Popp, E. Stein (eds.): *Gottfried Wilhelm Leibniz*: *The work of the great universal scholar as philospoher, mathematician, physicist, engineer*, Hanover, 2000; E. Stein and F.-O. Kopp, "Konstruktion und Theorie der leibnizschen Rechenmaschinen im Kontext der Vorläufer, Weiterentwicklungen und Nachbauten. Mit einem Überblick zur Geschichte der Zahlensysteme und Rechenhilfsmittel", *Studia Leibnitiana*, vol. 42(1), (2010), pp. 1-128; M. L. Jones, "Calculating machine", chap. 29 (pp. 509-525) in: M. R. Antognazza (ed.), *The Oxford Hanbook of Leibniz*, Oxford, 2018.

spring of 1680 – appear to have also suffered due to lack of time. Detlev Clüver's admonition, on July 26, 1680, that the completion of the calculating machine was more important than work for the Hanoverian court proved to be of no avail, not least because of Leibniz's commitment at the time to his time-consuming windmill project in the Harz mountains. A further difficulty was the lack of a suitable skilled craftsman in Hanover for work on the machine. At all events, Leibniz was pleased to be informed by Ferguson, on November 10, 1682, about two prospective young Dutch clockmakers, brothers who were willing to travel to Hanover and take up employment there.

Leibniz's English correspondents Clüver and Robert Hooke – to whom he turned to through the intercession of Theodor Haak – were the ones who emphatically enquired about progress in the construction of the calculating machine,[36] not least because the machine appeared to be a part of a larger project for the mechanization of thought predicated on an interdependency of philosophical principles and mathematical-scientific results. To Haak, for example, Leibniz wrote in February, 1680, that a general script was conceivable with the help of which one might be able, for every topic, to calculate and prove just like in algebra and arithmetic. He also recalled, in this letter, his visits to London (in 1673 and 1676) and his meetings there with Henry Oldenburg, and he expressly desired the involvement of Hooke.

Two machines, about which Leibniz reported in his correspondence with Bodenhausen and Huygens, deserve particular mention. In the summer of 1691, Leibniz possibly intensified his efforts to have the construction of the so-called 'older model' of his four-function calculating machine completed; perhaps, however, he was inspired to consider such machines because of a recommendation to the Tuscan hereditary or crown prince Ferdinand he was contemplating. At all events, at the end of a letter to Bodenhausen, on June 22, 1691, he referred to his "Arithmetische Machinam" and his desire to complete its construction. That the study of mathematical curves produced by movement would also require an apparatus, or machine, to draw them was obvious and was discussed in detail by Leibniz, both in a published article entitled "Supplementum

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[36] cf. M. L. Jones, *Reckoning with matter*: *Calculating machines, innovation, and thinking about thinking from Pascal to Babbage*, Chicago and London, 2016, and in particular (regarding Leibniz and Hooke) chap. 2, pp. 56-87.

geometriae dimensoriae", in the *Acta Eruditorum* of September 1693, and also in his letter to Huygens of October 11, 1693.

In the period 1694 - 1696, calculating machines came to the fore again, and were referred to more frequently in Leibniz's correspondence in these years than at any time in the previous two decades. An important reason for this was, no doubt, the completion in 1694 of his 'older model'. The elation in his accounts of the device served to motivate his correspondents to recall their own knowledge in the field. The great variety of models discussed in this context also clearly illustrates the extent to which the completion of such mathematical devices reflected the spirit of the time. When the landgrave, Karl of Hesse-Kassel, expressed his interest in the mode of operation of a machine he had received from his brother, Leibniz was enticed to provide a detailed report – in a letter sent to Johann Sebastian Haes on April 8, 1695 – about the recent history of mathematical calculating machines. In fact, the letters Haes sent to Leibniz, on March 28 and May 23, 1695, and Leibniz's corresponding letters, sent on April 8 and at the end of May or early June of that year, are of special significance here. These communications contained reports about the improvement of the 'Pascaline' (the calculator of Blaise Pascal)[37] by the Parisian watchmaker René Grillet, about variants of Samuel Morland's machine type,[38] that used slide rules and Napierian logarithms and that was to be seen in the guise of an exemplar in possession of the landgrave, about a little machine which Haes himself had made more than ten years earlier and which had previously been made known to Leibniz, about yet another little machine of Charles Cotterell and about the calculating cylinders of Caspar Schott and Pierre Petit. The adding machine of Haes, referred to in his letter of May 23, 1695, and a gearless machine conceived by Tschirnhaus, were, on the other hand, no doubt independent developments. The latter correspondent, on hearing of the completion of Leibniz's 'older machine', reported about his own very different device on February 27, 1694.

A first reference to the completion of the 'older machine' by Kölbing may be found in a letter (from which only an extract is

[37] cf. H. Loeffel, *Blaise Pascal 1623-1662*, Basel, Boston, 1987, in particular chap. 3 (Die Erfindung der Rechenmaschine).

[38] cf. H. W. Dickinson, *Sir Samuel Morland*: *Diplomat and inventor*, 1625-1695, Cambridge, 1970, in particular pp. 28-33, and plates I-VII.

extant) to L'Hospital of August 16, 1694, and in the correspondent's reply of November 30. In fact, L'Hospital immediately reacted to Leibniz's communication concerning the completion of the work on the first exemplar by commissioning a duplicate of the machine in return for appropriate remuneration. In the years between 1694 and 1696, L'Hospital continued to remind Leibniz about this order. In a letter to Bodenhausen, on October 13, 1695, Leibniz also referred to the completion of the machine almost a year earlier and – as in the case of L'Hospital – he was flattered and obliging when Bodenhausen requested further details of the machine, no doubt with the intention of enticing the duke of Tuscany to order a duplicate.

Yet another indication of the completion of the 'older machine' from the year 1694 is found in Leibniz's letter to Nicolas Toinard of October 14 (or perhaps 24) of that year. Furthermore, there can be little doubt that Crafft was able to give Huygens an account of Leibniz's calculating machine from his perspective, as we learn from Huygens' letter of December 27, 1694, to Leibniz. The machine was likewise presented to visitors in Hanover, as for example on the occasion of a passing visit by Tschirnhaus, in September or October 1694, which is recorded in Leibniz's letter to Jacob Bernoulli from the spring of 1696, albeit with the caveat that only a part of the machine was complete on that occasion. There is also evidence of a presentation of the machine for Thomas Burnett of Kemney, which took place in Hanover in April 1695, and which was referred to in Leibniz's final letter addressed to Huygens, on July 1, 1695.

At about the same time as the completion of the first exemplar of the 'older machine', work began on the second version, or so-called 'younger machine', which offered, for the same number of entry positions, sixteen result positions, as Leibniz explained in detail in his letter to Bodenhausen on December 23, 1695. However, in the four years that followed, the calculating machines played no great role in Leibniz's correspondence. Then, on February 25, 1700, the death took place of Hans Adam Scherp, who had been working on Leibniz's 'younger' calculating machine. The clockmaker Johann Levin Warnecke, from Helmstedt, became his successor having been recommended by Wagner, who himself assumed the role of a supervisor of the ongoing work on the machine. This course of events proved to be a stroke of good fortune, not least for posterity. Thus, on the basis of his reports concerning progress and problems in the construction of the machine, its coming into being can be retraced step-by-step. Already, in the month following Scherp's death, both the 'younger machine' (then under-construction) and the completed 'older machine', which served as a model for the new machine, were transferred to Helmstedt, together with a letter of March 15 addressed to Wagner. The latter succeeded in striking a balance between the respective interests of Leibniz and Warnecke, and he made the delays, which inevitably arose, plausible to the impatient Leibniz. Thus, in order to reduce expenditure, Leibniz at first wanted to have to pay only for the overhaul and reworking of individual parts, as he indicated in a letter of March 18. Wagner, replying on March 23, guaranteed Leibniz a daily control of the work in progress, to prevent waste or deceit, but he did point out, that the unobstructed interaction of the parts of the machine in itself demanded trials, lasting days at times, and that the remuneration would have to be orientated towards the effort involved rather than just the final product. The circumstance that progress was slow, Wagner attributed, in letters of early February, 1701, to other work commitments of Warnecke, to his diligence and painstakingness, to the difficulty of working long hours by candle light in winter and, above all, to the desolate state in which Wagner claimed Scherp had left the 'new machine'. Thus, progress and setbacks went hand in hand.

At the beginning of February 1701, Wagner could report the completion of the drawing spindle for moving and positioning the carriage. However, Wagner and Warnecke had ascertained here that holes could not be drilled uniformly, and had to be provisionally repaired, and also that rods could not be mounted at right angles with the result that, at that juncture, the machine could only be operated by applying force. Warnecke's predecessor had used neither compass nor protractor, Leibniz was told. The rotary disk was completed but, in putting the parts together, fresh imprecisions, construction defects, as well as evidence of tinkering and botching, became apparent, all matters which found expression in Wagner's letters to Leibniz in February and March, 1701.

On April 7 then, Wagner once again expressed his frustration regarding Warnecke's deceased predecessor. The latter had, Wagner asserted, been like a child. He had exploited Leibniz and only wanted to secure his income in order to indulge his passion for liquor, Leibniz learned from this communication. Leibniz surely felt piqued when he wrote his reply four days later, on April 11, in which he also recalled, in contrast to Scherp, his predecessor, namely the clockmaker Georg Heinrich Kölbing. Pragmatically, however, he had come to terms with the shortage of such qualified tradesmen or craftsmen. Wagner, in contrast, in his letter of August 12, considered Scherp's work to have been useless. Warnecke, he claimed, could have constructed a new machine in the time he spent doing repair work on the older model. He then proceeded to give precise details of three specific corrections that had been carried out on the machine.

In all of this, however, both Leibniz and Wagner were in agreement about the quality of the 'older machine' and about the fact that the structure of the 'new machine' was superior to that of the older one. On April 26, 1701, Wagner reported the completion of the upper part of the machine and, from July, Warnecke devoted himself to the improvement of the 'older machine'. On this device, Wagner also carried out the first calculation examples which he reported to Leibniz, on July 29. Instead of multiplying a four digit number (4286) by 4, as intended, Wagner – after the operating rules had slipped his mind – carried out the addition of this four digit number and a two digit number (16). The result he obtained contained an error in the third place (*i.e.* 4202 instead of 4302), which revealed that the decimal carrying operation was incomplete. A further addition (of 16), did however lead to the correct final result (4318). In his non-extant reply, Leibniz surely pointed to the role of the series of pentagonal disks, incorporated in the carrying mechanism, which served for the manual through-connection of all those positions that were, although activated, not brought to completion. Although Wagner heeded these disks in his following calculations (reported on August 5), these multiplication examples were also flawed. Wagner and Warnecke then developed a correction procedure, which combined the requisite corrective horizontal positioning of the pentagonal disks with a renewed manual rotation of the crank that operated the value transfer mechanism – between the setting mechanism (or input) and the result mechanism (or output) – of the machine. They were also able to eliminate some further errors by making precision-engineering alterations, whereas other errors Wagner considered to have already been eliminated in the ‘new machine’, as he reported on August 12.

Then, for a short time at the end of our period, late in the year 1701, everything was once again in the balance when Warnecke became gravely ill. To Wagner, who observed night vigils at the bedside of the patient, the development of the calculating machine appeared for a time to be cataclysmal, with the impending death of the clockmaker coming after that of his predecessor in the previous year. However, in his final letter of the year 1701, on December 16, Wagner was able to announce to Leibniz the recovery of the patient and the resumption of work on the calculating machine. The work on the perfection of the calculating machines was to continue for the rest of Leibniz’s life, and thereafter.[39]

Steganography and Cryptography

A central theme in Leibniz’s correspondence with the court archivist in Kassel, Johann Sebastian Haes, was the cryptograph or cipher code developed by the correspondent and printed in book form (and in a very limited edition), with the title *Steganographie nouvelle* (1693). The author included one copy of the work (with a dedication to the elector, Ernst August of Hanover) with a letter dispatched to Leibniz on May 4, 1693, and with the request that he pass it on to Franz Ernst von Platen, the prime minister in Hanover. The story of the coming into being of this work, as well as of its repudiatory reception at the Hanoverian court, is documented in Leibniz’s correspondence with Haes from its commencement in July 1691.

Steganology, copology (or deliberate deception), and specifically here steganography, represented a medium for the concealment of information and with the help of which a secret message could be hidden in an unsuspicious text. In the foreword to his *Steganographie nouvelle*, Haes stated that his cipher code would be particularly useful in diplomatic communications, being easy to write but difficult to decipher for the uninitiated. The author provided an historical summary of the development of cryptography, and he referred to pioneers like Johannes Trithemius (or Johann Trittenheim, 1462-

[39] cf. F.-S. Morar, “Reinventing machines: The transmission history of the Leibniz calculator”, *British Journal for the History of Science*, vol. 48(1), (2015), pp. 123-146.

1516), who was perhaps the first theoretician in the field, Gustavus Selenus (alias Augustus the Younger, duke of Brunswick-Lüneburg-Wolfenbüttel, 1579-1666), who was author of *Cryptomenytices et Cryptographiae libri novem* (1624), and the German Jesuits Athanasius Kircher (1602-1680) and Caspar Schott (1608-1666).[40]

Leibniz – who was honored with an anonymous acknowledgment in the "Avertissement" of the *Steganographie nouvelle* – had first made the acquaintance of Haes when he visited the natural-history collection of the landgraviate library in Kassel, at the beginning of November 1687, on which occasion various projects were discussed. That these included the projected stenographic tract is evident from Haes' first letter to Leibniz, on July 30, 1691. Subsequently Haes' interest was concentrated on the *Steganographie Nouvelle*, the completion of which was drawn out into the year 1693. He praised, again and again, the advantages of his cipher code, however without revealing any details. When, at the end of 1692, the tract had taken on a concrete form, Haes was finally willing to provide Leibniz with an insight into his system of encryption, which involved giving a different sense to individual letters or words with the help of tables, which he referred to in a letter of December 11, 1692. Putting the final touches to the work proved, however, to be most tedious, since the author wanted, for security reasons, to leave gaps in the text to be filled in by hand and to send encoding examples separately, and in handwritten form.

With the consignment of May 4, 1693, Haes then sent his *Steganographie Nouvelle*, together with an accompanying letter for Leibniz and a letter for prime minister Von Platen, as well as a separate package with additional tables and handwritten supplements to Hanover. The copy of the work in question – now preserved at the ducal library in Wolfenbüttel – with numerous marginal entries by the author consists of, in addition to the previously mentioned "Avertissement", thirteen chapters as well as a handwritten "Addition". In the course of the correspondence with Leibniz, Haes provided further annotations, examples and supplements to his opus. The appropriateness of the cipher code was made clear by the author's

[40] cf. for example, N. F. Johnson, Z. Duric, S. Jajodia, *Information hiding*: *Steganography and watermarking-attacks and countermeasures*, Dordrecht, 2001 (and New York, 2003), in particular chap. 1, sect. 2, pp. 2-4 (Steganography throughout history); G. Kipper, *Investigator's guide to steganography*, Boca Raton (FL), London, New York, Washington (DC), 2004, in particular chap. 3, pp. 15-36 (History).

choice of examples, which were derived from contemporary military conflicts. In the *Steganographie nouvelle*, reference is made to the siege of the town Montmélian (in 1691) in the form of a letter of the duke of Savoy, Victor Amadeus II, sent to Carlo Girolamo del Carretto, the Marchese di Bagnasco. In relation to this letter, further examples of encoding using the cipher were sent to Leibniz on July 1, 1693. Leibniz, for his part, had at first hesitated to pass on the copy of the *Steganographie nouvelle* he had received, together with the supplements, to prime minister Von Platen, as he informed the correspondent, on June 1, since the author's dedication of the work to the elector Ernst August had met with a mixed response in Hanover.

Finally, on the insistence of the correspondent, Leibniz forwarded the material to the court. At first Haes was confident of receiving recognition and reward from Ernst August, as he indicated to Leibniz on June 11. However, when a decision of the Hanoverian court in his favor proved not to be forthcoming, he made no secret of his disappointment in a letter of June 30. Yet another letter to Von Platen, which was attached to a letter to Leibniz of July 31, proved to be of no avail. In his final letter of the year 1693, on October 8, Haes expressed to Leibniz his great disappointment at the outcome, notwithstanding which, however, he remained convinced of the merits of his cipher code.

In the course of their mathematical correspondence, in the late 1690s, Leibniz attempted (alas without success) to persuade John Wallis to share his knowledge of cryptography.[41] To begin with, on March 29 and October 12, 1697, and again on April 3, 1698, he attempted to persuade the 80-year-old correspondent to impart his knowledge to the younger generation. Later, from the end of 1698, Leibniz pleaded for the sending of a younger man to Wallis to partake in his knowledge. To this end, he turned to the hereditary or crown prince Ferdinand of Tuscany, on November 3, 1698, as well as in the following year to the courts of Brandenburg (on February 24) and of Sweden (on April 17). Leibniz's motive was surely not the political

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[41] cf. P. Beeley, “"Un de mes amis": On Leibniz's relation to the English mathematician and theologian John Wallis”, chap. 5, pp. 63-82, in: P. Phemister, S. Brown (eds.), *Leibniz and the English-speaking world,* Dordrecht, 2007; P. Beeley, “Breaking the code: John Wallis and the politics of concealment”, pp. 49-81 in: W. Li, S. Noreik (eds.), *G. W. Leibniz und der Gelehrtenhabitus. Anonymität, Pseudonymität, Camouflage*, Köln, Weimar, Wien, 2016. Regarding Leibniz's interest in the theory and practice of cryptography and cryptanalysis, cf. Part 1, in particular, of: N. Rescher, *Leibniz and cryptography*: *An account on the occasion of the initial exhibition of the reconstruction of Leibniz's cipher machine*, Pittsburgh, 2012.

benefits that accompanied a knowledge of cryptography (even if these played a role in his argumentation at court), but rather the advancement of the "ars inveniendi", as well as the fear that Wallis' cryptographic knowledge could be lost to posterity, just as in the case of the death of François Viète (1540-1603) almost a century before.[42] Regarding the latter concern, he had quoted from his review – in the *Acta Eruditorum* of June 1686 – of Wallis' *A Treatise of Algebra* (1685), in his letter to the author on March 29, 1697. In this review, Leibniz had, in addition to the appeal to Wallis to share his knowledge, placed cryptography in the proximity of algebra and compared the author to Viète.

Regarding Wallis as a cryptographer, and his cryptographic knowledge,[43] Leibniz had already committed his desire to paper as early as 1673 and he continually repeated it to other English correspondents in the 1690s. Wallis' reaction was, however, noncommittal. As a specimen of his capability, he sent an encoded letter, with his notes for its decoding, to Mencke who, however, because of political considerations, refused publication and informed Leibniz accordingly on June 1, 1697. Hereupon, Wallis published the letter in the third volume of his *Opera*. Although he chose not to react to Leibniz's proposals, Wallis did benefit from Leibniz's interest in negotiations with the English court, which duly granted him a pension, in order to enable him to instruct his grandson, William Blencow, in cryptography. Ultimately, Wallis' work on cryptography, from the year 1653, was posthumously edited and published by John Davys – in *An essay on the art of deciphering* – in the year 1737.[44]

While Leibniz's attempts to persuade John Wallis to share his cryptographic knowledge proved to be futile – at least until the end of 1698 – the matter continued to be a topic in their correspondence in 1699 and 1700. Following persistent pressure, Wallis finally admitted that political considerations had influenced his decision not to respond to Leibniz's request to publish his methods, or at least to educate

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[42] cf. D. Kahn, *Codebreakers*: *The story of secret writing*, New York, 1967 (and 1996), and in particular (regarding Viète) pp. 116-188; P. Pesic, "François Viète, father of modern cryptanalysis - two new manuscripts", *Cryptologia*, vol. 21(1), (1997), pp. 1-29.

[43] cf. D. E. Smith, "John Wallis as a cryptographer", *Bulletin of the American Mathematical Society*, vol. 24, (1917), pp. 82-96.

[44] cf. J. Davys, *An essay on the art of decyphering. In which is inserted a discourse of Dr. Wallis. Now first publish'd from his original manuscript in the publick library at Oxford*, London, 1737, pp. 9- 58; K. Ellison, *A cultural history of early modern English cryptography manuals*, London, New York, 2017, in particular pp. 1-20 (Introduction: Crises of expression in seventeenth-century criptography manuals).

someone in these matters. Encryption was often necessary in negotiations, and a dissemination of cryptographic methods was therefore not at all desirable. Furthermore, as he informed Leibniz on April 9, 1700, he was unwilling to part with his knowledge in this area without the express consent of his sovereign. A further reason, as he explained in a letter of January 26, 1699, lay in the nature of the matter itself. Cryptography was difficult to transmit, since it consisted not merely of a method but rather of a clouded pursuit, in the course of which the method of operation needed to be continually adapted.

Military-Related Projects (Submarines, etc.)

The letters of Martin Elers in particular suggest that Leibniz had shown an interest, and had requested further details from his correspondents, regarding projects having military applications. This applies, for example, to Elers' work on the production of mail armor made out of silk. When, at the end of August 1681, Leibniz remarked that armor of that kind was obtainable in England at a high price, Elers replied, on September 2, that the kind of armor he had in mind – in which apparently a network of brass wire was incorporated – would be considerably cheaper. With the Elector of Brandenburg, Elers did not have any success in promoting his new armor idea, and on December 30, 1681, he informed Leibniz that the Elector had already received a similar coat of arms, in the form of a gift from king Charles XI of Sweden, and had tested the extent to which it was resistant to musket balls or shot, namely by having a condemned soldier, awaiting execution, wear the armor and serve as a target. Although the musket balls of the firing weapon did not penetrate the armor, the proband collapsed and the shot was found to have produced a bloated, purulent and bloody wound, and would have required surgery to treat.

Jobst Dietrich Brandshagen reported, on November 5, 1682, from Copenhagen, where preparations for a war with Sweden were underway, about certain bellicose inventions, like setting ships on fire with cannonballs. Brandshagen's subsequent account, on May 15, 1683, of the components of these incendiary cannonballs interested Leibniz, as did the function of a rifled gun in which the powder was automatically transferred to the priming pan. Remarkable was a ballistic mortar, allegedly made out of board or pasteboard by

Brandshagen, and reported in a letter sent to Leibniz, on April 3, 1683. Because of the easy transportability, the mortar, from which nine grenades had already been fired, was superior (according to Brandshagen) to mortars made from metal. The suggestion to use the peculiar material for the weapon had apparently come from Leibniz himself, who had been inspired by an article entitled "Extrait d'une lettre … touchant une nouvelle invention de faire des pendules de carton", by the French Jesuit astronomer, Jean Bonfa, in the *Journal des Sçavans* in January 1679.

Leibniz received intelligence, in the years 1691 and 1692, concerning Papin's Hessian pump (the "Rotatilis suctor et pressor Hassiacus") and, in particular, regarding its employment in the development of a submersible vessel in Kassel,[45] for example in a letter from Haes, on June 11, 1692, who reported about the trial of such a vessel in the presence of the landgrave, Karl of Hesse-Kassel. The centrifugal pump had first been developed by a tradesman in Stuttgart and had been made public in a work of Salomon Reisel in 1684 entitled *Sipho Würtembergicus, sive Sipho inversus cruribus aequialtis fluens et refluens hactenus inauditus*. Papin had studied this innovation intensively, while in London, and then (from 1688) in Marburg. Half a year after Papin first gave an account of this work, in the context of his article "Rotatilis Suctor et Pressor Hassiacus" in the *Acta Eruditorum* of June 1689, Reisel's book *Sipho Wurtembergicus per majora experimenta firmatus* (1690) was published, and then reviewed in the March 1690 number of the *Acta Eruditorum*. To this, Papin then responded with an account of his investigation "Examen siphonis Wurtemburgici", in the May 1690 number of the journal. Finally, after an interval of five years, Papin published his concluding study of the centrifugal pump in his bilingual collection *Recueil de diverses pieces touchant quelques nouvelles machines* and *Fasciculus dissertationum de novis quibusdam machinis* (1695), respectively.

The lift pump, or the suction pump or suction lift pump, had been developed in Europe in the late middle ages and existed alongside the force pump, which was known since Hellenistic times, as a reciprocating pump for raising water. A newer development then was the 'suck and press' pump, developed by Reisel and Papin, which

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[45] cf. F. Tönsmann, "Wasserbauten und Schifffahrt in Hessen um 1700 und die Forschungen von Papin", pp. 89-104 in: F. Tönsmann, H. Schneider (eds.), *Denis Papin*: *Erfinder und Naturforscher in Hessen-Kassel*, Kassel, 2009.

was powered by the uniform movement of a human hand, and which operated with the fluid (water or air) entering the machine in the direction of the axis and escaping in a tangential direction.[46] It then became a central element in Papin's trials of a submersible vessel (his "navis urinatoria") in 1691 and 1692. According to the accounts – given by Robert Boyle (in 1660/ 1661) and Balthasar Monconys (in a posthumous publication of 1666) – about the experiments of Cornelis Drebbel (1572-1633) with a submersible vessel on the Thames, in about 1620, the requisite air exchange or renewal had been achieved by chemical or alchemical means using drops of a quintessence. Papin's trials of his submersible vessel then gave Leibniz occasion to recall once again the methods Drebbel was thought to have employed more than seventy years earlier.

A correspondent in Marburg, Hermann Peikenkamp, who informed Leibniz about Papin's efforts, recalled Drebbel's submersible vessel in a letter of August 3, 1692. Whether or not the air renewal took place, by the use of hoses or tubing to connect the submerged vessel with the atmosphere, as in the case of Papin's "Navis urinatoria", was considered in a further letter from Peikenkamp, written on October 12, 1692. In this letter, the correspondent also attributed a dubious role to Boyle in the matter, through his sequestering of first-hand accounts of the undertaking.[47] In a letter he wrote to Papin, almost three years later, in the first half of August 1695, Leibniz expressed the view that burning spirit of wine might well have been the quintessence in question. Even if this spirit of wine had not been a substitute for fresh air, it might well have had a beneficial effect. In this connection, he recalled that he had, while in London, discussed Drebbel's submarine passage across the Thames, both with Boyle (presumably on February 12, 1673) and with Drebbel's daughter, Katharina, together with her husband Johann S. Kiefler (or Kuffeler). He had not, however, been able to ascertain from any of them, whether or not fresh air had been supplied to the submersed vessel.

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[46] Regarding the lift pump, the suction pump and the 'suck and press' pump, cf. G. Hollister-Short, "On the origins of the suction lift pump", *History of Technology*, vol. 15, (1993), pp. 57-75; M. T. Wright, "On the lift pump", *History of Technology*, vol. 18, (1996), pp. 13-37; E. Gerland, *Leibnizens und Huygens' Briefwechsel mit Papin nebst der Biographie Papin's*, Berlin, 1881 and Wiesbaden, 1966, in particular pp. 37-41.

[47] cf. L. E. Harris, *The two Netherlanders*: *Humphrey Bradley and Cornelis Drebbel*, Leiden, 1961, in particular chap. 14, pp. 160-170 (regarding Drebbel and submarine navigation) and p. 173 (regarding the question of breathing, or the supply of air, in a submerged boat, and regarding the role of Boyle).

Papin of course attached little credibility to a procedure for air exchange or renewal, which was to be achieved by chemical means, and in the construction of his underwater vessel, he employed, first, a ventilator pump and, then, the centrifugal pump to achieve an efficient intake of fresh air and, likewise, for the expulsion of the foul or exhaust air. This air exchange through hosepipes or tubing, between the submerged vessel and the water surface, was of course crucial for the boat occupants, supplying both the human respiratory system and a lamp flame for illumination.

To build and set up the submersible vessel, Papin had travelled from Marburg to Kassel, in June 1691, and the Kassel resident Haes was able to report regularly to Leibniz about Papin's activities there. In its first design, the boat consisted of a rectangular parallelepiped box made of tinplate, with a hull made of wood and iron guide rails, as Papin informed Huygens, in a letter of August 26 of that year. The vessel was provided with lockable openings, in the floor and roof, that were not, however, to be opened simultaneously. The upper hatch served the purpose of entry and exit, before and after immersion, respectively, whereas the bottom hatch provided an opening for sculling, or for grabbing objects, while submersed. A hole was bored in the roof of the vessel, and a cylinder was soldered in there. At the outlet of this cylinder, a leather tube – having been reinforced on the inside with spiral springs – was fixed. By means of this tube or hose, at whose upper end a piece of light wood was attached to act as a buoy on the water surface, the vessel was to maintain contact with the atmosphere while submerged. The lower end of the cylinder was located inside the vessel, within an additional cylinder which was provided with a downward-opening valve. Through an up and down movement of this second cylinder air would be drawn into the interior of the vessel. According to Archimedes' Principle, the weight of the immersed boat, with its machinery and occupants, should be equal to that of the displaced volume of water. To make the vessel sink, recesses in the floor were to be filled with lead ballast. Through the bottom hatch, this ballast was then to be offloaded again in order to make the vessel rise to the surface once more. To measure the depth, a barometer was installed in the interior of the submersible vessel. In order that the bottom hatch could be opened, the pressure inside the vessel had to be equal to the sum of the atmospheric air pressure and the hydraulic thrust in order to prevent the intrusion of water from below into the interior. In addition to the barometer, a compass was supplied to aid the navigation of the vessel.

On July 30, 1691, Leibniz too was informed – both by Friedrich Lucae and Haes – about the progress being made in the construction of this vessel. When, in mid-August, the boat was being launched it was considerably damaged in an accident, concerning which event Haes sent a detailed report to Leibniz, on November 19. According to this account, a crane being employed to help lower the vessel onto the river failed to hold its load, and the vessel crashed into the water and sank. Already, about a week after the accident, in his letter of August 26, Papin sent a detailed report about his submersible vessel, and its demise, to Huygens in which he also dealt with the utilization of his invention, suggesting that its purpose had been purely experimental. In the same letter, Papin likewise informed Huygens about his design for a new, improved bathyscaphe.

In the spring of 1692, Papin was once again able, with the support of the landgrave, to travel to Kassel to undertake fresh experiments with the new submersible vessel. The new boat was – according to the account sent to Huygens on August 26, 1691 – of oval shape and made of wood. In the cabin, or machine room (with measurements: 6.5 feet height, 5 feet width and 3 feet depth), three persons could be accommodated. There was no longer an opening and hatch in the floor of the vessel; instead there were openings at the sides, which were sealed with leather, and intended for the operation of oars. The centrifugal pump was now employed in combination with the hose, or tubing, reaching to the water surface for the supply of fresh air. The removal of foul, or exhaust, air was achieved by means of a separate hose. In order to submerge the vessel, water was let in using a faucet and collected in receptacles or ballast tanks. The rise of the submarine vehicle, from a depth below the water surface, was to be achieved by pumping the water in the receptacles out of the vessel. The depth of the vessel under water was to be determined using a manometer.

Again on this occasion, Haes informed Leibniz about the progress of Papin's efforts, first of all in a letter of May 1, 1692. Then, in a further letter of May 22, Haes praised especially the superiority of the method of air exchange and renewal being employed, in comparison with Drebbel's supposed procedure. Finally, on June 11, 1692, Haes was able to report about a successful demonstration of the submersible vessel in the presence of the landgrave, and he used the occasion to give a detailed description of the form of the new ship, the air exchange system, the method of submergence and reemergence, the illumination of the machine room, and the instruments for navigation.

This report was complemented by a further letter from Haes, of October 23, 1692, in which the principal innovations of Papin were accentuated. In contrast to the first design of the previous year – that had been conceived solely for the purpose of salvaging objects and carrying out tasks under water – the new design envisaged journeys under water and attacks on hostile vessels. Once again, Haes highlighted the centrifugal pump, combined with tubing for air exchange, as well as the water containers, or ballast tanks, fitted with water pumps as important improvements. Independently of Haes' accounts of the two submersible vessels, Leibniz received an independent report, written on October 12, from Hermann Peikenkamp, who related that he had been informed by Johann Philipp Heppe, an engineer and artillery officer; the latter's account of events, as reported to Leibniz, was in good agreement with that of Haes in all essential points.

With the appearance of Papin's bilingual work *Fasciculus dissertationum* and *Recueil de diverses pieces*, in 1695, which contained chapters entitled "Navis urinatoriae … constructae descriptio", and "Description du Batteau plongeant", respectively, questions relating to the submersible or diving vessel were discussed in Leibniz's correspondence with the author. Whereas Haes had raised the issue of the quintessence – allegedly used by Cornelis Drebbel and concerning the composition of which Leibniz had long tried to gain an insight – both Leibniz and Papin were decidedly skeptical about the possible effect of such a quintessence. To Papin, Leibniz wrote, in the first half of August 1695, that he conjectured that the substance used by Drebbel might have been the spirit of wine, *viz*. an aqua vitae prepared by distilling wine. A further more general question Leibniz posed, in this context, concerned the possible use of spirit of wine as a fuel to power a two-stroke piston engine – with a combustion or rarefaction stroke followed by a compression or condensation stroke – similar to the use of water vapor from water held over a lamp flame.

Papin answered, on September 1, that the flame producing the fumes of the spirit of wine, as well as all other flames aboard the submersible, would only further pollute the air within the submerged vessel. And he announced that Leibniz's conjectures, about the power of spirit of wine as a fuel, were in agreement with experiments he had carried out, but that the costs involved in the use of this fuel would be prohibitive. In a further letter of early October, 1695, Papin dealt in more detail with the use of a spirit of wine lamp in a submersible or diving vessel. Once the connection with the outside atmosphere was removed, the flame would be extinguished, just as if it were an oil lamp, and would add to the pollution of the air inside the vessel. As regards the possible use of a cycle of rarefaction and condensation, using the spirit of wine rather than water vapor as part of a piston engine, Papin admitted that his experimental investigation of the idea had never attained the necessary precision to allow a judgement on the matter. He was, however, skeptical as to whether the cylinder and piston would be impermeable, as they were generally found not to be completely impervious to the water that was used as a seal over the piston.

In connection with seafaring and the demands of navigation – be it in a civil or military context – stood the development of sea-worthy and precise clocks. Leibniz had been active in this area in his younger years, as is evidenced, for example, by "An Extract of a Letter of the Learned Dr. Gothofredus Guil. Leibnitz, concerning the Principle of exactness in the portable Watches of his invention", which was part of his letter for Jean-Paul de La Roque of mid-March 1675. Huygens' efforts in this area in the early 1690s met, no doubt, with Leibniz's approval. After this correspondent had reported the completion of a new clock at the end of his article "De problemate Bernoulliano", of October 1693, he addressed the matter once again in a letter of May 29, 1694, to Leibniz.

Navigation, and in particular the method of steering and maneuvering a sailing ship, was also the subject of a public dispute between Huygens and Bernard Renau d'Eliçagaray, concerning which Leibniz's opinion was requested. Renau's anonomously published book *De la théorie de la manoeuvre des vaisseaux* (1689) was criticized by Huygens in his "Remarque … sur le livre de la manoeuvre des vaisseaux" (1693). Renau duely replied with his "Reponse … à la Remarque de M. Huguens" (1694), which in turn was countered by Huygens with his "Replique … à la Reponse de Mr. Renau" (1694). On May 29, 1694, Huygens had requested Leibniz's judgement for inclusion in the "Replique … à la Reponse". As Leibniz had not seen Huygens' "Remarque", and had only vague memories of his study of Renau's book, he desisted from giving a definitive judgement and only presented a single point of criticism – namely the author's failure to take the center of gravity of the ship into consideration – in his letter to Huygens of June 22. He welcomed, however, the practical nature of Renau's work, and he recalled that the author had cited comte de Tourville's *Exercice en général de toutes les manoeuvres qui se font à la me*r (1693).

On August 24 then, Huygens reiterated once again his highly critical standpoint regarding Renau d'Eliçagaray. However, even after L'Hospital had sent Leibniz the documents relating to this dispute, he restricted himself, in writing to this correspondent, to rather general comments concerning issues of force, speed, and leeway or windward drift of a vessel, like, for example, in a letter of June 24, 1695, and again on September 30, 1695. Nevertheless, Leibniz thought that he could obtain the correct rule for leeway, or drift, and he believed that the time he should invest in the study of Renau's book would be rewarded, and, indeed, would give him occasion to show the power of his own dynamics.

Economic and Techno-Economic Projects

In the late 1670s and early 1680s, there was no shortage of economic and technical project conceptions in Leibniz's correspondence, and new schemes were constantly being discussed or implemented. Two correspondents, in particular, epitomized a type of Baroque discoverer, or projector, namely the merchant Martin Elers and Leibniz's associate Johann Daniel Crafft, who was a pioneer in manufacture and manufacturing in Germany.[48] With Elers and Crafft, Leibniz discussed a multitude of enterprises, or undertakings, intended

[48] cf. W. Loibl, "Johann Daniel Crafft (*Wertheim 1624-+Amsterdam 1697): Ein Chemiker, Kameralist und Unternehmer des 17. Jahrhunderts", *Wertheimer Jahrbuch 1997*, pp. 55-251, Wertheim, 1998.

to provide national economic benefits. Most such projects were of a kind that required the financial support of, and the granting of privileges by, a prince. Thus, the technical and economic proposals were discussed, for the most part, in the context of the realization chances at one or other European court. Thus, we find Elers at the ducal court in Celle, at the court of the elector of Brandenburg in Berlin, and finally at the court of the Danish king in Copenhagen, busy in each instance with his efforts to convince the prince in question, alas mostly without success. Correspondingly, Crafft repeatedly reported about discussions and negotiations with the Saxon mercantile community – whose trade was being adversely affected by the establishment of manufactories in their territory – as well as with ministers, and with the estates or the broad orders of social hierarchy, of the territory. The difficult ambient conditions, combined with the lack of maturity of many a project, was not without effect on the cooperation of Leibniz and the two correspondents in question. Good agreement, mutual recommendations, and common intentions, alternated with intrigues and scheming in which, for example, letters were tactically withheld from addressees, or regurgitated. Following a suggestion of Leibniz, both he and Crafft adopted a cryptographic script or cipher (*viz.* intentional alteration of individual alphabetic characters in order to hamper the decryption by other parties) in their letters, which, however, occasionally led to confusion or misunderstanding on Crafft's part, as a result of false encryption, or of vague intimation in non-encrypted text passages.

In the mercantile policy, that he and Crafft wanted to propose to the emperor, Leibniz saw a secret formula, not only for restoring Germany unscathed to an integral whole, but also for achieving happiness and for rendering his imperial majesty formidable once again. In an aide-mémoire for Crafft, written in the second half of July 1680, Leibniz proposed that the correspondent write to Philipp Wilhelm von Hörnigk – the brother of the Imperial privy counsellor in Vienna, Johann Moritz von Hörnigk – introducing the thoughts of an unnamed reference person, or third party, namely Leibniz himself. It was argued that with the establishment of manufactories in the German empire – along with the introduction of import barriers for French goods – wealth and tax intake would be increased and, at the same time, the power of France would be weakened. Furthermore, according to Crafft, the establishment of manufactories should be recommended to the German princes at the diplomatic conference on reunifications, meeting at Frankfurt, since all or most of that pertaining to the prosperity of Germany was rooted in such disprized manufactories, as Crafft wrote, in his letter of September 2, 1681, to Leibniz. Of course Crafft knew from experience that those wielding power failed to realize that the greatest benefit for themselves lay in the provision of sustentation for their subjects, as he wrote in his letter of October 3, 1680. Leibniz developed the same train of thought, but without an anti-French accentuation, in the draft of a letter written for Crafft, in the second half of July 1680, which was to be sent to the Elector of Brandenburg. In order not to come into conflict with the foreign policy of the elector, Leibniz stressed that the embargo on French goods would not be required, since domestic goods, like silk and wool products, could be produced better and more inexpensively with the result that, in the long term, even the export of manufactured goods might be conceivable.

Crafft placed particular hopes in his invention of new machines for textile manufacture. He told Leibniz, in a letter of December 6, 1680, that he had wonders in hand and would teach the world a lesson, having developed a veritable philosopher's stone. Crafft stressed in a letter – composed the end of May 1681 during a meeting with Leibniz – to the pensionary of Haarlem, Michael ten Hove, the usefulness of a new invention, namely the ribbon-loom, or mola limbolaria, which was known in Germany as 'Mühlstuhl', 'Schnurmühle' or 'Bandmühle', and which has long been a matter of interest in social and economic history.[49] Although the loom needed to be deployed in a purpose-built building, Crafft nevertheless believed he could market the device even in Holland. Then, in a letter of January 8, 1682, he requested that Leibniz approach Jan Hudde in Amsterdam in this matter. On December 25, 1682, Crafft forwarded a fabric sample and recommended to Leibniz that he get the opinion of a braid and lace maker concerning it. He had, however, also to confess that his three machines were idle and needed to be replaced by a modified machine,

[49] cf. U. Troitzsch, *Technischer Wandel in Staat und Gesellschaft zwischen 1600 und 1750*, pp. 9-267 in: A. Paulinyi, U. Troitzsch, *Mechanisierung und Maschinisierung 1600-1840*, (*Propyläen-Technikgeschichte*, vol. 3), Berlin, 1991, in particular pp. 156f. (Bandmühle); R. Reith, "Technische Innovationen im Handwerk der frühen Neuzeit? Traditionen, Probleme und Perspektiven der Forschung", pp. 21-60 in: K. H. Kaufhold, W. Reininghaus (eds.), *Stadt und Handwerk in Mittelalter und früher Neuzeit*, Cologne, Weimar, Vienna, 2000, and in particular (regarding the ribbon loom) pp. 35-41.

since, contrary to all expectations, the fabric in question had gone out of fashion.

At the end of 1680, and in early 1681, Crafft and Leibniz followed with interest the efforts of Elers to persuade the duke of Celle to establish a new town, near Harburg (south of Hamburg), for emigre Huguenots. The duke of Celle insisted on financial participation in the scheme by the duke in Hanover, who, in turn, insisted on the fulfillment of certain other conditions. A decision about the matter was delayed, and Elers finally had to depart without success, at the end of 1681. Another one of several proposals that Elers presented to the Brandenburg court, proved likewise to be a failure. The Brandenburg-African company was to bring a large number of Africans into the territory, and the elector would then make them available to farmers (in return for payment), as slaves or farm laborers. In addition, it was argued, if the Africans were to be trained once a week in the use of fire arms, then the elector would acquire cheap and good soldiers since these were, by their very nature, hardy and strong. Elers outlined his project in a letter of February 7, 1682, to Leibniz. Crafft was likewise approached by Elers in the matter, and his judgement was that the project was totally impractical, and that the projector could expect to experience more dishonor than honor with this proposal, as he wrote to Leibniz, on February 24, 1682.

Leibniz's letter to Elers, of February 17, 1682, has not been found, but it was referred to at the beginning of the correspondent's reply, on March 1, 1682. There Elers related that a copy of his proposition had been taken to Vienna for presentation to the emperor. From this reply, an insight can be obtained into Leibniz's thoughts on the matter. In the context of the foundation of the Brandenburg-African Company, Leibniz must have recalled that the Dutch had forbidden the holding of serfs, or slaves, in the republic itself.[50] Elers had not heard of such a total prohibition of the slave trade in the Dutch republic, but simply that slavery and serfdom in the county itself was prohibited and the ruling that black people, brought into the country, should enjoy freedom. Just the same, Elers insisted that no small

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[50] cf. J. Postma, *The Dutch in the Atlantic slave trade, 1600-1815*, Cambridge, New York, Melbourne, 1990; J. Postma, "The dispersal of African slaves in the west by Dutch slave traders, 1630-1803", chap. 10, pp. [283]-300, in: J. E. Inikori, S. L. Engerman (eds.), *The Atlantic slave trade*: *Effects on economies, societies and peoples in Africa, the Americas, and Europe*, Durham, NC, 1992 (and 1998). Regarding the Brandenburg-African Company (1682-1721), cf. H. Weiss (ed.), *Ports of globalisation, places of creolisation*: *Nordic possessions in the Atlantic world during the era of the slave trade*, Leiden, 2016, in particular chap. 1 (Introduction), p. 12.

number of black people were being held in Holland, even among the Jews there. Once again he insisted that the black laborers, once provided with appropriate clothing and following a period of acclimatization, would be hardier than their European counterparts. Following this, Elers recalled Crafft's skepticism about the prospects for the project, and he suggested that Crafft's views were very much at variance with Leibniz's opinion on the matter. Crafft was to have the last word on Elers' project relating to black Africans ("wegen der Schwartzen"), namely, in a letter to Leibniz, on May 7, 1682. He was of the opinion that the demographics of Germany differed from those of certain north American territories, like Canada, where the rural settlement of black Africans might indeed make economic sense. He also believed that Elers' resettlement project would – like many another project of his – in due course die a natural death.

The trend found in the epistolary exchanges of the late 1670s, where questions arose regarding the possible application of machines, for example, in the mechanization of silk and wool manufacture, continued in the early 1680s. In a letter from Dresden, on January 30, 1680, Crafft referred to a wool, or silk, manufactory, and to a proposal, which had been submitted to the Elector of Saxony, for the establishment of a workhouse, and orphanage, in connection with a bag cloth and stockings manufactory. For the duchies of Brunswick and Lüneburg, he also proposed the establishment of a bag cloth manufactory, and his exchange of ideas with Leibniz, about the possibility of steel production in the Harz district, resulted in Leibniz turning to duke Ernst August in the matter.

Even greater was the diversity of the projects in which Elers was involved. During a visit to the glassworks in the hills of the Weser Uplands, he found a process to facilitate the making of burning glasses or lenses, as he informed Leibniz from Hanover, on May 15, 1681. From Dresden, on July 8, 1681, he informed Leibniz about his quest for a new kind of wax bleachery, and from Berlin he reported, on December 30 of the same year, that he had informed the elector there about an inventor, who claimed to have a means of preventing ships from sinking. Over several months, Elers promoted a so-called "infallible project", as he informed Leibniz in a letter from Dresden, on September 2, 1681. The intention here was to market a wallpaper, consisting of silk printed with gold or silver, and Elers enclosed samples with his letter to Leibniz. Crafft, for his part, as he informed Leibniz on May 7, 1682, considered this project to be impractical and inefficient. Elers finally abandoned the project for lack of start capital. Although there exists no statement from Leibniz about this particular project, the letters of Crafft and Elers leave no doubt that he had shown an interest, and had requested further details from his correspondents. Communications and discussions of technological, or engineering, projects were not limited to the correspondences with Elers and Crafft, however. On March 21, 1682, Tschirnhaus reported that he had seen in Paris a recently discovered repeater clock that could be made to chime on awakening in the night.

In finance and commerce, Leibniz's interests encompassed calculations of interest and discount, of bonds and debentures, as well as the evaluation of life annuities and insurance (reflected in his correspondence with Johann Jakob Ferguson between July 1683 and March 1684). In an article in the *Acta Eruditorum* entitled "Meditatio juridico-mathematica de interusurio simplice", in October 1683, Leibniz treated the problem of determining the current value of a loan repaid ahead of schedule. The difficulties Leibniz experienced following the publication of this article – which included the accusation that he was an advocate of the then frowned-upon method of compound interest ("Anatocismus") – can be followed in his correspondence with Christoph Pfautz, in August, and on December 21, 1683.

Leibniz's proposals for improvement of monetary systems are to be found in his correspondence and collaboration with Crafft, specifically in their joint memorandum for the emperor written in Vienna, in the second half of 1688, and in discussions Leibniz had, also in Vienna, with the metallurgist and refiner of metals, Christian Holeysen, at the end of April or in the first half of May, 1690. Questions of cost effectiveness, and economic feasibility, of processes and of undertakings and business ventures, were also taken to heart by Leibniz. Thus, he excerpted passages from the papers of Holeysen concerning the economic efficiency of the Hungarian mines. He also carefully noted Crafft's communication of a claim, namely that gold could be made from the best iron slag, during discussions they had in Graupen (now Krupka), at the end of January 1688. Without discussing the truth or validity of such gold extraction processes, Leibniz found that, because of the cost of related ingredients, such processes could simply not be cost-effective. But other more legitimate processes, such as salt production, referred to in letters from Georg Mohr (on February 5, 1686) and from Friedrich Heyn (on November 30, 1686, and March 26, 1687), or the introduction of street illumination, using oil as a fuel for lamps, referred to by Crafft (on June 26, 1689, and on July 15, 1690) were always assessed by Leibniz from the viewpoint of cost effectiveness.

In addition to such considerations of cost effectiveness, there was yet another aspect which determined Leibniz attitude to the projects and processes under consideration, namely cameralism, or a German variant of mercantilism, which developed at the end of the 17th century. It was, in essence, an approach to government and administration, involving police order and supervision. It incorporated a set of practically-orientated academic disciplines, concerned with state administrative organization, and a form of a 'science', dedicated to reforming society while promoting economic development.[51] Within the sphere of cameralism, and the cameral sciences, the concept and economic doctrine of technology emerged in Germany in the eighteenth century. The *Anleitung zur Technologie* (1777) of Johann Beckmann (1739-1811),[52] a prominent figure in German cameralism, was the first work that self-consciously developed the concept of technology as a discipline devoted to the systematic description of handicrafts and industrial arts.[53] At the beginning of this development, almost a century before Beckmann, stands Leibniz's rival, and adversary, Johann Joachim Becher, whose satirical work entitled *Närrische Weißheit und weise Narrheit* (foolish wisdom or wise foolery/ folly'ish wisdom or wise folly) of 1682 has been referred to above. The subtitle of the work in question "Ein Hundert so Politische alß Physicalische Mechanische und Mercantilische Concepten und Propositionen" (A hundred both political as physical, mechanical and mercantile, concepts and propositions) reveals the

[51] cf. for example, A. Wakefield, *The disordered police state*: *German cameralism as science and practice*, Chicago, 2009; M. Seppel, K. Tribe, *Cameralism in practice*: *State administration and economy in early modern Europe*, Woodbridge (Suffolk) and Rochester (NY), 2017.

[52] J. Beckmann, *Anleitung zur Technologie oder zur Kenntnis der Handwerke, Fabriken und Manufacturen, vornehmlich derer, die mit der Landwirtschaft, Polizey und Cameralwissenschaft in nächster Verbindung stehn*, Göttingen, 1777.

[53] cf. C. Mitcham, E. Schatzberg, "Defining technology and the engineering sciences", pp. 27-63 in: A. Meijers (ed.), *Philosophy of technology and engineering sciences*, (*Technology, engineering and the sciences*, vol. 9, part I), Amsterdam, 2009, in particular p. 36.

standpoint of the author, who has been seen as a pioneer in the development of ideas regarding technology, or in technological thinking.[54] On the basis of such a mercantilist-cameralist conviction then, Leibniz's interest developed in silk and wool manufactories, referred to by Brandshagen (in late August or early September, 1683) and in the memorandum of Leibniz and Crafft for the emperor (from the second half of 1688), in iron and steel production and in the wine trade, referred to in Leibniz's discussions with Crafft in Graupen and in the memorandum for the emperor, in the production of armor, referred to by Elers (on August 1, 1684), in textile printing, referred to by Brandshagen (in late August or early September, 1683), in the improvement of the luster of pearls, referred to by Elers (on August 12, 1684), and in a range of other economic projects.

Furthermore, Leibniz's correspondence reveals a wide range of proposals he made in the area of government economic planning and administration, both at state level in Hanover as at the Imperial level in Vienna. Thus, in the memorandum, intended for presentation to the emperor, that had been prepared in Vienna in the second half of 1688, we find Leibniz, in the guise of Crafft, advocating the establishment of a "Bergkollegium", an Imperial mining college or council that would establish and coordinate the occurrence of mineral and ore deposits within the empire. To this end, a laboratory was to be set up and a chamber of arts maintained, where the most important mechanical inventions and innovations would be presented. This mining institution was intended to preempt the import of ores and minerals, that were already available in Germany, and to play an important role in the colonization of those regions of Hungary that had, shortly before, been freed from Turkish rule, that is after the ending of the siege of Vienna and the defeat of the Turks, in 1683, and the Habsburgs' reconquest of Hungary that followed. At the outset of his petition to the emperor, Crafft (or rather Leibniz) provided a brief account of his life and studies, his travels in Europe and in the

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[54] cf. U. Troitzsch, *Ansätze technologischen Denkens bei den Kameralisten des 17. und 18. Jahrhunderts*, (*Schriften zur Wirtschafts- und Socialgeschichte*, vol. 5), Berlin, 1966, in particular chap. 1, pp. 11-19. Regarding the history of the notion, or concept, of technology, cf. A.-F. Garçon, "The three states of technology: An historical approach to a thought regime, 16th - 20th centuries", pp. 11-26 in: M. Faucheux and J. Fores (eds.), *New Elements of Technology*, (*Collection Sciences Humaines et Technologie*, UTBM: l'université de technologie de Belfort-Montbéliard), Sevenans, 2012; A.-F. Garçon, "Technologie: histoire d'un régime de pensée, xvi[e]-xix[e] siècle", pp. 73-102, in: R. Carvais, A.-F. Garçon, A. Grelon (eds.), *Penser la technique autrement*: *En hommage à l'oeuvre d'Hélène Vérin*, Paris, 2017; E. Schatzberg, *Technology*: *Critical history of a concept*, Chicago, 2018.

American colonies, his professional life in the service of the electors in Mainz and Saxony, and his experience over a broad spectrum of manufactories.

Chemical substances too, like paints, were available in nature and were of interest from the viewpoint of their economic utilization. On July 10, 1687, Heyn reported, for example, about veins of iron ore which he had observed on the river Elbe. Several of these veins, when mixed with crude ores, were found to be suitable as paint, providing fine umbra and brown ocher pigments. Likewise, in the long memorandum composed jointly by Leibniz and Crafft for the emperor, the experience gained by Crafft and Heyn in producing and applying paints was emphasized. A complete factory, or plant, for the processing of mineral ores was contemplated here in the light of ongoing building activity in Hungary, and Lower Austria, where such paint products would be particularly useful, especially for the conservation of wood and even of stone.

A range of physical and chemical issues arose in Leibniz's correspondence, both in the context of scientific and engineering applications and of techno-economic projects. Examples from the 1680s from the latter category included, for example, the dyeing of garments, production of ruby glass, perfection of pearls, retrieval and extraction of gold and silver, phosphorus production, and the desalinization of sea water. Thus, in Leibniz's correspondence with Ramazzini, the desalination of seawater being pursued by a certain Nathan Lacy, an Englishman living in Modena, was referred to by Leibniz in a letter from Venice on February 25, 1690. Even the topic of emissions from laboratories, and protection against such emissions, arose in Leibniz's correspondence. At the end of 1689, Leibniz made the acquaintance in Modena not only of the physician Ramazzini but also of the chemist Bernardino Corradi. With the approval of Ramazzini, Leibniz supported Corradi in a dispute, with a certain Giovanni Paolo Stabe de Cassina, about dangerous emissions being produced in applications, or processing, using vitriol. Leibniz's backing took the form of a contribution to Corradi's polemical pamphlet against his opponent, entitled *Raccolta di tutto quello che fin ora estato scritto nella virtuosa gara iatro-chimica* (1690). Leibniz's contribution consisted of a letter sent to both Ramazzini and Corradi, on January 24 and 26, 1690, respectively, and it was essentially an historical note about the “Historia inventae tincturae Scarlatinae”, or the discovery of scarlet dye by the Dutch innovator Cornelis Drebbel (1572-1633). Leibniz referred here specifically to Drebbel’s tract entitled, in its German translation, *Ein kurzer Tractat von der Natur der Elementen* (1608).

Political economy, and the application of mathematics to economico-political matters, was yet another interest of Leibniz in the early 1690s, and later. The work of William Petty (1623-1687), in particular, had attracted his interest at this time, as is evident from remarks in letters sent to Ludwig Justus Sinold (alias von Schütz), on October 20, 1690, and to Henri Justel, on January 23, 1691, in which he referred to Petty’s works on political arithmetic,[55] namely *Deux essays d’arithmetique politique, touchant les villes de Londres et Paris* (1686) and *Two essays in political arithmetick, concerning the people, housing, hospitals &c. of London and Paris* (1687). In the years that followed, Leibniz continued to refer, or allude, to Petty’s work on political economy in his correspondence, for example, in a letter of February 11, 1697, to Thomas Burnett of Kemney, in a memorandum attached to a letter to Johann Theodor Jablonski, on March 19, 1701, and in a letter to Christian Titius, on April 12, 1702, where he referred once again to the seminal work of Petty as being a specimen from the field of political arithmetic (“quodam Arithmeticae politicae genus, cujus specimen dedit Guilielmus Pettius Anglus”).

In the early 1690s, topics in the area of mercantile economics continued to have a special significance in Leibniz’s correspondence. These included the improvement of the system of coinage and of the wine and brandy trade, the economic development of kiln technology for ore and glass smelting, increasing of agricultural production by the use of manures, and the possibility of silk production through the growing of mulberry trees in combination with the rearing of silkworms. Likewise of importance in these years was the discussions, that emerged or continued, regarding metal refinement or ennoblement, specifically for gold, silver and lead production, and regarding pearl cleansing procedures, or about retort manufacture, about salt production and oil production processes, and much more besides. However, the considerations of these processes, or process improvements, did not have the importance they had in earlier years, a

[55] cf. T. McCormick, *William Petty and the ambitions of political arithmetic*, Oxford, 2009.

situation reflected, for example, in remarks made by Crafft, in a letter of March 5, 1691, about the futility of entrepreneurial involvement in manufactories without princely or baronial participation.

Likewise, in the years between 1693 and 1696, Leibniz did not find any great sphere of activity as regards his interest in economic and trade advancement. Although he was informed by his correspondents about a range of different projects, he failed in several instances – for example, regarding salt works, linen drapery or wallpaper manufacture – to advance beyond the reception, or intake, of intelligence or, at best, he could only offer encouragement to others as, for example, regarding glass working for optical equipment or porcelain manufacture. In end effect, apart from his renewed activities in mining in the Harz region, there was but a single undertaking in the economic field, in which he was seriously involved in this period, namely that for the production of brandy from native sugar. This project was also motivated in part by his obligations towards his old, and in the meanwhile luckless, associate, namely Crafft.

In the course of the War of the Grand Alliance (1688-1697), the helplessness of the German empire, in the face of the conquest-oriented French king, caused Leibniz to reflect very early on possible counter measures on the economic front. To this end, a trade war seemed to be an option and, by a favorable coincidence, Crafft learned, in the fall of 1693, of a projected brandy manufactory in the town of Münden, an enterprise in which he immediately involved himself. In the same vein, Crafft had been able to inform Leibniz, on October 19 of that year, about a new ferment that had been developed in Hamburg. Since the greatest part of the brandy and cognac, consumed in Germany, was imported from France, it seemed that considerable economic damage might be inflicted on the enemy through the domestic production of such distillates. Unlike the French brandy production from wine, sugar solutions (syrup or treacle) were to be employed in the contemplated German scheme. After Crafft had reconnoitered the processes used for such distillates in Holland, he and Leibniz signed a contract for the formation of a company, whose aim was the production of brandy or a brandy substitute. According to the contract – that was done at Hanover on May 14, 1694 – a quarter of the proceeds of the company were to be used for pious or charitable purposes. A final stipulation was that the company so formed be limited to the two signatories to the agreement, a clause that in the end would prove to be ominous for Crafft.

Since Leibniz was not yet convinced of the profitability of the production process, he ordered, on the one hand, further trials to be carried out with, among other things, the goal of producing vinegar from the residue of the distillation process – a matter which was referred to in Crafft's letter of August 8, 1694 – and, on the other hand, he carried on detailed negotiations with a merchant in Hamburg, called Danneberg, about the process he employed. There was also contention between the parties to the contract regarding the location of the production facility. While Crafft advocated England as the place of production, Leibniz favored Holland, as is to be seen from a passage in Crafft's letter of early October 1694. And so it was agreed to undertake the initial preparations in Holland, to where both of them travelled at the beginning of November. In Amsterdam, during the second half of November, they wrote a series of memoranda and letters, which were intended for the Stadhouder (or head of state of the Dutch Republic),[56] William III, and (in the wake of the revolution of 1688-1689 and the Dutch invasion) king of England, for his diplomat George Stepney, and for the general field marshal of the forces of the States-General, and governor of Mastricht, duke Johann Adolf of Holstein-Sonderburg-Plön.

The half-English prince of Orange (son of Maria Henriette or Mary Stuart and grandson of Charles I) had come to power in 1672, the so-called calamity year in Dutch history which saw, in the spring of that year, the outbreak of the 'Third Anglo-Dutch War' (1672-1674), in which England fought in alliance with France against the Dutch Republic, and additional declarations of war by the German bishoprics of Münster and Cologne.[57] The threat of full invasion, and the ensuing domestic fury and civil strife, then culminated in the brutal assassinations of the 'grand pensionary' of Holland, namely the mathematician and author of *Elementa Curvarum Linearum* (1661), Johan de Witt, together with his brother Cornelis de Witt, in August of that year.[58] Apart from their very extensive literary estate,[59] a series of

[56] cf. for example, J. I. Israel, *The Dutch Republic*: *Its rise, greatness, and fall, 1477-1*806: *The Oxford history of early modern Europe*, New York, 1995.
[57] cf. Q. Barry, *From Solebay to the Texel*: *The third Anglo-Dutch war, 1672-1674*, Warwick, 2018. Regarding the 'year of disaster' in particular, cf. K. E. Hollewand, *The banishment of Beverland*: *Sex, sin, and scholarship in the seventeenth-century Dutch Republic*, Leiden, Boston, 2019, in particular the 'Prologue' (p. 25).
[58] cf. for example, H. H. Rowen, *John de Witt, Grand pensionary of Holland, 1625-1672*, Princeton, 1978.

references to the de Witt brothers are also to be found in Leibniz's manuscript papers and correspondence, and the *Elementa Curvarum Linearum* was alluded to, for example, in letters exchanged with John Wallis (on August 9, 1697, and January 8, 1699),[60] and with L'Hospital (on March 23, 1699).[61]

Also to be found among Leibniz's manuscript papers, and in his correspondence, are numerous reports about William's campaign in Ireland in 1690 following the revolution of 1688-1689.[62] Thereafter William also advanced in terms of personal wealth and, with his acquired fortune at the time of his death in 1702, he was to head the list of the 500 richest individuals in the Dutch Republic during the whole of the 17th and 18th centuries.[63] And so, in approaching the king of England in November 1694, seeking support of their enterprise for brandy production, Leibniz and Crafft were in fact knocking on the door not just of a head of state, but also of a prince with enormous personal wealth.

Of the two letters, written by Leibniz and Crafft and addressed to William III, only that of November 18, 1694, was actually dispatched. It was included as an attachment to a letter, dictated by Leibniz and written by Crafft, to Stepney on the same day. It was, however, never presented to the addressee, as is evident from Stepney's letter to Leibniz of March 4, 1695. Stepney reported that he had handed Crafft's latter to Charles Talbot, the duke of Shrewsbury and 'secretary of state', who was not willing, however, to pass it on, since Crafft had not been prepared to disclose the details of his secret process. In the letter in question addressed to William III, Leibniz and Crafft argued that part of the strength of France lay in trade in foodstuffs and merchandising, on which its neighbors were dependent. Their research had then revealed a method of circumventing this

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Regarding Johan de Witt's mathematical work, cf. F. van Schooten (ed.), J. de Witt, *Elementia curvarum linearum*, in: R. Descartes, *Geometria*, vol. 2, 1661, pp. [153]-340; A. W. Grootendorst, *Jan de Witt's Elementa curvarum linearum: Liber primus*, (*Sources and studies in the history of mathematics and physical sciences*), London, Dordrecht, Heidelberg, New York, 2000; A. W. Grootendorst, *Jan de Witt's Elementa curvarum linearum*: *Liber secundus*, (*Sources and studies in the history of mathematics and physical sciences*), London, Dordrecht, Heidelberg, New York, 2010.

[59] Regarding the mammoth De Witt epistolary estate, cf. Bodleian Libraries, University of Oxford, EMLO: *Early Modern Letters Online* (http://emlo.bodleian.ox.ac.uk/).

[60] cf. A III,7 N. 128, p. 528, and A III,8 N. 3, p. 11.

[61] cf. A III,8 N. 21, p. 77.

[62] cf. J. G. O'Hara, "Leibniz and the Jacobite war: Reports and reflections on the battle of the Boyne and events in Ireland, 1689-91", *Proceedings of the Royal Irish Academy*, vol. 91C, (1991), pp. 1-20.

[63] Regarding the 500 wealthiest persons, and wealth, belief, power and culture in the Dutch Republic, cf. K. Zandvliet, *De 500 rijksten van de Republiek*: *Rijkdom, geloof, macht en cultuur*, Zutphen, 2018.

French trade monopoly, namely by enabling the English, together with their allies, to independently obtain the requisite products in great quantity, of high quality and at a low price, a development which would, in due course, lead to irreversible damage to French foreign trade. Furthermore, it was claimed that such a trade war might even be legitimately continued in times of peace and would thus inflict long-term damage and, in effect, be tantamount to the destruction of a French province. Such damage would of course affect only the adversaries of England and Holland, and would promote commerce in the provision of the requisite raw materials, give increased turnover, and serve to increase the wealth and power of the allies, promoting navigation and plantations, a development which might even lead to overseas expansion, like in south America. Thus, in end effect, it was claimed that France would be mortified, or humiliated, while William and his allies would be the beneficiaries. For the realization of such projects, a company should be formed and provided with prohibitive privileges to exclude any French influence. In effect, they were requesting a Royal privilege for the protection of participating entrepreneurs, and they expressed their willingness to particularize the details together with a minister appointed by the king.

Finally, their submission called for a portion of the company's profits to be set aside for the promotion of pious or charitable causes, and of the practical arts, under the guidance of the applicants.

On December 26, 1694, following Leibniz's return to Hanover, Crafft was able to report, from Amsterdam, for the last time about a general acceptance of the project. Thereafter, there followed a succession of bad news reports and evil tidings in relation to the project. At first – as reported in Crafft's letter of December 30, 1694 – there arose contractual difficulties. These were followed by reports of the need for a better ferment, and for the establishment of smaller subsidiary companies, all of which contributed to delays. In due course, a disappointed Leibniz had to abandon all hope of a successful conclusion of the enterprise, and he wrote off the advance payments he had made, the sole consolation for him being that his lost investment had been in the service of the commonweal, as he wrote in his letter to Crafft of July 5, 1695.

After an extended period of silence, Crafft finally acquiesced, on February 23, 1696, to Leibniz's decision in listing economic factors that had made the death of the undertaking inevitable. In particular, he suggested that sugar and syrup prices were only low enough in America to enable the profitable production of brandy from this raw material. However, the imaginative and relentless Crafft did propose a new project, which he had encountered in connection with his personal fight against gout, namely for the removal of the fusel oils from fruit and corn liquor by means of distillation with quicklime. But Leibniz's reaction, in his reply on March 2, was cool, noncommittal, and even recriminatory.

By mid-1696, the brandy project seemed wholly and permanently debilitated. And so Crafft's economic survival became increasingly difficult, and he was forced to seek new possibilities to secure his livelihood. The frequency of letters to Leibniz decreased and the two long-time companions became increasingly estranged. In the last nine months of his life, Crafft wrote a total of three letters to Leibniz from Amsterdam. The final stroke, that would wipe the slate clean in this correspondence that had been conducted since 1671, was inflicted by Leibniz, on March 8, 1697, just one month before Crafft's death. Initially however, on September 26, 1696, Crafft could, in spite of all, report progress on the brandy project to Leibniz. He was still hoping to be able to live from the project in the future and even to generate surpluses. In addition, he informed Leibniz about contacts to a German business partner, named Ludwig Wilhelm von Stauff zu Löwenstadt, whom Leibniz, however, regarded as dubious and unsavory. Notwithstanding his optimistic outlook, Crafft now found himself in the role of solicitant before Leibniz. Efforts for the relocation of his wife to join him in Amsterdam, and payments to an assistant there, had led to a financial shortfall so that he was now forced to request a payment of 40 Taler from Leibniz. When, on February 26 1697, he complained to Leibniz about the outstanding payment, he must have realized that their relationship had suffered. He presented, among other things, a follow-up project to the brandy project that would be much better and to which he had aspired over a period of forty years. Being gout-ridden, however, he had been prevented from pursuing this and further projects. Crafft's desperate situation was repeatedly articulated in between moments of excitement about his conceptions and discoveries. He suggested that Leibniz should seek financial support for the brandy project from the court in Celle. Furthermore, he once again insisted that Leibniz should send him money.

Leibniz's reply, on March 8, reveals the fact that he had already supported Crafft financially to a considerable degree and that he had, as a quid pro quo, called for a continuation of their correspondence on a regular basis. He had, however, been bitterly disappointed by Crafft's failure to meet this condition. Leibniz complained, above all, about the circumstance that the promised communication of information had not materialized. He felt himself exploited and treated "like a cow being milked", and he insisted that he was not pursuing personal advantage but rather the public interest. He expressed doubts concerning the prospects for the brandy project, in particular, and on the practicability of Crafft's projects, in general, demanding presentable results in advance of any further financial support. He reproached Crafft with the circumstance that his ambitious plans, in collaboration with Baron von Stauff, had come to nothing since there had been no further mention of them. In the final sentence of this final letter, Leibniz then laid down strict and rigorous conditions for a continuation of their business partnership and, in doing so, he effectively terminated an association, and even friendship, that had existed for more than 25 years. A month later, on April 9, 1697, Crafft died ill and poverty-stricken in Amsterdam.

In connection with the death of Johann Daniel Crafft stood Leibniz's correspondence with Crafft's widow, Dorothea Crafft, as well as with the Dutch correspondents Nicolaas Listingk and Ameldonck Block. Leibniz had met Listingk during his stay in Amsterdam, in November 1694, and it was from this correspondent that he learned – in reply to a query of his – of Crafft's death from a letter of July 9, 1697. In mid-July 1697, Leibniz then passed on the sad tidings from Listingk's letter to the widow. In this letter, he justified his dealings with Crafft, pointing out that his financial support for the deceased had been misappropriated again and again.

Almost twenty years before Crafft's death, and during a previous visit to Amsterdam in mid-July 1677, Leibniz – in a letter sent from Hanover to Friedrich Adolph Hansen and Henri Justel in Paris, for forwarding to Jean Paul de la Roque – had given the correspondents a detailed account of Crafft's association with Heinrich Brand, the discoverer of phosphorus. The opening words of this letter characterized Crafft as an inquisitive person working in Holland for the sake of personal fortune and glory: “Monsieur Krafft est un curieux, qui travaille en Hollande pour sa fortune et pour sa gloire”. Then, in the wake of Crafft’s death, Leibniz once again spoke critically of him, in his letter, of mid-July 1697, sent to Ameldonck Block with whom Crafft also had debts. Here it becomes evident how objectionable and malodorous Leibniz had found Crafft’s business relationship with Baron von Stauff, whom he referred to as “un certains Baron Allemand”, and which ultimately had led to his demise. While Leibniz praised Crafft as a chemist and technician, he attested him impaired judgment and inability in managing money, and he complained about his ingratitude and greed for profit. Crafft had hoped through a great discovery to become rich someday. Leibniz claimed that he had, again and again, cautioned and advised him to follow an ordinary profession and, like himself, to work for the common good. Furthermore, he explained how he had supplied Crafft with money, that was partly his own, and that he had been willing to continue doing so, provided Crafft adhered to the terms of the agreement between them.

The Organization of Science and Education

Throughout the 1680s and 1690s, Leibniz had a pronounced interest in the establishment or promotion of academies and learned societies, both in Germany and in other European countries.[64] Besides his personal ambition to receive recognition of the Académie des Sciences, both a draft of a letter addressed to Jean Baptiste Colbert and one dispatched to Jean Gallois, in October 1682, reveal a particular commitment on Leibniz’s part to the organization and the advancement of science with government or princely support. The fact, that the French Académie was in a position to carry out large-scale projects, was repeatedly revealed to Leibniz through his correspondence with Mariotte. The latter not only reported continuously about regular meetings of the Académie but also, for example, about the journey of a group of savants to the equatorial region, in the course of which the astronomer Jean Richer’s disputed

[64] cf. H. Rudolph, “Scientific organizations and leraned societies”, chap. 31 (pp. 543-562) in: M. R. Antognazza (ed.), *The Oxford Hanbook of Leibniz*, Oxford, 2018.

measurements of the length of the seconds pendulum in Cayenne, in French Guiana, were confirmed. A further group of academicians undertook journeys for the preparation of an improved map of France and, furthermore, they were to dissect samples of rare fish species.

Whereas the correspondence with Nehemiah Grew – who had relinquished his office as secretary of the Royal Society of London at the end of 1679 – was interrupted in the spring of 1680, Leibniz was kept informed about the activities of the Royal Society by Theodor Haak, although not as comprehensively and regularly as by Mariotte regarding the activities of the Académie des Sciences. Leibniz was also able to maintain contact with the Leopoldina, the Academia Naturae Curiosorum in Halle, with the help of the Frankfurt physician Sebastian Scheffer. Through the intercession of Leibniz, an article about an oversized kidney from the *Journal des Sçavans* appeared, under Scheffer's name, and in a Latin translation with the title "De rene monstroso", in the *Miscellanea Curiosa Medico-Physica*, the journal founded by the Leopoldina in 1670. Leibniz had of course used his contact to Scheffer to propose, to the Academia Leopoldina, a system of corresponding terrestrial magnetic observations. This proposal in turn gave Johann Georg Volckamer reason to consult with Johann Christoph Sturm about the creation of a mathematical-magnetic association for such an undertaking. Sturm, for his part, wrote an *Epistola invitatoria ad observationes magneticae variationis …instituendas* (1682), in which the learned and the scholarly were called upon to undertake corresponding observations. Sturm's appeal – following the initiating step taken by Leibniz and revealed in his correspondence with Scheffer, between June and September 1681, and on August 18, 1682 – may not have had quite the desired success, yet it did find a greater resonance than similar previous invocations.

With another proposal Leibniz was less successful, namely, that to encourage the Leopoldina to pursue utile activities. Leibniz prompted Volckamer, through Scheffer, to encourage the physicians of the town of Nuremberg, for the sake of science, to establish contact with the renowned tradesmen or craftsmen of that city, and to publish the results of such discussions. Volckamer's reply, quoted in Scheffer's letter to Leibniz of April 3, 1682, was to the effect that, while the suggestion was by no means bad, no scholar would be willing to communicate his knowledge to tradesmen or craftsmen, especially without financial compensation or remuneration. As Leibniz confided to Scheffer, in his reply in mid-April (see the leading quotation in the heading of this introductory section), he considered the reaction from Nuremberg to be ludicrous. His vision was that the bookish erudition of the scholars should be annotated with countless and useful explanatory notes of the practitioners and craftsmen. Here Leibniz broached a topic which would find the interest of historians of science in the twentieth and early twenty-first centuries, namely the relation of the scholar or scientist to the craftsman, artisan and practitioner, since the Renaissance, and particularly at the time of the Scientific Revolution.[65] The French pedagogical reformer Petrus Ramus (1515-1572), for example, believed that a way to unify theory and practice could be drawn out of the mix of practical mathematics and artisanal activity going on in Nuremberg and, in 1568, he visited the workshops of artisans there.[66] Likewise, the mathematician and instrument maker Georg Hartmann (1489-1564) moved to Nuremberg, where he set up an instrument shop and where he made globes, astrolabes, sundials and quadrants.[67] It was likewise in Nuremberg, that an expanding cumulative knowledge, acquired from minting coins, was first documented in the mid fifteenth century; this invention was at the heart of the central European mine boom, producing increased yields of silver.[68] The scholar / craftsman cleavage was of course not confined to Nuremberg but was also evident, for example in England,[69] and in many places in continental

[65] cf. for example, A. R. Hall, “The scholar and the craftsman in the scientific revolution”, pp. 3-23, and the following commentaries by R. K. Merton (pp. 24-29) and F. R. Johnson (pp. 30-32), in: M. Clagett (ed.), *Critical problems in the history of science*, Madison (Wisconson), 1969; D. Raven, W. Krohn, R. S. Cohen (eds.), *Edgar Zilsel*[(1891-1944)]: *The social origins of modern science*, (*Boston Studies in the Philosophy of Science*, vol. 200), Dordrecht, 2003; P. H. Smith, *The body of the artisan*: *Art and experience in the scientific revolution*, Chicago, 2004 (and 2012); P. O. Long, *Artisan / practitioners and the rise of the new sciences, 1400-1600*, Corvallis (Oregon), 2011.
[66] cf. P. H. Smith, (note 65[= 161]), p. 66.
[67] cf. P. O. Long, (note 65), p. 98.
[68] cf. p. 110.
[69] cf. E. G. R. Taylor, *The mathematical practitioners of Tudor and Stuart England*, Cambridge, 1954 and 1967, and *The mathematical practitioners of Hanoverian England*, Cambridge, 1966; S. Johnston, “The identity of the mathematical practitioner in 16th-century England”, pp. 93-120 in: I. Hantsche (ed.), *Der “mathematicus”*: *Zur Entwicklung und Bedeutung einer neuen Berufsgruppe in der Zeit Gerhard Mercators*, (*Duisburger Mercator-Studien*, vol. 4), Bochum, 1996; G. Wickel, “Landvermessung als praktische Geometrie in England um 1600”, pp. 263-280 in: B. Heinecke, I. Kästner (eds.), *Wettstreit der Künste*: *Der Aufstieg des praktischen Wissens zwischen Reformation und Aufklärung*, (*Europäische Wissenschaftsbeziehungen*, vol. 17), Aachen, 2018; P. Beeley, “Practical mathematics and mathematical practice in later seventeenth-century London”, *British Journal for the History of Science*, (Special issue: *London 1600-1800*: *Communities of natural knowledge and artificial practice*), vol. 52(2), (2019), pp.[225]-248.

Europe,[70] where the reality of practical mathematics and the role of mathematical practitioners was manifest. It was, however, the physicians and surgeons of Nuremberg towards whom Leibniz's ire was directed, a professional group to whom technical knowledge was indeed transferred at times, for example in the development of artificial limbs and of prosthetic technology in early modern Europe.[71]

Shortly after the accession of duke Ernst August in 1680, Leibniz proposed to his prince the establishment of a military academy in Hanover, or Göttingen, perhaps with the ulterior motive of assembling a circle of scholars nearby. As mathematics professor for the proposed academy Leibniz had the Dutch mathematician Ferguson in mind and, perhaps, the aristocratic Tschirnhaus as its director. Later, writing from Paris on May 27, 1682, and again on August 6 of that year, Tschirnhaus informed Leibniz about a plan of his own to assemble a group of scholars around him at his manor in Kieslingswalde, near Görlitz. Tschirnhaus aspired to a pension from the Académie des Sciences, with which he hoped to pay salaries to the Danish mathematician Georg Mohr, to a tradesman, a physician as well as an individual versed in algebra, all of whom would work to carry his inventions to execution. Although, in the case of Tschirnhaus, the pension never did materialize, Leibniz surely followed his plans with interest, just as in the case of the foundation of a scientific academy in Venice, by Ambrose Sarotti, the secretary of the Republic of Venice, which was referred to by Friedrich Schrader in a letter of April 23, 1682. Sarotti had returned from a diplomatic mission to England and drew inspiration for his academy from the Royal Society and, while in London, he had arranged for Denis Papin to participate in the enterprise. From Schrader and Scheffer, Leibniz requested further details in July-August of the same year and Scheffer, replying on August 18, raised the prospect of soon being able to provide him with further details about Sarotti's undertaking.

During the early 1690s, Leibniz continued to be interested in the establishment or promotion of academies and societies as well as of institutions like the "Collegium Imperiale Historicum", in Vienna, the

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[70] cf. L. B. Cormack, S. A. Walton, J. A. Schuster (eds.), *Mathematical practitioners and the transformation of natural knowledge in early modern Europe*, (*Studies in History and Philosophy of Science*, no. 45), Cham (Switzerland), 2017.

[71] cf. H. Hausse, "The locksmith, the surgeon, and the mechanical hand: Communicating technical knowledge in early modern Europe", *Technology and Culture*, vol. 60(1), (2019), pp. 34-64.

“Kunst- Rechnungs- liebende Societät”, in Hamburg, or a projected “Societas Germana” that might be independent of the grace and favor of a sovereign. As regards the organization of science in England, and its institutions, there was also a long-standing interest of Leibniz that continued after 1690. Following his return from Italy, he had resumed his correspondence with Henri Justel, on October 20, 1690. Through this channel he received, between 1691 and 1693, information about English scientists and about the Royal Society including, for example, the appointment of Robert Southwell as President and that of Edmond Halley as secretary of the Society, as well as about the latter’s planned research journey in the Atlantic, during which the variation of the magnetic needle was to be investigated.

After Leibniz had learned from Justel, in a letter dated “le 25 mars 92”, that Halley was prepared to correspond with him, he undertook the first step to initiate this correspondence. His letter of June 3, 1692, was forwarded by Justel to the prospective correspondent. However, Halley’s answer failed to materialize, and there was to be an interval of eleven years until the correspondence between the two eventually developed in July 1703. From Justel and Halley, as the letter of June 3 reveals, Leibniz hoped above all for information about the literary bequest and manuscript estate of Robert Boyle, and about the scientific treasures this was thought to contain. More detailed information about recent English advances in science and technology was also requested. Thus, Leibniz was interested in a sea-water desalination process of the English physician and Modena resident Nathan Lacy, in an English mining engineer called Kirckby (or Kirkby), who was involved in mining in the Erzgebirge or Ore Mountains in Saxony, and in the extraction yield of a recently discovered silver mine in Wales. Leibniz likewise enquired about English scientists and mathematicians he had previously been acquainted with, like John Collins (1625-1683), John Pell (1610-1685), Robert Hooke, Christopher Wren, John Wallis, and of course Newton whose reaction to the objections to his *Principia mathematica* – formulated by Huygens in the *Discours de la cause de la pesanteur* (1690) – was of particular interest.

In the 1690s, Leibniz was able to uphold his life-long ambition, firstly, to establish and advance societies, colleges and institutions for the collection, advancement and resourcing of knowledge and practical skills and, secondly, to improve and extend existing institutions in order to serve the commonweal, or “bonum commune”, in both theory and practice. The nature of his engagement, or commitment, included the conception of plans and memoranda to support the initiatives of kindred spirits, and even the exertion of influence in the filling of vacancies and appointments. The spectrum of institutions and associations considered was quite broad. It included, on the one hand, renowned and established academies (like the Académie des Sciences, the Royal Society of London, and the Leopoldina), universities (like in Gießen, Helmstedt and Wittenberg), military academies (like the one in Wolfenbüttel), grammar schools (like that in Göttingen) and, on the other hand, scholarly coteries (like the “Kunst- Rechnungs- liebende Gesellschaft” in Hamburg, and the “Collège de curieux” in Kassel). Thus, when on January 31, 1695, Leibniz was informed by Haes that landgrave Karl wanted to establish such a “Collège de curieux” in his principality – in which Papin was to be one of the first members – he was prompted to provide a detailed representation on the matter, which he included with his reply to Haes of March 6 for presentation to the landgrave. From the extant penultimate version of this reply, it can be seen that Leibniz was sending the landgrave a proposal for the establishment of an Academy of Sciences and Arts (“Akademie der Wissenschaften und Künste”). Haes could, in turn, inform Leibniz, on March 28, of the admiration and gratitude of the landgrave. The birth of this academy (the “Collegium Illustre Carolinum”) was, however, to be delayed until the year 1709.

The projects of Leibniz’s former mathematics professor (at Jena in 1663) Erhard Weigel, like his “Collegium artis consultorum” project, his pedagogical ideas and his school reform project,[72] and even his calendar reform efforts in the year 1700,[73] deserve special attention in this context. A (non-identified) letter Weigel wrote to Leibniz, on February 18, 1693, as well as letters and attachments Leibniz sent to Huldreich von Eyben (in June 1693), to Wilhelm Ernst

[72] cf. L. Friedrich, “Pädagogische Perspektiven zwischen Barock und Aufklärung: Die Pädagogik Erhard Weigels”, pp. 39-68 in: R. E. Schielicke, K-D. Herbst, S. Kratochwil (eds.), *Erhard Weigel –1625 bis 1699*: *Barocker Erzvater der deutschen Frühaufklärung*, (*Acta Historica Astronomiae*, vol. 7), Frankfurt am Main, 1999; K. Habermann, K.-D. Herbst, *Erhard Weigel (1625-1699) und seine Schüler*: *Beiträge des 7. Erhard-Weigel-Kolloquiums 2014,* Göttingen, 2016.
[73] cf. J. Hamel, “Erhard Weigel und die Kalenderreform des Jahres 1700”, pp.135-156 in: R. E. Schielicke et al. (eds.), note 72 [= note 168].

Tentzel (on June 29), and to Tschirnhaus (at the end of June), contained proposals for the improvement of the organization of science. Among such proposals was Weigel's project for a "Collegium artis consultorum", which he referred to in a letter to Leibniz of April 26, 1694. This project provided occasion for Leibniz to think once again about scientific institutions that would not be dependent on the grace and monetary support of princes. The issue of the "Collegium" was likewise addressed, not only in Leibniz's correspondence with Tschirnhaus, but also in the first letter of November 29, 1694, that Leibniz received from the physician Alexander Christian Gakenholz following a meeting of the two, in Hanover, shortly before.

By 1693, Weigel's commitment to pedagogy had already persisted for more than a decade.[74] In fact, the year 1681 had marked the beginning of a creative period in Weigel's life which was dominated by pedagogy. He approached both the Imperial Diet (the "Reichstag") in Regensburg (in 1683), and also princes willing to invest in his schemes and, furthermore, he campaigned for support in realizing his school reform enterprise. In the year 1683, he started a private school project in his own house. Based on this experience, and following the completion of the necessary building measures, there followed a public school project in 1690. An outstanding aspect of Weigel's School of Virtue ("Kunst- und Tugendschule"), as it was called, was the range of teaching materials he developed himself. At the core of his method of teaching was the activity concept, with the children being taught in such a way that they remained active as much as possible during the learning process. In this context, Weigel developed a so-called "Schreibregel", or writing rule, that availed of a mechanical instrument he had designed. This was used in elementary instruction, for the training of the motor function in learning to write, and it allowed the simultaneous execution of scribal movements by a large number of children. In addition to this writing rule, there was also a so-called "Leseregel", or reading rule, for school starters and, for teaching arithmetic, a corresponding learning aid was made available. A special attraction of Weigel's private school was the so-called "Schwebeclaß", or floating class, which was intended to enable the scholars to accompany their memory exercises with swaying

[74] cf. W. Hestermeyer, *Paedagogia Mathematica*: *Idee einer universellen Mathematik als Grundlage der Menschenbildung in der Didaktik Erhard Weigels, zugleich ein Beitrag zur Geschichte des pädagogischen Realismus im 17. Jahrhundert*, Paderborn, 1969.

movements. It consisted of desks mounted on a floor plate or platform made of wooden planks. The platform was suspended by means of strong ropes attached to iron hooks, and it was constantly maintained in a horizontal position parallel to the ground. In this way, a pleasant tranquility in the midst of movement was achieved, and the rhythmic movements of the individual children were combined with the common movement of the entire class. The syllabus of instruction combined rhythmics and calculation, reading and swinging, on the "Schwebeclaß" platform. Weigel's dynamic instruction retained, by and large, the traditional syllabus but shifted the emphasis more towards mathematics and science. The vernacular language, or tongue, was introduced as a full-fledged medium of instruction. Weigel chose not to curtail the amount of material, that had to be learned, but rather the time that had previously been required. His commitment to pedagogy and learning was reflected in in his correspondence with Leibniz, for example in his letter of April 26, 1694, in which he elaborated his school reform plans. Replying on May 20, 1694, Leibniz strongly praised Weigel's efforts and he announced his continuing support for these in political circles.

In connection with the establishment in the year 1700 of the Berlin Society of Sciences,[75] or the Prussian Academy of Sciences,[76] membership was offered to mathematicians, scientists and physicians, like Johann Bernoulli, Friedrich Hoffmann, Philippe Naudé, Pierre Dangicourt and Georg Wolfgang Wedel. In taking this step, Leibniz was guided as well by his own interests as, for example, in the construction of an astronomical observatory. While he hoped for support from Hoffmann, in the realization of his long-entertained project for gathering medical and meteorological ephemerides, he tried to influence Naudé and Dangicourt to do research on dyadic or binary mathematics. Leibniz would have liked to be able to entice Johann Bernoulli into his proximity – possibly by providing him with a mathematical professorship at Frankfurt an der Oder – but the Berlin Society did not have the requisite resources, as his letter of June 24, 1701, to Bernoulli reveals. The foundation of the Society did indeed meet with goodwill, but the dilatory start also led to some skepticism.

[75] cf. H.-S. Brather (ed.), *Leibniz und seine Akademie*: *Ausgewählte Quellen zur Geschichte der Berliner Sozietät der Wissenschaften 1697-1716*, Berlin, 1993.
[76] cf. E. Knobloch, "Mathematics at the Prussian Academy of Sciences", pp. 1-8 in: H. G. W. Begehr, H. Koch, J. Kramer, N. Schappacker, E.-J. Thiele (eds.), *Mathematics in Berlin*, Basel, Boston, Berlin, 1998.

At first, Bernoulli hoped that the new society would – in comparison with its foreign counterparts – develop like a cypress among the fellow botanical species viburnum or arrowwood, as he wrote to Leibniz on October 16, 1700. However, nine months later, Bernoulli had the impression that the Society was moribund again, a sentiment he expressed in his letter to Leibniz, on July 9, 1701.

Hoffmann reported, on August 30, 1701, that many were beginning to seriously have doubts about the prospects for the success of the Society. In Hoffmann's view, expressed in his letter of October 4, only Leibniz's influence and involvement could guarantee the success of the undertaking. In a letter of November 8, Hoffmann likewise expressed the fear that too many members had been accepted, and that this was to the detriment of the reputation of the Society abroad. Writing to Tschirnhaus, on April 17, 1701, Leibniz referred to the fact that the financing of the project was a major problem. It is understandable, therefore, that Leibniz did not respond to Bernoulli's repeatedly expressed desire for financial support for his experiments. Interesting for Bernoulli – whose articles were on occasions rejected by Otto Mencke, the editor of the *Acta Eruditorum*, because of the provocations they contained – was the prospect of having access to a journal of his own, a matter alluded to by Leibniz in letters of September 6, 1700, and September 13, 1701. However, the first volume of the Society's envisaged journal, namely the *Miscellanea Berolinensia*, only appeared in the year 1710. Also unresolved, at the end of the year 1701, was the financing of Hoffmann's lectures in experimental physics in Halle which, while not directly connected with the Berlin Society, was rooted in the broader context of the promotion of science by the court at Berlin. Leibniz backed this endeavor, in the wake of his meeting with Hoffmann in Halle in September 1700, since he was convinced of the great benefit to be gained from experimental science. In his letter of November 1, 1701, Leibniz informed this correspondent that the authorities had provided about a hundred Taler per year for his lectures. In this context, Leibniz expressed a remarkable sentiment, namely that a single lesson of a "collegium experimentale" – concerned with physical-mathematical inventions and experiments – had a greater value for him than a hundred corresponding lessons in metaphysics, logic or ethics. Hoffmann's problem was, however, not just of a financial nature, as he reported to Leibniz on November 8, 1701. His advocacy of an empirical science, built on the foundation of a mechanical world view inspired by Descartes, was being thwarted at the University of Halle by Christian Thomasius, who offered his own experimental lectures to promote his spiritualistic approach.

Leibniz attempted to communicate enthusiasm for science to the Prussian king Friedrich I – who was also elector Friedrich III of Brandenburg-Prussia – by means of spectacular experiments. Thus, on February 16, 1701, Leibniz requested that Hoffmann confide to him a recipe for a fiery spirit ("spiritus igneus"), by which two oils catch fire on being mixed together. The spectacle, he thought, would benefit both the Society and the correspondent himself. The circumstance that Johann Bernoulli applied, on October 16, 1700, for membership in the Berlin Society, by presenting mercury vessels that could be made to glow following shaking, also proved to be highly welcome. Leibniz suggested to Hoffmann (on March 19, 1701), and to Wagner (in a letter sent to Johann Andreas Schmidt on February 12, 1701), that they produce, with the aid of Bernoulli's process, curiosa such as luminescent insignia, scepters and crowns, as well as a luminous showcase or "museolum", which he might present to the king in the name of the Society. The attempts to replicate Bernoulli's experiments had a prominent place in Leibniz's correspondence with Wagner, in the months of February and March 1701. In the vessels, a vacuum had to be created, and Wagner had first to construct the requisite instruments. In his letter of March 29, he revealed to Leibniz that he had succeeded in producing a luminescence which, however, was not comparable to that of Bernoulli. In the end, a luminous vial, sent by Bernoulli, was presented by Leibniz himself at the court, and then reported to the correspondent on December 27, 1701. Thereafter, the interpretation of Bernoulli's experiments played only a secondary role, even though Bernoulli had provided starting points for an explanation. In addition to impressing the king, Leibniz hoped – as his letter of December 31, 1700, to Bernoulli reveals – through a comparison of different illuminant or luminescence phenomena, like mechanoluminescence – or the luminescence resulting from mechanical action on a solid, such as the sparkle produced when hard sugar is broken or scraped in the dark – to gain an insight into the cause of refulgence, or of luminescence in general.

In spite of all difficulties, the Society's project of establishing a system of medical ephemerides appeared to have achieved success by the end of the year 1701. Leibniz presented Hoffmann's "spiritus igneus" to the royal family, in the autumn of 1701, following which the king mandated the establishment of the ephemerides program, as Leibniz informed Hoffmann on November 1, 1701. This success marked the conclusion of a long-standing commitment. Shortly after Hoffmann had established contact with him, at the end of 1699, Leibniz took up again the project that he had initiated back in 1691. On January 19, 1700, he then asked Hoffmann to endeavor to establish a system of annual observations, under the aegis of the Academia Leopoldina, following the example of Bernardino Ramazzini in Modena. Just like the efforts of the theologians and mathematicians in their support of the calendar reform, physicians could, he thought, serve the public interest by collecting observations. Leibniz had indeed found the right addressee, since Hoffmann himself had for years been recording barometric, thermometric and hygroscopic data, as well as producing occasional ephemerides, as he informed Leibniz at the end of January 1700. His goal had been to understand the connection between weather and maladies, as well as the mode of operation of the barometer.

Hoffmann most likely did not make the requisite effort to obtain an involvement of the Leopoldina, an institution that had previously not gone beyond a reprinting of Ramazzini's ephemerides from the early 1690s. However, he did keep his promise to publish, for the following year, observational data that he had been systematically collecting in consultation with practitioners. The publication, entitled *Observationes barometrico meteorologicae, et epidemicae Hallenses anni MDCC* (1701), was dedicated to Leibniz and sent to him with a letter of April 10, 1701. That Leibniz was flattered by the dedication of the work to him, is evident from the beginning of his letter of April 18, 1701, to Hoffmann. The appearance of this work prompted Leibniz's proposal to work towards achieving that the Prussian king decree the public funding of physicians in the provinces, in order to record weather and ephemeral data following Hoffmann's example. Thereafter, Leibniz and Hoffmann strove to achieve this goal during visits to Berlin, and in correspondence with the court. The measure, that would be easy to implement, and cost nothing, could – as Leibniz wrote to the Brandenburg-Prussian minister Paul von Fuchs – provide an incomparable treasure of knowledge for human life. The theologian Daniel Ernst Jablonski, however, considered it advisable to await the constitution of the Berlin Society, as Hoffman informed Leibniz on June 15, 1701. Nonetheless, Leibniz and Hoffmann continued to plan the concrete organization and implementation of the royal mandate. Hoffmann translated a part of his *Observationes* into German and conceived a project, initially entitled "Entwurf zur Einrichtung von medizinisch-meteorologischen Beobachtungen" (Plan for the establishment of medical-meteorological observations), and sent to Leibniz with a letter of October 4, 1701.

Hoffmann also compiled, as an example, the data for a month, prepared drafts for a mandate, and proposed the names of certain suitable physicians. And, from his "Entwurf" or plan, it is clear that he considered it necessary that, at every location, the data be recorded by two physicians for purposes of mutual control. Besides weather and illnesses, they should also observe the living conditions and circumstances of the population at the specific locations, and in addition, the welfare of animals and field crops in order to explain the connection with illnesses. Hoffmann did not insist on the employment of barometers and thermometers but, rather, only recommended them, since Leibniz had expressed doubts, in his letter of September 23, 1701, that all participants would have access to such instruments. Hoffmann lauded the undertaking, not only with the expectation that insights into the occurrence and prevention of epidemics were to be expected, but he also hoped to throw light on the connection between weather, the human condition and planetary aspects. Although astrology was rejected by most philosophers and astronomers, at this juncture, nonetheless experience seemed to suggest a certain influence of celestial bodies. Hoffmann recalled that even Kepler had been affine to an "astrologiam meteorologicam". Leibniz formulated the edict for king Friedrich I, along with detailed instructions based at least in part on Hoffmann's drafts. Thus, borrowing from Hoffmann, he referred to lunar and solar phases but not, however, to the planetary aspects. An annotation with the words "non communic[atum]", found on a copy of the edict, is indicative of the fact that this part of the project came to grief in its final stages. At the end of 1701, however, Leibniz was – as he reported to Sloane on December 27 – still optimistic about a mandate, that had been approved by the king, for the carrying out of such annual observations in the provinces by learned physicians.

Further projects of the Belin Society played only a subordinate role in Leibniz's correspondence at this juncture. In 1701, first on March 15 and then on December 27, he enquired of Wagner and Johann Bernoulli, respectively, about fire engines which the Society was willing to finance. The projects, which he mentioned to Tschirnhaus in his letter of April 17, 1701, included a calendar monopoly, the drainage of swamps and marshlands, and the idea of producing a German technical or specialized dictionary.

Besides the Berlin academy, Leibniz also had his sights on other national academies. In 1699, Denis Papin was offered the post of curator of experiments by the Royal Society of London, and he was considering returning to England, as he confided to Leibniz on June 18, 1699. Leibniz, however, in his reply of July 4, advised the correspondent against pursuing this offer. The commitment of the Royal Society was not as great as in former times, he insisted, and furthermore the landgrave, of whose "curiosité grande et universelle" he had a high opinion, could effectuate more for Papin. Leibniz had already expressed to Wallis, on April 9, 1699, his desire that the Royal Society be reinvigorated, just like the restructured Académie des Sciences. In his reply on April 30, Wallis informed him about new rules that would support scientific investigations, but he did not fail to acknowledge the contrasting financial endowments, and the corresponding possibilities, of the two academies.

On the occasion of the appearance of Leibniz's *Novissima Sinica* (1697), Wallis had reported about journeys to China by English merchants, which were also concerned both with Christian missionary ambitions and with the advancement of science. Then, on April 9, 1700, the English correspondent could inform Leibniz that mathematical instruments were to be acquired in China. Leibniz announced to Wallis, in his reply of September 3, that the Berlin Society wished to support the mission along the overland route to the orient, and could accordingly contribute to the advancement of the Anglican missionary efforts.[77] That the propagation of the faith, with

[77] Regarding Leibniz's missionary zeal, cf. for example: F. J. Swetz, "Leibniz, the Yijing, and the religious conversion of the Chinese", *Mathematics Magazine*, vol. 76(4), (2003), pp. 276-291.

the aid of science, was an objective of the Berlin Society, Leibniz also confided to Sloane, on December 27, 1701, after he had learned of the newly founded 'Society for the Propagation of the Gospel'.

8) Alchemy and Chemistry

"et experimenta lucifera magis quam lucrifera quaerimus".[78]
Leibniz to Johann Andreas Stisser, April 3, 1699.

In Leibniz's correspondence with Heinrich (or Henning) Brand, Johann Daniel Crafft and Georg Hermann Schuller during the first three years in Hanover (1677-1679), issues of alchemy and chemistry came to the fore, with questions arising about phosphorus and about the centuries-old problem of gold extraction, or reduction, and of the improvement or ennoblement of base metals *viz*. Chrysopoeia, the process of transmuting base metals into gold.[79] White phosphorus was first discovered in 1669, or in the early 1670s, by the Hamburg alchemist and pharmacist Brand, concerning which discovery Leibniz later published an account, entitled "Historia inventionis phosphori", in the first volume of the *Miscellanea Berolinensia* (1710). The new substance was first scientifically studied by Johann Kunckel (von Löwenstern from 1693) and Robert Boyle and publicized in their works *Phosphorus mirabilis* (1678) and *The aerial noctiluca* (1680), respectively.[80] When Leibniz met Boyle in London, on February 12,

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[78] A III,8 N. 25, p. 85; Translation: and we require 'luciferous' or enlightening experiments more than 'lucriferous' (*viz*. enriching or profit-bringing) experiments.

[79] cf. A.-L. Rey, "Alchemy and chemistry", chap. 28 (pp. 500-508) in: M. R. Antognazza (ed.), *The Oxford Hanbook of Leibniz*, Oxford, 2018; L. M. Principe, "Wilhelm Homberg: Chymical corpuscularianism and chrysopoeia in the early eighteenth century", pp. 535-56 in: C. Lüthy, J. E. Murdoch, W. R. Newman (eds.), *Late medieval and early modern corpuscular matter theories*, (Series: *Medieval and early modern philosophy and science*, vol. 1), Leiden, Boston, 2001; L. M. Principe, L. De Witt, *Transmutations*: *Alchemy in art*: *Selected works from the Eddleman and Fisher collections at the Chemical Heritage Foundation*, Philadelphia, 2002, pp. 1-41, and in particular "Alchemy-chemistry in the seventeenth century" (p. 2), "The transmutation of metals, or chrysopoeia" (pp.2f.), "Chemical medicine, or iatrochemistry" (p. 4), "Chemical industry" (p. 5), "The ambiguous status of chemistry" (p. 6), and "The marriage of art and alchemy" (pp. 8ff.).

[80] cf. C. Wahl, ""Im tunckeln ist ein blinder so guth als ein sehender": Zu Leibniz' Beschäftigung mit Leuchtstoffen", pp. [225]- 259 in: M. Kempe (ed.), *Der Philosoph im U-Boot*: *Praktische Wissenschaft und Technik im Kontext von Gottfried Wilhelm leibniz*, Hanover: Gottfried Wilhelm Leibniz Bibliothek, Forschung vol. 1, 2013; H. Peters, "Kunckels Verdienste um die Chemie", *Archiv für die Geschichte der Naturwissenschaften und der Technik*, vol. 4, (1912), pp. [178]-214; H. Peters, "Leibniz als Chemiker", *Archiv für die Geschichte der Naturwissenschaften und der Technik*, vol. 7, (1916), pp. [85]-108, [220]-235, [275]-287; J. R. Partington, "The early history of phosphorus", *Science Progress*, vol. 30, no. 119, (1936), pp. 402-412; J. Golinski, "A noble spectacle: Phosphorus and the public cultures of science in the early Royal Society", *ISIS*: *Journal of the History of Science Society*, vol. 80(1), (1989), pp. 11-39; H. Kragh, *Phosphors and phosphorus in early Danish natural philosophy*: *Historisk-filosofiske Meddelelser* , 88, 2002. Det Kongelige Danske Videnskabernes Selskab; The Royal Danish Academy of Sciences and Letters Commission, Copenhagen, 2003;

1673, their discussions evidently embraced a phosphorus-like substance. Seven years later, in a letter to Nehemiah Grew, on March 19, 1680, Leibniz reported the visit to Hanover of an Englishman named Roger Breatridge, who claimed to have a kind of powder that would ignite spontaneously after a certain time, and, in this context, he recalled the discussions he had with Boyle and the reference made to such a substance on that occasion. Also, about 1674, Christian Adolph Balduin (1632-1682) prepared a phosphorescent form of calcium nitrate, by mixing chalk and nitric acid, about which he published a tract entitled *Phosphorus hermeticus, sive magnes luminaris* (1675). This development was made known to Leibniz in a discussion with Crafft, on March 12, 1677, following which he made a note about the preparation of the so-called "Phosphorus Balduini".

Crafft had also become acquainted, in February or March 1676, with Brand's phosphorus and its discoverer and a little time later he received a sample of the new chemical substance. Then, in mid-May 1677, he presented the substance at the court in Hanover and, no-doubt, confided the name of the discoverer to Leibniz. At all events, in his letter of mid-July 1677, which he sent to Friedrich Adolph Hansen and Henri Justel in Paris for forwarding to Jean Paul de la Roque, Leibniz gave the correspondents a detailed account of Crafft's (or Brand's) phosphorus, which was referred to as "Le Phosphore de M. Krafft". In this letter, he also informed the correspondents that Balduin had sent a sample of his phosphorus to king Charles II. Leibniz had in fact previously been informed by Henry Oldenburg, on March 4, 1677, about the phosphorus sent by Balduin to the king.

In July 1678, during a visit to Hamburg, Leibniz availed of the opportunity to call on Brand and to negotiate a contract with him for the divulgement of his secret, and the optimization or perfection of the production process. The outcome was the completion of a contract between the two, that was done at Hamburg on July 24, 1678. Brand had first aspired to the position of personal physician to duke Johann Friedrich in Hanover, but in the end settled for an appointment as "Medicus" and "Chymicus". He then accompanied Leibniz to Hanover, where they arrived around September 5 of that year. The circumstances of, and events surrounding, Brand's employment in the

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H.-J. Kruse, "Johann Kunckel - der bedeutendste Plöner?", *Jahrbuch für Heimatkunde im Kreis Plön*, vol. 42, (2012), pp. 89-150 and, regarding phosphorus in particular, pp. 100-104 (and notes 98-141).

service of the duke of Hanover are reflected in his correspondence with Leibniz in 1678, 1679 and between 1680 and 1683. In a letter of September 2, 1682, for example, Brand requested the payment of the final installment of his salary from his employment in Hanover during 1678 and 1679. Notwithstanding such restitution claims, Brand was clearly referred to in Leibniz's letters as the "inventor primus" of the new substance. In fact, this attitude on Leibniz's part mirrored the fashion in which he referred to Otto von Guericke's role in the development of the vacuum pump, that was subsequently improved by Boyle. Thus, for example, in a letter of July or August 1679 to Grew, Leibniz characterized Guericke as the "inventorem primum" of the vacuum pump and he referred to the "phosphorum fulgurantem, quem ut nostis primus invenit Henricus Brand".

Like Leibniz, Robert Boyle learned of the discovery of phosphorus from Crafft, who visited him in London, on September 25, and on October 2, 1677.[81] In his tract *The aerial noctiluca*, presented to the Royal Society in December 1680, Boyle referred to the discovery, and his knowledge of it, in the opening prefatory address where he referred in particular to Crafft's role in disclosing to him the nature of the new substance, or in his words: "After the experienced Chymist Mr. Daniel Krafft had, in a Visit that he purposely made me, shewn me and some of my Friends, both his Liquid and Consistent Phosphorus ... he … confest to me at parting, that at least the principal matter of his Phosphorus's, was somewhat that belong'd to the Body of Man".

By the early 1680s, phosphorus was becoming internationally well-known and this was also reflected in Leibniz's correspondence. Thus, at the end of a letter of July 18, 1680, from London, Friedrich Slare referred to the various forms of phosphorus, and to the intelligence about the new substance provided by Crafft during his visit in 1677 and the ongoing effort to produce it. Robert Hooke too was interested in the new substance and, in a letter of July 22, 1680, he sent to Theodor Haak, for forwarding to Leibniz, he requested that "If D^{r} Leibnitz knows any thing of the composition thereof I should take it as a great favour if he would please to Impart any thing concerning it".

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[81] cf. M. Boas, *Robert Boyle and seventeenth-century chemistry*, Cambridge 1958 and 2015, and, regarding phosphorus in particular, pp. 137, 139, 193, 226f.; J. Golinski (note 80 [= note 176]), and specifically regarding Crafft's meetings with Boyle, p. 19.

Leibniz, who had produced phosphorus in Hanover with the assistance of Brand, informed Tschirnhaus, at the end of June 1682, about both his own (superior) process and about the (inferior) one of Boyle, both of which involved heating and repeated and protracted distillation procedures, starting with the requisite raw material, namely human urine. In the production process, a series of intermediate products were produced, namely concentrated urine ("dicken urin"), oil of urine ("oleum urinae"), a so-called "caput mortuum oleosum" containing a hard superfluous salt and a black loose or soft material ("eine schwarze lückere materi"), and then an amber-like hard stone ("eine ganz harte materi wie ein börnstein"). The final product was characterized by its brightness and property of glowing in the dark but the core fire-containing substance was the "caput mortuum oleosum". In fact, the superiority of his own process over that of Boyle, Leibniz saw in an additional step that involved the refinement of the "caput mortuum oleosum" giving a hard salt byproduct and the core soft black matter.

Tschirnhaus' letter of May 27, 1682, to Leibniz contains the intelligence that in Paris a secret formula for the production of phosphorus was being offered for sale by an Englishman and, Mariotte's letter, of April 13 of that year, revealed that various members of the Académie des Sciences were experimenting with the substance. While in Copenhagen, Jobst Dietrich Brandshagen had the opportunity to produce a large quantity of phosphorus, but, when he presented the product to the king, the latter saw in the new substance a source of amusement and, to the dismay of the correspondent, besmeared the entire consignment in the course of an evening. In his letter of mid-January 1682, Brandshagen also related that, in order to enhance phosphorescence in the dark, he himself had rubbed the substance into his own face, which resulted in severe nausea along with a feeling of having nothing under the skin, and the following morning his whole face had an ulcerous or pyogenic appearance. Besides such playful applications, which made phosphorus most suitable for public performances, Leibniz saw an eminent theoretical importance of this novel fiery substance. And Tschirmhaus wrote, in his letter from the end of June 1682, that he knew of no better process which squared with the three universal alchemical principles, namely mercury, sulfur and salt, since the end product, or fiery substance, derived neither from a solid state, or a fixed salt, nor from a volatile or mercurial spirit, but rather from an intermediate oily or sulfuric liquid.

The Académie des Sciences too was appreciative of the fact that Leibniz was willing – for the sake of supporting the advancement of his compatriot Tschirnhaus – to disclose the production process for phosphorus, in exchange for other scientific secrets, as Mariotte acknowledged in a letter of June 22, 1682. Leibniz received two such secrets from the Académie through Tschirnhaus, referred to as a “Sel vegetans; et l’or rendu volatile sans fulminer”, the first of these being a salt which grew like a plant in water.

The experiment of an Italian, who had demonstrated a smoking or fuming liquid at the court in Celle, was described by Leibniz in a report for the *Journal des Sçavans*, sent to the editor Jean Paul de La Roque, in January or early February, 1681. In September 1680, it had led to a discussion with the professor of medicine in Helmstedt, Günther Christoph Schelhammer, who in turn involved Georg Wolfgang Wedel, a professor in Jena. Schelhammer had conjectured, in a letter of June 14, 1680, that the smoke rising from the liquid was attributable to an inner fire in the fluid, and he seized the opportunity, in this letter to Leibniz, to enquire about phosphorus. Replying on September 24, 1680, Leibniz made clear that the smoking liquid had nothing in common with phosphorus, and he in turn enquired of Schelhammer about where Wedel’s description of the smoking liquid had been published.

The properties of afterglow, or phosphorescence, and ignitability were in the seventeenth century the principal motive for investigating phosphorus. However, other methods of encapsulating fire and combustion also attracted the interest of Leibniz and his correspondents. Thus, for example, Leibniz recorded – in the memo of a conversation with Christoph Pratisius between 1683 and 1687 – a means of distilling without fire which the conversation partner had learned about from a carbonarius or charburner. To this was added a further application, namely that of preserving heat over an extended period during a journey.

As in the years prior to 1683, phosphorus continued to be an important topic in Leibniz’s correspondence in that year, and indeed throughout the decade. Thus, Brandshagen reported from Copenhagen, in July 1683, about the distrust he was experiencing there because of his reluctance to provide information about his mortar bombs, and about phosphorus. Sometimes, Leibniz himself even received incorrect or inaccurate reports from his correspondents. As regards the transfer of knowledge about phosphorus to England, for example, Friedrich Heyn reported, on November 30, 1686, that intelligence about this German discovery had been communicated by Johann Joachim Becher to Robert Boyle, who then had his German laboratory assistant produce it. Boyle's more accurate version of events, as given in his *The aerial noctiluca* (1680), was that he had received the essential intelligence about the production process from Crafft, and from another German informant referred to as "A. G. M. D.", a reference probably to Ambrose Godfrey Hanck(e)witz.[82] Leibniz corrected the text of Heyn's letter, introducing the correct name of the discoverer ("D. Brand"), and correcting the name of Boyle's informant by replacing Becher's name with the words "ist ein ander", and adding the name "Hangwiz".

In mid-year 1687, Leibniz commissioned Brandshagen to carry out chemical experiments in Hanover, including on phosphorus production, and he duly compiled a list of what was required to produce phosphorus. During Leibniz's absence from Hanover, in late April and early May 1687, the master tailor Curd Reimers had to make sure that Brandshagen was able to collect enough urine for the phosphorus production and that he was accordingly compensated. On the eve of his Italian journey then, and almost twenty years after its discovery, Leibniz was able to pride himself on his knowledge of the discovery, and of the production process, of phosphorus. Three years later, on February 20 and March 4, 1690, in fulfillment of a promise made to prince Ferdinando in Florence, he sent from Venice details of the production process, as well as verses he had composed regarding this wondrous substance, to Bodenhausen, the prince's tutor. Then, on August 12, 1690, Bodenhausen was able to report that he had recited the details of the process in Leibniz's name to the prince, who immediately joined in a disputation with him. In addition, Bodenhausen reported that the prince's younger brother – prince Gian Gastone – had expressed his admiration and praise for Leibniz and the recited verses about phosphorus. Even after 1690, Leibniz's interest in

[82] cf. L. M. Principe, L. DeWitt, note 79 (= note 175); regarding Ambrose Godfrey Hanckwitz (1660-1741) see p. 5 (with engraving).

the discovery and investigation of phosphorus continued. In 1692, in the *Mémoires* of the *Académie des Sciences*, he found an account of the history of the discovery of phosphorus, from the viewpoint of Wilhelm Homberg, which became a subject of discussion in his letters to Simon Foucher (on October 27, 1692) and to Bodenhausen (on January 23, 1693). Alas, his own "Historia inventionis phosphori" would only appear in the first volume of the *Miscellanea Berolinensia* (1710).

A multitude of chemical considerations in Leibniz's correspondence may be categorized under the heading of the economic utilization of chemical processes. Often the dividing line to the techno-economic projects is difficult to draw. Thus, for example, writing to Grew on March 18, 1680, Leibniz desired to learn whether the Royal Society could produce a fluid gold paint with which clothing might be dyed. In the production process of ruby glass ("artificiall Rubine"), Leibniz and Robert Hooke were equally interested. In the letter of July 22, 1680, sent by Hooke to Theodor Haak for forwarding to Leibniz, the correspondent requested information concerning the production of both phosphorus and ruby glass. In Crafft's and Elers' endeavors for the perfection of pearls, the correspondents believed themselves to be in a position to report initial success at the beginning of September, 1681. Above all, however, it was the range of very different chemical processes for the preparation of gold and silver, that repeatedly played a role in the correspondences with these two projectors. Leibniz apparently esteemed such projects less than the techno-economic processes, referred to above, and he was accordingly impatient on occasions as, for example, in his letter to Crafft, on April 7, 1681. Nevertheless, there can be no doubt about Leibniz's interest in the preparation, or separation, of gold and silver from suitable raw materials or chemical precursors. Thus, we find Elers reporting, at the beginning of September 1681, about his efforts – together with the personal physician at the court in Hanover, Christof Pratisius – to obtain silver from cinnabar through the application of sulfur and lead.

Crafft, Christoph de Rojas y Spinola – the Dutch-born Franciscan priest and Bishop of the Viennese new town district ("Wiener Neustadt") – and Leibniz himself, discussed the possibility of obtaining silver from the liquation, or segregation, of Spanish copper coins, as is to be seen from Crafft's letter to Leibniz of December 25, 1682. In January 1680, both Leibniz and Crafft had followed attentively the efforts of various chemists in Dresden seeking to obtain gold from copper, mercury, and silver. In July 1682, Elers reported the sale of a process for obtaining gold – on the basis of intelligence obtained from Leibniz – to a Berlin chemist for a sum of 8000 Taler. Alas, he appears not to have received the sum in question, a part of which was intended for Leibniz. A much larger sum, namely 20,000 Taler, was mentioned in relation to the offer of the Dutch punchcutter and engraver, Christoff Adolphi, whom Leibniz had probably first encountered during his time as a student in Leipzig. In January 1680, Adolphi offered Crafft different chemical secrets, including a process to obtain mercury from all metals except gold, and in addition, to separate sulfur and mercury. Crafft forwarded this proposal to Leibniz who, in early February 1680, duly requested further details from Adolphi, as well as a demonstration of the truth of his propositions. A reply from Adolphi proved not to be forthcoming.

Leibniz also used contacts with his correspondents to clarify problems that arose in his reading of chemical literature, or to make inquiries about further investigations. In a letter to Sebastian Scheffer, in March 1682, he referred to a polemical work from the year 1656, which was directed against Johann Rudolf Glauber (1604-1670)[83] – and specifically against his opus *Widerlegung oder vielmehr Warnung vor der groß prallenden Explicatio Miraculi mundi, und der betriegerischen genandten Wolfahrt Teutschlands Johann Rudolph Glaubers* (1656) – in which the author, Christoph Fahrner, had referred to a chemical process through which ostensibly, and with little effort, an appreciable quantity of silver could be obtained from lead. In January-February 1683, Leibniz asked Scheffer – who in his youth had worked as an assistant with Fahrner – for information about the process in question. Scheffer duly consulted his former mentor about the matter before replying to Leibniz, on February 27, 1683, with the information that Fahrner was at the time indisposed and unable to comment on the issue. The production of gold and silver from tin – along with a passage in a work of Glauber – were also at

[83] cf. J. R. Partington, *A history of chemistry*, vol. 2, London, 1961, in particular chap. X (Glauber and Kunckel), and specifically pp. 341-361 (Glauber); H. Gebelein, R. Werthmann, and S. Nomayo (ed.), *Johann Rudolph Glauber*: *Alchemistische Denkweise, neue Forschungsergebnisse und Spuren in Kitzingen*, (Series: *Schriftenreihe des Städtischen Museums Kitzingen*, vol. 4), Kitzingen, 2009.

the center of an enquiry Leibniz sent to Crafft at the end of August 1681. In connection with this query, which he was unable to answer, Crafft made a remark – in his reply on September 2 – that epitomizes chemical research at the time, namely that he was from day to day becoming more and more confirmed in his conviction, that all was possible and available in nature and required only to be diligently sought and dealt with by means of the correct aptitude or ingenuity. This belief, that everything seemed possible, implied also that there could be a quest for very remarkable things in nature. Thus, for example, Crafft was persuaded by an alchemist at the Leipzig Fair that a non-wetting water existed in nature, as he reported to Leibniz on November 11, 1682. While Leibniz's response to this has not been found, it seems that his attitude may well have been characterized by a cautious skepticism. Indeed, even Crafft himself relativized – in a letter of December 25 – his search for this mysterious fluid with a degree of melancholic self-reprobation.

In the fall of 1681, Leibniz invited the alchemist Jakob Vierort to a presentation of an alleged transmutation of his, which was to take place at the court in Hanover. Leibniz had made thorough enquiries in advance about Vierort, contacting, among others, the renowned medical professor in Helmstedt, Heinrich Meibom, and of course Crafft. The latter, on September 2, 1681, recommended a strategy for exposing the presumed swindler. In the end, Leibniz demanded that the alchemist himself not be present during the performance of the transmutation. Since Vierort rejected this condition, it is probable the planned performance, in the presence of duke Ernst August, never did take place.

Saltpeter was – as the main ingredient of gunpowder – also of great interest at that time, whereby the focus was on improved processes for its manufacture rather than the investigation of its chemical properties.[84] Thus, in a letter from Copenhagen, on August 1, 1684, Elers referred to a hypothetical process, by which one might be able to establish a perpetual saltpeter works – at low cost and

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[84] Regarding the history of gunpowder, and gunpowder artillery, cf. B. S. Hall, *Weapons and warfare in renaissance Europe*: *Gunpowder, technology and tactics*, (*Johns Hopkins Studies in the History of Technology*), Baltimore, 1997; J. R. Partington, and B. S. Hall (Intro), *A history of Greek fire and gunpowder*, Baltimore, 1999, in particular "Introduction, 1999", pp. xv-xxix, and chap.7, pp. 298-339 (Saltpeter); B. J. Buchanan (ed.), *Gunpowder, explosives and the state*: *A technological history*, Oxford, New York, 2006 (and 2016), in particular Part two (The production of saltpetre and gunpowder in Europe); E. de Crouy-Chanel, *Le canon au moyen âge et à la renaissance*: *1338-1559*, Tours, 2020.

providing a high weekly production output – without having to leach and concentrate in ditches or trenches in the usual fashion. In January 1688, Leibniz also noted, after a conversation with Crafft in Graupen, the damming opinion of his conversation partner about a suggestion for the improvement of saltpeter production using a vault or dome – in which the product might appear on rocks following blasting – without the need for leaching and concentrating.

The range of chemical issues, that were subjects of discussion in Leibniz's correspondence, included processes for obtaining precious metals and, in particular, gold and silver. The work of the assayers along with their analytical methods – in the circle of Leibniz and his correspondents – forms part of a German tradition extending back to the Middle Ages.[85] On August 1, 1684, Elers reported from Copenhagen about the trial of a chemical process – communicated by Leibniz – for the reduction of gold powder in aqua fortis (nitric acid). Regarding the course of the trials, it was reported that, at the outset, the correspondent could have sworn that the actual outcome would be six times the anticipated result. However, it transpired that, after the preparation had been left standing for a certain time, all of the product was consumed once again. A repeat of the trial, with fresh acid, also fell short of expectations, and this had accordingly shattered the correspondent's belief in the process.

In his discussion with Crafft in Graupen, in January 1688, Leibniz learned details about the technique of gold panning in rivers. A few years earlier, he had received from the Académie Royale des Sciences through Tschirnhaus – in exchange for the communication of the phosphorus process, as outlined above – a description of two other processes, referred to as "l'or rendu volatile sans fulminer" and "un sel vegetant", respectively. After Tschirnhaus had given him an account of these processes, at a meeting in October 1682, he included written transcripts with his letter of September 4, 1683. Alas, Leibniz displaced these copies and he had to request them again, both in a letter to Jean-Baptiste Du Hamel, on July 21, 1684, and in the postscript to a letter of October 17, 1684, sent to Tschirnhaus. Often such processes were treated as secrets as, for example, one "pour

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[85] cf. D. Thorburn Burns, R. K. Müller, R. Salzer, G. Werner, *Important figures of analytical chemistry from Germany in brief biographies*: *From the middle ages to the twentieth century*, Berlin, 2014, in particular chap. 1, and specifically "Introduction and overview" (pp. 1-10) and "Important figures in analytical chemistry: From the middle ages to the nineteenth century" (pp. 11-47).

rendre le plomb en couleur de bronze à la fonte" that Douceur had promised him in January, and again on August 6, of the year 1683.

From Venice, Christof Pratisius reported, on October 26, 1685, about the activity of several hundred Italian alchemists, all of whom were occupied with the investigation of a certain cinnabar process. After Leibniz learned that Bodenhausen wanted to join this effort, he wrote to him, in August 1690, approving the study of the chemical process in question, which involved a remarkable chemical reaction, or "transplantatio", as it was called. He had also been informed about an adulteration of the process, by falsifying the cinnabar using lead oxide, and the possible use of cinnabar of antimony.[86]

A central concern in Bodenhausen's chemical experiments was the study and investigation of mercury. In this connection, he reported to Leibniz, on September 16, 1690, about his work on the writings of the famous eastern Arab writer on alchemy, Geber (or Gebir, *i.e.* Jabir ibn Hayyan, fl. c. 721- c. 815) and, in particular, about Geber's edited work, entitled *Chymia sive traditio summae perfectionis et investigatio magisterii* (1668).[87] In his reply, on November 5, 1690, Leibniz advised the correspondent to record his experiments in writing, and in the form of a diary, for the benefit of science. In addition, Leibniz could report the establishment of a chemical laboratory in Hanover under the direction of Pratisius. Although Leibniz was impressed by the alchemist Geber, and considered his writings to be well-founded, he had certain doubts about the correctness of Geber's results and, as an instance of this contrariness or inconsistency, he cited the chapter on the sublimation of mercury. Being unable to undertake experiments himself, Leibniz hoped to obtain clarification of important questions from those of Bodenhausen. As regards Geber, he was willing to keep an open mind, notwithstanding his predominating skepticism. Even the clarification of a specific point in this complex matter could amount to a breakthrough, he told the correspondent. Bodenhausen then reported to Leibniz, on November 11, 1690, that one of his princely students – presumably the hereditary or crown prince Ferdinando – was adept at

[86] cf. W. R. Newman, L. M. Principe, *Alchemy tried in the fire*: *Starkey, Boyle, and the fate of Helmontian chymistry*, Chicago, London, 2002, and specifically, regarding cinnabar of antimony, chap. 2, p. 104, note 34.
[87] cf. S. Nomanul Haq, "Jabir ibn Hayyan", pp. 459f. in: H. Selin (ed.), *Encyclopaedia of the history of science, technology, and medicine in non-western cultures*, Dordrecht, Boston, London, 1997; H. S. Redgrove, *Alchemy*: *Ancient and modern*, London, 1911 and later, most recently Sweden (Ulwencreutz Media), 2008, Washington (DC), 2016, and New York, 2018, in particular chap. 3, sect. 32.

doing chemical experiments and had, a few days before, produced mercury in his chambers from the regulus of antimony – *viz*. the metallic antimony reduced from its ore – without any mercurial addition, an experiment that Bodenhausen himself also hoped to repeat.

Leibniz regularly used his contacts, with correspondents, associates and friends, to obtain new information about known chemical processes. On June 26, 1689, he obtained intelligence from Crafft about the efforts of Johann Elias Rothmaler in Vienna to demonstrate a transmutation of metals, a demonstration which, it was claimed, the whole world ought to heed as a proof of the veracity of the transmutation of metals. However, Leibniz, for his part, wrote the following skeptical comment about the steadfastness of the matter between the lines of Crafft's text: "vereor ne sit stantiarismus". On another occasion, in August 1689 and April 1690, Crafft likewise reported about a process, named after a certain count Lobkowitz, for the transmutation of silver into gold and silver, using, among other substances, mercury. Yet another example was the separation process of Christian Holeysen. The latter resided in Vienna from 1688 to 1692 in order to present his purported process, for an improved yield of gold from auriferous silver, to the emperor. At the end of April, or in the first half of May 1690, Leibniz was able to make detailed excerpts from Holeysen's submissions to the emperor, and to carry on conversations with him which he recorded in writing. Besides the possible production and extraction of gold and silver, by means of the chemical transmutation of metals, Leibniz was especially interested in an improvement in the processing of ores – referred to as the "maturation" of metals – not just for obtaining new knowledge, but also for greater economic benefit, as he explained to the mining official Johann Christian Orschall, in a letter sent from Hanover in August 1687.

In the early and mid-1690s, alchemy and chemistry played only a minor role in Leibniz's correspondence. During his final two and a half year stay in Amsterdam, Crafft, for example, reported about projects based on chemical knowledge. Thus, on April 22, 1695, and again on February 23, 1696, he reported about projects for desalination and salt extraction from seawater, including one on the basis of a chemical precipitation process. Leibniz, although skeptical regarding the prospects for such projects in general in the Dutch climate, did nonetheless express an interest in the latter method in his reply on March 2, 1696.

With a letter of May 24, 1698, Johann Andreas Stisser, who was a university professor at the University of Helmstedt (the Academia Julia), initiated a correspondence with Leibniz. The prelude to this correspondence was the transmission, as an attachment to Stisser's letter, of a work on chemistry of his, entitled *Actorum laboratorii chemici in Academia Julia specimen tertium medico-chemica observata quaedam rariora exhibens* (1698). This work dealt with, among other things, a certain "Tinctura vitrioli", and to which Leibniz referred in his reply to Stisser on June 1. In doing so, he recalled the medieval alchemical text "Turba philosophorum", in which mercury was treated as a basic principle of metals. Leibniz now saw vitriol in this role.

Leibniz – like other contemporary philosophers of nature including Robert Boyle and Isaac Newton – had a long-standing and profound interest in alchemy. As regards Newton, he sought to make advances in the knowledge of alchemy, through laboratory experiments and the study of alchemical texts.[88] He studied alchemical literature extensively, and he treated the language of alchemy as a code to be deciphered, thus providing recipes for laboratory applications, including the decomposition or transmutation of metals, not least with the hope of making gold. Boyle, for his part, as a natural philosopher, ranks alongside Newton as a remarkably wide-ranging, penetrating and rational thinker, who was a pioneer of the modern experimental method and a champion of a novel mechanical view of nature. While Boyle (like Newton) reflected deeply on philosophical and theological issues related to science, he was also fascinated by alchemy and magic, and plagued with doubts about faith and conscience, which was at odds with his rational thinking.[89]

As for Leibniz, his interest in alchemy had existed since his stay in Nuremberg – between the spring and autumn 1667 – when, as a

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[88] cf. N. Guicciardini, *Isaac Newton and natural philosophy*, London and Chicago, 2018, in particular pp. 105-108; W. R. Newman, *Newton the alchemist*: *Science, enigma, and the quest for nature's "secret fire"*, Princeton, 2019.

[89] cf. M. Hunter, *Boyle*: *Between God and science*, New Haven, CT, 2009. Regarding Newton, cf. for example, J. E. Force, R. H. Popkin (eds.), *Newton and religion*: *Context, nature and influence*, (*International Archives of the History of Ideas*, no. 161), Dordrecht, Boston, London, 1999; R. Iliffe, *Priest of nature*: *The religious worlds of Isaac Newton*, Oxford, 2017.

twenty-year-old, he became secretary of an alchemical society there. Almost thirty years later, on August 10, 1696, after Gottfried Thomasius had reported to him about an alchemist called Friedrich Kleinert, Leibniz recalled, in his reply of December 17, the names of certain alchemists of earlier times including Ramon Lull, Nicolas Flamel, Daniel Keller, Johann Conrad von Richthausen (a baron with the title "Freiherr von Chaos"), as well as a former monk called Johann Wenzel Seyler. Keller was a practitioner of the art of the gold-maker, in sixteenth-century Augsburg, whereas Baron Chaos had demonstrated, in Mainz in 1658, an alleged process for the transmutation of mercury into gold. Wenzel Seyler possessed a powder, with the help of which gold could allegedly be produced, and he stood in high regard until his process was found to be fraudulent. On his way to Italy, on May 17, 1688, Leibniz had inspected – at the Imperial Treasury in Vienna – the counterfeit, or fake, gold from the workshops of Chaos and Seyler. He told his correspondent Thomasius, in his letter of December 17, 1696, that he had personally witnessed the demise of practitioners in the field, like Johann Joachim Becher and others, and he urged circumspection in judging alchemical activity. His Swedish correspondent, Magnus Gabriel Block, who had lived in Florence, had the same cautious attitude to alchemy as Leibniz himself, which was epitomized in the quotation of an old Spanish proverb in his letter of July 1, 1698. Thus, Block wrote on that occasion: "je approuve le proverb des Espagnols *Alequimia provada es tener rienta y no gastar nada*", an admonition to the effect that the true philosopher's stone is to have wealth and not spend it.

In his correspondence between 1699 and 1701 – more than thirty years after his stay in Nuremberg – Leibniz's continuing interest in the field is reflected in letters exchanged with, besides Block, Peter Moller, Johann Andreas Stisser and Georg Wolfgang Wedel. Block enquired about Leibniz's views on astrology, palmistry (palm reading or chiromancy), necromancy (necromantia), and the branch of alchemy concerned with transmutation (chrysopoeia). Leibniz's skeptical reaction, in a non-extant letter of April 17, 1699, can be sensed from the tenor of Block's reply two months later, on June 24. Leibniz warned, again and again, against investing time and money in the search for possible transmutations. The probability of success would be less than 1:100,000. But, one ought not to discredit or abandon alchemy entirely, which was the tenor of his reply to Block of September 8, 1699. He did not fundamentally cast doubt on the notion of a transmutation, which he certainly considered to be possible. However, many claims of such transformations failed to pass the test of proof, as he maintained in a letter to Block, written between mid-December 1699 and the end of January 1700. Unlike contemporaries (and correspondents) like Gottfried Kirch, and Friedrich Hoffmann, Leibniz condemned outright “astrologia judiciaria”, and saw himself here in the company of renowned astronomers like Cassini, Huygens and Hevelius, as he wrote in his letter of September 8, 1699, to Block. He proposed exposing, or unmasking, the astrologists by means of a statistical experiment that would show that the fulfillment, or coming true, of their predictions was entirely accidental.

For Leibniz, the fact that a transmutation was difficult to achieve, and at best only revealed to adepts in well-informed circles, was a work of providence that in turn contributed to the maintenance of the world order, and for the same reason, the quest for it seemed to him to make no sense. That one might find a small particular or singular process which worked, he considered to be more likely. Writing to Peter Moller of Hamburg, on January 2, 1699, he complained that in spite of his contacts to renowned chemists, his intensive study of alchemistic writings, and his visitations to laboratories, he had witnessed no credible transmutation but, on the contrary, had encountered a number of impostors. Moller, replying on January 7, found it hardly surprising that Leibniz had had little success in his dealings with chemists of fame, since the true adepts in the field – in contrast to those imposters – operated incognito, and worked secretly. Moller claimed that he had contact with several alchemists, who were working more or less in secret, and about whom he reported to Leibniz. He had, for example, just learned from an old acquaintance that he was involved in alchemy. Alas, the individual in question could only survive as a “capitalist”, and not as a chemist. He recalled yet another adept who had resigned from his employment in Brandenburg, because he had been discovered, and had then moved to Hamburg. Moller was impressed by Leibniz’s early involvement with alchemy, more than thirty years before, and, although he himself had seen a lot, he admitted that he had not carried out any laboratory work due to lack of instruction in the field.

The discoverer of phosphorus, Heinrich Brand, was still living in Hamburg and, in a letter of November 7, 1698, he touted to Leibniz an ostensibly very lucrative process for metal ennoblement. Leibniz then sought the judgement of Moller in the matter. The latter, however, – in his reply of January 7, 1699 – considered Brand to be a braggart who, although he had come far, had in fact not discovered phosphorus himself at all. Furthermore, Moller suggested, Brand was too poor to finance laboratory work. For the claimed effect, a universal or pansophist knowledge, which Brand simply did not have, would be required. Moller had not yet met such a person, but he was convinced that an acquaintance of his did possess a very lucrative particular, or singular, process, about which he promised to inform Leibniz, as soon as he received intelligence in the matter, as he wrote in a second letter of July-August 1699.

According to Stisser, Johann Joachim Becher had (in the 1670s) hoped, and tried in vain, to become rich by means of a process that purported to turn sand into gold.[90] Stisser himself had been a witness to one such demonstration by Becher – carried out both in Amsterdam and Hamburg – but one where the announced effect had failed to materialize. This he now reported to Leibniz, in a letter of February 5, 1699, in which he replied to a query about the transmutation of salts, with or without useful applications. Stisser confirmed, on this occasion, that he himself was aware of some transmutations of salts, albeit without particular use and only in small quantities. For Leibniz, as he wrote in his reply of April 3, 1699, the gain of enlightening experimental knowledge – like concerning the transmutation of salts – meant more than that of lucrative or lucre-bringing experimental knowledge, namely the leading quotation of this section (“et experimenta lucifera magis quam lucrifera quaerimus”). Although efforts were indeed being made everywhere, to bring chemistry into the form of an art, hitherto little light had been shed on the foundations of the subject, he thought. Many had postulated principles that were more melodious than veritable. He hoped, therefore, that

[90] cf. H. A. M. Snelders, “Johann Joachim Becher und sein Gold-aus-Sand-Projekt”, pp. 103-114 in: G. Frühsorge, G. F. Strasser (eds.), *Johann Joachim Becher (1635-1682)*, Wiesbaden, 1993.

Stisser might advance chemistry through a combination of method and experiment.

Stisser then promised, on June 2, to actively work for the consolidation of chemistry provided the means were made available to him for the meticulous experimental examination of the entire subject. And, he communicated to Leibniz some examples of salt transmutations from all three kingdoms of nature, namely the mineral, vegetable and animal realms. For Leibniz however, in his reply on December 22, it remained unclear whether, in fact, in each of these examples, a "transmutatio" was involved and not just a "transplantatio" in which chemical substances were merely exchanged in the reaction or process. Taking the example of Glauber's salt – treated in the third part of Johann Rudolph Glauber's *Prosperitatis Germaniae* or *Theütschlandes Wohlfahrt* (both 1659) – and, considering also Robert Boyle's discussion of Glauber's works in *Some specimens of an attempt to make chymical experiments usefull to illustrate the notions of the corpuscular philosophy* (1661),[91] Leibniz considered different alternative explanations of the transmutation of chemical substances – including the revivification or transanimation of Glauber's salt – for which he also proposed further investigation. Chemical substances could be veiled or unveiled in reactions, and the products of such a process might be already contained as subtle particles in the starting substances, and could possibly alter their form depending on their environment.

Stisser's open letter, of February or March, 1700, addressed to Leibniz and entitled *De variis erroribus, chemiae ignorantia in medicina commissis dissertatio epistolaris*, maked the end of the correspondence. The author and correspondent died on April 21 of that year. Leibniz's reply, written before he learned of Stisser's

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[91] Regarding seventeenth-century atomism and the corpuscular philosophy, cf. C. Meinel, "Empirical support for the corpuscular theory in the seventeenth century", pp. 77-92 in: D. Batens, J. P. van Bendegem (eds.), *Theory and experiment*: *Recent insights and new perspectives on their relation*, (*Synthese library series*, vol. 195), Dordrecht and Boston, 1988; C. Meinel, "Early seventeenth-century atomism: Theory, epistemology, and the insufficiency of experiment", *ISIS*: *Journal of the History of Science Society*, vol. 79(1), (1988), pp. 68-103; C. Meinel, "'Das letzte Blatt im Buch der Natur': Die Wirklichkeit der Atome und die Antinomie der Anschauung in den Korpuskulartheorien der frühen Neuzeit", in: *Studia Leibnitiana*, vol. 20, (1988), pp. 1-18; C. Lüthy, J. E. Murdoch, W. R. Newman (eds.), *Late medieval and early modern corpuscular matter theories,* (Series: *Medieval and Early Modern Philosophy and Science*, vol. 1), Leiden, Boston, 2001, in particular "Introduction: Corpuscles, atoms, particles and minima", pp. 1-38; W. R. Newman, "The significance of 'chymical atomism'", *Early Science and Medicine*, vol. 14(1/3), (2009), pp. 248-264; M. P. Banchetti-Robino, *The chemical philosophy of Robert Boyle*: *Mechanicism,chymical atoms, and emergence*, Oxford, 2020, in particular chap. 3, sect. 2, pp. 84-90 (Boyle's corpuscular theory of matter).

passing, is erroneously dated May 25 instead of the probable date, April 25. In his *Dissertatio epistolaris*, Stisser had, to begin with, characterized chemistry as the oldest of the arts. This prompted Leibniz, in his reply, to consider the importance and reliability of tradition, from the ancient times, in relation to chemistry. He did believe that chemical knowledge had existed in antiquity and that distillation had been known then. However, he considered chemical interpretations – for example the legend of 'The Golden Bough' from the *Aeneid*, the epic of the Roman poet Virgil (70-19 BC) – to be more elegant than credible. And, the portrayal of the Egyptian art of gold making – found in the Byzantine encyclopedia of the ancient Mediterranean world, the *Suda* – he considered to be hardly reliable either, since other authors chose not to mention it. The fact that he himself had once pursued the idea of editing the alchemical writings of the ancients, he had previously admitted to Block in a letter of September 8, 1699.

Leibniz had likewise, as he wrote in his final letter to Stisser, attempted to motivate the Dutch classicist Jacobus Tollius (1633-1696) to obtain alchemical information from mythology, not least with the intention of dissuading him from pursuing any further what he saw as a senseless undertaking. After Georg Wolfgang Wedel had sent him two writings regarding 'The Golden Bough', Leibniz, referring to Plato and Aristotle, made clear to this correspondent – in a letter written between February and April, 1700 – how difficult it was to identify substances described in the writings of antiquity, not least because of the strange terminology employed. Wedel's solution of an alchemical number puzzle of George Starkey – published under the pseudonym 'Philalethes' – appeared also to Leibniz to be uncertain, and he pointed out, in this letter to Wedel, that there was an infinite number of solutions. To begin with, one ought to convince oneself of the scientific pedigree of the author. The vague notation of Philalethes gave the impression that one was dealing with a sophist, rather than an adept in the field. Wedel had searched in vain in Erfurth for a manuscript on quintessence of Basilius Valentinus, and he asked Leibniz, on August 24, 1699, to search for it in the library at Wolfenbüttel. In his reply, on September 9, Leibniz had to disappoint the correspondent. However, in contrast to the writings of Philalethes and others, those of Basilius Valentinus – although he considered them to be feigned – stood out above the rest in Leibniz's opinion because of their concrete character.

The identities of alchemical authors, and the contents of alchemical records, were often the subjects of speculation in Leibniz's correspondence. On November 28, 1699, Block reported to him from Stockholm that his then deceased correspondent and collaborator in Florence, namely Rudolf Christian von Bodenhausen, had left behind numerous records and notes on chemical processes and concerning transmutation. One particular note of Bodenhausen provided the intelligence – derived from a conversation with the, in the meantime, likewise deceased personal physician at the court in Hanover, Christof Pratisius – that Leibniz possessed the manuscript of a work entitled *Lucerna salis philosophorum*, which had been published in 1658 under the pseudonym 'Sendivogius filius', and that Johann Joachim Becher was possibly its real author. This was disputed by Leibniz in his reply to Bloch, in December 1699 or January 1700. He told Block that he himself had indeed known the author in Nuremberg, whose real identity was Johann Harprecht and who was synonymous with Johann Hiskia Cardilucius. Becher, on the other hand, had preferred the pseudonym Solinus Salzthal Regiomontanus. Yet another pseudonym, namely 'Eirenaeus Philalethes', was in reality the American physician and alchemist, George Starkey (1628-1665), who had died in the great plague of London. He was alluded to, for example, in Georg Wolfgang Wedel's aforementioned letter to Leibniz on August 24, 1699.[92]

In his letter of June 24, 1699, Block also promised Leibniz transcriptions of Bodenhausen's alchemical records, some of which had never been intended for dissemination. To prevent the scribe, or amanuensis, from understanding these, Block planned to encrypt them and he sent Leibniz the secret-key encryption. In addition, following a request by Leibniz on September 8, Block passed on – with his letter of November 28 – a recipe of a process of Amund (Anund) Tyresson

[92] Regarding the identities of the alchemical authors, cf. P. H. Smith, *The business of alchemy*: *Science and culture in the Holy Roman Empire*, Princeton, 2016, in particular pp. 40f. (regarding Becher's "pseudonym of Solinus Salzthal of Regiomontanus"); W. R. Newman, *Gehennical fire*: *The lives of George Starkey, an American alchemist in the scientific revolution, with a new Foreword*, Chicago, London, 2003; W. R. Newman, *From alchemy to "chymistry"*, chap. 21, pp. 497- 517, and in particular pp. 513f. (regarding George Starkey), in: K. Park, L. Datson (eds.), *The Cambridge History of Science* : *Volume 3*, *Early modern science*, Cambridge, 2006; W. S. Shelley, *Science, alchemy and the great plague of London*, New York, 2017, in particular chap. 2, pp. 23-32 (George Starkey and Eirenaeus Philalethes); C. Wahl, "Zum Leibniz-Korrespondenten Johann Hiskias Cardilucius – alias Johann Fortitudo Hartprecht", *Studia Leibnitiana*, vol. 49(1), (2017), pp. 111-116.

for making iron malleable (and hard again), that surely evoked memories for Leibniz of the Douceur process, which had been acquired more than twenty years before.

9) Earth Sciences: Geology, Mineralogy, Paleontology and Ethnography, Etymology

"j'ay trouvé des choses si éloignées de l'opinion commune touchant l'origine des mineraux, et cependant si aisées à demonstrer par des raisons entierement mechaniques".[93]
Leibniz to Jean Gallois, mid-October 1682.

Leibniz's first years in the Harz mountains saw the beginning of the investigations that would culminate in his posthumously-published *Protogaea sive de prima facie telluris* (1749).[94] This work was composed in the early 1690s, and it was publicly announced for the first time in an advertisement in the *Acta Eruditorum* in January 1693, where it was designated "Protogaea" for the first time. A first intimation of an intended article for the *Acta Eruditorum* is found as early as October 22, 1681, in a letter to Otto Mencke. As is evident from another letter of mid-October 1682 to Jean Gallois, Leibniz had arrived at results regarding the formation of minerals, which strongly deviated from the received view, and which he thought might easily be given a mechanical foundation and verified accordingly. He explained to Gallois that he had made important discoveries regarding the formation of rocks and of the ore deposits found in lead and copper mines. In addition, he told the correspondent that he had made unique discoveries regarding copper mines and had found an explanation for a certain wonder of nature, which was probably a reference to the fish fossils he had come across.

In practical terms, Leibniz's frequent journeys to the Harz mountains provided him with a welcome opportunity for geological and mineralogical studies, in view of the fact that he considered a

[93] cf. A III,3 N. 407, p. 725; Translation: I have found things far removed from the common opinion regarding the origin of minerals, and nonetheless so simple to demonstrate solely on the basis of mechanical reasoning.
[94] cf. C. Cohen, A. Wakefield (trans. and eds.), *Protogaea*: *Gottfried Wilhelm Leibniz*, Chicago, 2008; Ch. L. Scheid, and W. von Engelhardt, F.-W. Wellmer (trans., eds.), *Gottfried Wilhelm Leibniz*: *Protogaea sive de prima facie telluris et antiquissimae historiae vestigiis in ipsis naturae monumentis dissertatio*, Göttingen, 1749; Stuttgart, 1949; Hildesheim, Zürich, New York, 2014; A. Wakefield, "The origin and history of the earth", chap. 25 (pp. 453-465) in: M. R. Antognazza, *The Oxford Hanbook of Leibniz*, Oxford, 2018.

scientific treatment of all matters relating to mining to be a desideratum. In a letter to Nehemiah Grew, on March 19, 1680, Leibniz posed the question as to whether amber found in the ground, near the location Wunstorf (not far from Hanover), could have originated there. In January and March, 1682, Ferguson replied to queries received from Leibniz about a goldmine on Sumatra. Already, on November 24, 1681, Leibniz had requested information from the rich treasure trove of experience of the director of that mine, Benjamin Olitsch, a former Saxon mining official who had joined the Dutch East India Company. In this letter to Olitsch, Leibniz referred to fossilization specimens found in Mansfeld slate, which had revealed the likes of natural fish, and which he found to be of particular interest. About the time Leibniz composed his letter to Olitsch, in October-November 1681, an inspector of the mint in Zellerfeld named Becker enquired, in conversation with him, about the processing procedures for various ores, on which occasion reference was also made to ores from other regions of geological or mining interest, like Muscau (near Görlitz in Saxony), or in Poland and even in East India.

In the mid-1680s, having accepted the commission as court historian, Leibniz began to extend his project to write a history of the House of Welf (or Guelph) and to include prehistory. His long-standing interest in the natural history of regions, like the Harz district, accordingly led him to include earth history, or the geological history of the Welf territories. In relation to the genesis of this work – that was originally conceived as the prelude to the history of the Welfs and largely founded on his knowledge of the Harz mountain range – there exists a report, in the form of an extract from a letter of January 1687, sent to the clergyman named Barthold Meier, whom he probably met on a visit to the Harz mountains in late October or early November 1685. This report concerned the "Baumannshöhle", a cave near the small town of Rübeland, which he visited during that journey in the fall of 1685.

In addition there are some scattered reports in Leibniz's correspondence, between 1683 and 1690, about interesting prehistorical finds. Thus, at the end of a letter to Georg Mohr in the second half of July 1683, Leibniz wrote that he had discovered fish fossils in shale, and that he suspected that the fish had lived in water before being petrified. Likewise, in his letter to Jean-Baptiste Du

Hamel, on July 21, 1684, Leibniz reported about his recent studies, and views, concerning earth history and, in particular, about the formation of rocks and minerals (mineralogenesis), which were at variance with those of Agricola, Descartes and Nicolas Steno (Niels Stensen), the Danish physician, geologist, Catholic theologian and apostolic vicar in Hanover, under duke Johann Friedrich, with whom Leibniz had discussions, for example on December 7, 1677.[95]

The same line of thought is found in a letter he wrote to Detlev Clüver, at the end of July 1686. Concerning the formation of metals, Georg Agricola had supposed – in *De ortu et causis subterraneorum* (1546) – that mineral veins were formed when groundwater permeated the rocks and was boiled by subterranean heat, to attain a certain denseness and so to form metal ore deposits. Leibniz attributed the process of the subterranean formation of minerals by fire to spirits trapped in the mines, and he insisted that he could reproduce the process in experiments. Descartes had, in his *Principia philosophiae* (1644), disputed Agricola's hypothesis, that groundwater was the source of the subterranean fluids from which minerals form, and he suggested instead that they are formed from molten rock. Leibniz considered Descartes' account to be particularly meager and off the mark, the author having had no experience in the mines and having been beguiled by written sources. Finally, on June 6, 1690, Friedrich Heyn sent Leibniz samples of mineral ores, from the Ilmenau mines, specifically shale and limestone, in which fossilized plants were to be seen.

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[95] cf. K. Müller, G. Krönert, *Leben und Werk von G. W. Leibniz*: *Eine Chronik*, Frankfurt am Main, 1969, p. 50. Regarding Leibniz's connection with Stensen, cf. A. Vibeke Vad, "Polidore and Théophile: The rationalist and the faithful observer", pp. 39-47, in: K. Ascani, H. Kermit, G. Skytte (eds.), *Niccolo Stenone (1638-1686)*: *Anatomista, Geologo, Vescovo*, *Atti del seminario organizzato da Universitetsbiblioteket i Tromsø e l'Accademia di Danimarca lunedi 23 ottobre 2000* (Proceedings of a Conference on October 23, 2000), (*Analecta Romana Instituti Danici*, Suppl. XXXI),Rome, 2002; M. Lærke, "Leibniz and Steno, 1675-1680", chap. 3, pp. 63-84, in: R. Andrault, M. Lærke (eds.), *Steno and the philosophers*, (*Studies in Intellectual History*, vol. 276), Leiden, 2018. Regarding Steno and the natural history of the earth, cf. the following chapters in this work: J. E. H. Smith, "Thinking from traces: Nicolas Steno's palaeontology and the method of science", chap. 7 (pp. 177-200), and D. Garber, "Steno, Leibniz, and the history of the world", chap. 8 (pp. 201-230). Regarding Stensen's biography and papers, cf. T. Kardel, P. Maquet (eds., trans.), *Nicolaus Steno*: *Biography and original papers of a 17th century scientist*, Berlin, Heidelberg, 2013 (and 2018). Regarding 'mineralogenesis', cf. J. E. H. Smith, *Divine machines*: *Leibniz and the sciences of life*, Princeton and Oxford, 2011, in particular chap. 6 (pp. 228f.). Finally regarding Leibniz's geological research in the Harz mountains (including his trip to the Baumannshöhle cave), cf. H.-J. Waschkies, "Leibniz' geologische Forschungen im Harz", pp. 187-210, in: H. Breger, F. Niewöhner (eds.), *Leibniz und Niedersachsen*: *Tagung anläßlich des 350. Geburtstages von G. W. Leibniz, Studia Leibnitiana,* (Special issue vol. 28), Stuttgart, 1999; J. Mattes, "Mapping the invisible: Knowledge, credibility and visions of earth in early modern cave maps", *British Journal for the History of Science,* vol. 55(1), (2022), pp. 53-80, in particular pp. 60-62.

Leibniz's projected work *Protogaea* also forms the context of his correspondence with the Hamburg pastor, Caspar Büssing, and, in particular, the exchange of views regarding the theories of Thomas Burnet and William Whiston. Büssing, in his work *De situ telluris paradisiacae et chiliasticae Burnetiano, ad eclipticam recto, quem T. Burnetius in sua Theoria sacra telluris proposuit, dissertatio mathematica* (1695), published a critique of Burnet's views expounded in his two-volume work entitled *Telluris theoria sacra, originem et mutationes generales orbis nostri, quas aut jam subiit, aut olim subiturus est, complectens. Accedunt archaeologiae philosophicae, sive doctrina antiqua de rerum originibus* (1681-1689). In a letter of October 16, 1696, Büssing then informed Leibniz about his "Dissertatio Anti-Burnetiana". He was not sure, however, if his publication had reached England, and if Burnet would heed it. Büssing's opus was reviewed by Christoph Pfautz in the *Acta Eruditorum*, in November 1695, and subsequently referred to by Leibniz in his correspondence with, among others, Thomas Burnett of Kemney and Wilhelm Ernst Tentzel. On December 26, 1696, Büssing reported to Leibniz that he had just received Burnet's publication *Archaeologiae philosophicae; sive doctrina antiqua de rerum originibus, libri duo* (1692). This work had angered some English theologians, but Burnet, enjoying the protection of the king, was able to retain his standing. Büssing was also disappointed by Burnet's publication, and he was of the opinion that it represented no more than a literary tale ("historiam quandam literarariam") and failed to dispel any of the doubts that had been raised. Leibniz could then inform Büssing, on January 3, 1697, about William Whiston's *A new theory of the earth, from its original to the consummation of all things wherein the creation of the world in six days, the universal deluge, and the general conflagration, as laid down in the Holy Scriptures, are shewn to be perfectly agreeable to reason and philosophy* (1696). In this work, Whiston had postulated the origin of the earth from the atmosphere of a comet, and all major changes in the earth's history were attributed by him to the action of comets.[96] It was also directed

[96] Regarding Thomas Burnet and William Whiston, cf. M. Farrell (F.C.J.), *The life and work of William Whiston*, Ph. D. thesis submitted to the Faculty of Technology of the University of Manchester, 1973, and New York, 1981, in particular chap. 2 (Speculations in earth history 1660-1700: Whiston's contribution to this debate); cf. also the following more recent studies: P. Rossi, L. G. Cochrane (trans.), *The dark abyss of time: The history of the earth and the history of nations*, Chicago and London,1984, in particular chap. 10, pp.66-69 (Burnet's Heritage); J. E. Force, *William Whiston*: *Honest Newtonian*, Cambridge, London, New York,1985, in particular

against Burnet's *Archaeologiae philosophicae* and, concerning which, he had been informed from a letter sent from London, by Burnett of Kemney, to the electress Sophie of Hanover, on December 16, 1696.

Burnet had presented the view that God had created the earth in a perfect and regular form, but that it had been transformed into its present form by the deluge. Büssing's alternative scenario assumed a spongy solidification of the earth's crust through which, as a result of the subsidence or settlement of the earth's surface, subterranean waters had been pressed upwards causing the deluge. Büssing's explanatory model of the deluge appealed to Leibniz, as is evident from his letter of January 3, 1697. He was, however, of the opinion that a sinking of the earth's surface would not have been possible without fissures being created in the existing crust of the earth. Leibniz's skeptical questions in this letter, as to where such a quantity of water might have disappeared following the deluge and whether, for example, the water had sunk back into cavities in the earth's interior, remained no doubt unanswered by the correspondent.

On August 16, 1699, Leibniz reported to John Wallis about Gustav Daniel Schmidt's geographical explorations of the coasts of the North Sea and of the Baltic Sea. Leibniz was also interested in the geological formation history of the English Channel, and accordingly in being able to establish temporal changes of the earth's surface. Following inducement by Leibniz, Schmidt had prepared a questionnaire, on the configuration of the coasts near Calais and Dover, which Leibniz sent to the Abbé Jean-Paul Bignon and to Hans Sloane, on May 14 and 15, respectively, of the year1701. Furthermore, in correspondence with Wallis,[97] Leibniz discussed Olof Rudbeck's geographical interpretation of mythology which, although rooted in literary legend, might just contain some truth, as he thought

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chap. 2, pp. 32-62 (Whiston, the Burnet controversy, and Newtonian biblical interpretation); T. Heidarzadeh , *A history of physical theories of comets*: *From Aristotle to Whipple*, (*Archimedes*: *New Studies in the History of Science and Technology*, vol.19), Cham, Switzerland, 2008, in particular pp. 129-135 (The post-Newtonian theory of comets: William Whiston and Edmond Halley); W. Poole, *The world makers*: *Scientists of the restoration and the search for the origins of the earth*, Oxford, 2010, in particular chap. 5, pp. 55-74 (The world makers: Burnet, Woodward, Whiston) ; T. Rossetter, *The theorist: Thomas Burnet and his sacred history of the earth*, Thesis submitted for degree of Doctor of Philosophy, Department of Philosophy, Durham University 2019 (E-Theses Online: http://etheses.dur.ac.uk/13080). Finally, regarding the development of geological, geomorphological, cosmological and cosmogenic theorizing, which served to undermine the strict historical veracity of the biblical narrative, cf. pp. 16-19 (Natural History) in: I. Leask, "Constant process: The science of Toland's Pantheisticon", *Eighteenth-Century Ireland / Iris an dá chultúr* [Ireland of the two cultures], vol. 34, (2019), pp. 11-27.

[97] cf. P. Beeley, "Physical arguments and moral inducements: John Wallis on questions of antiquarianism and natural philosophy", *Notes and Records of the Royal Society*, vol. 72(4), (2018), pp. 413-430.

and wrote in a letter to Wallis, on April 30, 1699. Rudbeck had located Atlantis and Odysseus' journey in northern Europe. Magnus Gabriel Block considered Rudbeck's hypotheses to be ridiculous, and these sentiments about his compatriot he expressed to Leibniz in his letter of January 10, 1699. Block also reported in this letter about rejoinders to Rudbeck's theory.

In addition to questions of the geological configuration of the European Atlantic coastline, there was the issue of the pre-Christian Celticization of the lands and islands along and off these shores.[98] It is not surprising then, that historical linguistics, in general, and, in particular, the theory of the relationship of languages, and alphabets, developed by the astronomy professor Edward Bernard, became an interest of Leibniz in the early 1690s. The discussion in his correspondence of the interrelationship, and development or evolution, of the Celtic languages, or protolanguages, and of Irish (or Proto-Irish) in particular, probably began in 1694.[99] In a letter to Bernard, on January 6 of that year, Leibniz referred to John Wallis' *Grammatica linguae Anglicanae* (1653 and 1674), in which the author had criticized Joseph Justus Scaliger's *Diatriba de Europaeorum linguis* (1610), and other works, for separating Irish from Welsh and placing it among the "matrices" – *viz.* the isolated or unrelated languages – of Europe like Basque, Hungarian, Finnish and Lappish. Near the end of his letter to Bernard, Leibniz ruled out a connection between the Irish and Basque languages. In a letter to Daniel Larroque a month later, on February 5, Leibniz suggested once again that Irish seemed to be one of the languages of Europe which appeared isolated and difficult to relate to others, although there were people (like Wallis) who saw a connection with Welsh and Breton. A connection between Irish and Welsh, based on a comparison between

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[98] Regarding Celticization, cf. for example: B. Cunliffe, J. T. Koch (eds.), *Celtic from the west: Alternative perspectives from archaeology, genetics, language and literature*, (*Celtic Studies Publications*, book 15), Oxford, Philadelphia, 2012; *Exploring Celtic origins*: *New ways forward in archaeology, linguistics, and genetics*, (*Celtic Studies Publications*, book 22), Oxford, Philadelphia, 2019.

[99] cf. E. Poppe, "Leibniz and Eckhart on the Irish language", *Eighteenth-Century Ireland / Iris an dá chultúr* [Ireland of the two cultures], vol. 1, 1986, pp. 65-84. Regarding the language "evolutionary theory" and the concept of a "protolanguage", cf. W. Wildgen, *The evolution of human language*: *Scenarios , principles, and cultural dynamics,* (Series: *Advances in consciousness research*), Amsterdam, 2004, and in particular, chap. 8, pp. 159-184 (The form of a "protolanguage" and the contours of a theory of language evolution). More generally, regarding a possible analogy between Leibniz's 'language dynamics' and his dynamics in natural philosophy and physics, cf. W. Wildgen, *Dynamische Sprach-und Weltauffassungen* (*in ihrer Entwicklung von der Antike bis zur Gegenwart*), *Philosophische Grundlagen der Wissenschaften* (*Book series of the Center for the Philosohical Foundations oft he Sciences*), vol. 3, Bremen, 1985, and 2005 (in electronic/digital form), and in particular pp. 25-32 (Naturdynamik und Sprachdynamik bei Leibniz).

contemporary Irish and Welsh texts of the Lord's Prayer, was also a focus of Leibniz's correspondence with Thomas Smith, in late 1694 and early 1695.

The origins of the peoples and languages of Great Britain and Ireland were again considered in Leibniz's correspondence with Wallis, at the end of the decade. Thus, Leibniz's words in his letter of December 4, 1699, refer to the Anglo-Saxon settlement and reveal an inkling of the later formulated division of the Celtic peoples and languages into two groups, namely the Brythonic or P-Celtic ("Cymraeos … vel Cambros") and Goidelic or Q-Celtic ("Scotos antiquos seu Hibernos"). Leibniz alluded here to recent works of the Welsh naturalist, botanist, linguist, geographer and antiquary, Edward Lhuyd, including his catalog of fossils entitled *Lithophylacii Britannici ichnographia, sive, lapidum aliorumque fossilium Britannicorum singulari figura insignium ... distributio classica* (1699) – which had been published with the financial assistance of the author's friend Isaac Newton[100] – and, specifically, the author's observations concerning Irish Gaelic ("de Lingua Hibernica quaedam non vulgaria observasse"). Lhuyd had noted the similarity between the two linguistic families, namely P-Celtic (Breton, Cornish and Welsh) and Q-Celtic (Irish Gaelic, Manx and Scottish Gaelic). The first formulation of the P-Q split of the Celtic languages, advanced by Lhuyd and referred to by Leibniz in his letter, of December 4, 1699, to Wallis, is however generally traced back in the literature to Lhuyd's glossography (or study of ancient words or languages) of 1707, namely his *Archaeologia Britannica*, which was published after Wallis' death in 1703.[101] Subsequently, in the years following Wallis' demise, Leibniz (alongside Johann Georg Eckhart) also developed a more complex theory, in which the Irish language was integrated into his concept of the history and the relationship of the European languages. The most prominent Irish speaker – with a lifelong interest in the Celtic languages and their cultures – known to Leibniz was surely John Toland,[102] particularly during the latter's Hanoverian

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[100] cf. R. S. Westfall, *Never at rest: A biography of Isaac Newton*, Cambridge, 1983, specifically p. 581.

[101] cf. for example, J. MacKillop, *Myths and legends of the Celts*, London, 2005, and specifically, regarding the Celtic languages in general, pp. xi, xiv, xvi, xvii, xviii, 6, 47,146, and regarding the so-called P-Q split in particular, pp. xvif.; J. Lennon, *Irish orientalism: A literary and intellectual history*, Syracuse (NY), 2004 and 2008, in particular chap. 2 (Ogygia, pp. [58]-114), and specifically p. 90 (regarding the P-Q split of Celtic languages as advanced by Lhuyd).

[102] cf. A. Harrison, *Béal eiriciúil as Inis Eoghain: John Toland* (1670 -1722) [Heretical voice from Inishowen: John Toland (1670 -1722)], Dublin, Belfast, 1994, in particular chap. 3 (John Toland mar Ghaeilgeoir [John

years (1701-1707).[103] Ultimately, the culmination and conclusion of Leibniz's efforts in this field, together with Eckhart, was no doubt the posthumous publication of his *Collectanea Etymologica, illustrationi linguarum, veteris Celticae, Germanicae, Gallicae, aliarumque inserventia*, in 1717.

10) Biology and Life Sciences

"Ex pollinis autem granulis spirituosum aliquid perductum ad ovarium, ut sic dicam, vel siliquam penetrare, atque ova vel semina illic foecundare". [104]
Leibniz to Alexander Christian Gakenholz, April 23, 1701.

The interests of Leibniz and his correspondents in the living world were closely connected with the growth of biological thought in the seventeenth century and later. This encompassed questions of the meaning and diversity of life, the science of classifying – specifically pre-Linnaean classification, or the classification of plants and animals before Carl Linnaeus (1701-78) – and the science of species, as well as the characteristics of living organisms that distinguish them from inanimate systems. The latter category of characteristics included capabilities for evolution, and specifically for self-replication or reproduction, as well as for growth and differentiation, binding and releasing of energy, self-regulation, and response to stimuli through perception and sense organs.[105]

Toland as a Gaelic speaker], pp. 57-93, and regarding Leibniz in particular p. 64); A. Harrison, "Sur les origines celtes de John Toland", *Revue de Synthèse*, vol. 116 (2/3), (1995), pp 345–355. (https://doi.org/10.1007/BF03182049). As regards the Gaelic language used in the Urris region of Inishowen, cf. E. Evans, "The Irish dialect of Urris, Inishowen, Co. Donegal", *Lochlann*: *A Review of Celtic Studies* (*Norsk tidsskrift for sprogvidenskap*, Universitetsforlaget, Oslo), vol. 4, (1969), pp. 1-130.

[103] cf. M. Brown, *A political biography of John Toland*, London, New York, 2012 (and 2016), in particular chap. 3 (Hanover, 1701-7).

[104] A III,8 N. 253, p. 660; Translation: Moreover, from the pollen grains a kind of spirit is led to the ovary, so to speak, or penetrates the pod and fecundates there either the eggs or the seeds.

[105] cf. for example, E. Mayr, *The growth of biological thought*: *Diversity, evolution, and inheritance*, Cambridge (MA), London, 1982, in particular Part I (Diversity of life), and specifically chap. 4 and chap. 6 (concerning the 'Science of classifying' and the 'Science of species', respectively), and Part II (Evolution), specifically chap. 7 and chap. 8 (concerning 'Origins without evolution' and 'Evolution before Darwin', respectively); E. Mayr, *This is biology*: *The science of the living world*, Cambridge (MA) and London, 1997 and 2001, in particular chap. 1 (What is the meaning of "life"?, treating the physicalists, the vitalists, the organicists, and distinguishing characteristics of living organisms). Furthermore, cf. G. Toepfer, *Historisches Wörterbuch der Biologie*: *Geschichte und Theorie der biologischen Grundbegriffe*, 3 vols, Stuttgart, Weimar, 2011, and in particular vol. 1, pp. 481-539 (Evolution, and concerning Leibniz's thought, pp. 486f.), and pp. 577-605 (Reproduction, and concerning Leibniz's thought, pp. 579f.). Regarding medieval thought on evolution, cf. G. Wicklein, "Die explication: Ein mittelalterliches Denken von Evolution", pp. 13-24 in: C. Asmuth und H. Poser (eds.),

Alongside the development of biological theory, practical issues and experiments were also often considered in Leibniz's recorded discussions and correspondence. For example, the topics of discussion in Leibniz's interlocution with the Marburg physician and Cartesian Johann Jakob Waldschmidt, on November 6, 1687, included two experiments of a botanical or zoological nature involving a vacuum pump. In the first experiment, the leaves of a plant were inserted into a vacuum flask while the roots remained outside and, in the second experiment, vice versa. When the vacuum pump was put in operation, water and vital spirit, or sap, were drawn from the roots through the meatus to the leaves, but not with the inverse experimental arrangement. Waldschmidt attributed the effects observed to the presence of valves in the vessels of the plants, through which liquids flow, whereas Leibniz supposed that inflected fibers were operative.

The second experiment discussed by Leibniz and Waldschmidt involved introducing a small fine tube into the vein of a dog, and then pumping air into this tube. The outcome was the immediate death of the animal, because the blood was suddenly pumped through the veins to the heart and the blood circulation accordingly blocked. This conversation also touched on a bell mouth (speaking tube or trumpet), or acoustic horn, discovered by Waldschmidt and referred to by Leibniz as "eine redende Trompete" for voice transmission over a distance of a quarter or half a mile.

In Leibniz's letter to Hendrik van Bleiswijk, on January 6, 1699, the theory of animal origins and development is referred to in connection with a recent discovery of Antoni van Leeuwenhoek, but one which was distinct from his earlier discovery of 'animalcula', or so-called little animals, in mammalian sperm.[106] The discovery in question may, however, be that referred to in an article by Martin

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Evolution: *Modell – Methode – Paradigma*, Würzburg, 2007. Regarding Leibniz's conception of organism, cf. M. Echelard-Dumas, *"*Der Begriff des Organismus bei Leibniz: „biologische Tatsache" und Fundierung*"*, *Studia Leibnitiana*, vol. 8(2), (1976), pp. 160-186.

[106] Regarding van Leeuwenhoek, cf. C. Dobell, *Antony van Leeuwenhoek and his "Little animals"; being some account of the father of protozoology and bacteriology and his multifarious discoveries in these disciplines*, New York, 1932, and 1958 (another first edition); N. Lane, "The unseen world: Reflections on Leeuwenhoek (1677) 'Concerning little animals'", *Philosophical Transactions of the Royal Society*, (2015), B370: 20140344 (http://dx.doi.org/10.1098/rstb.2014.0344). Regarding early theories of sexual generation in general, cf. C. Pinto-Correia, *The ovary of Eve*: *Egg and sperm and preformation*, Chicago and London, 1997, in particular chap. 3, pp. 105-109, and p. 326 (notes); J. Klein, N. Takahata, *Where do we come from? The molecular evidence for human descent*, Berlin, Heidelberg, New York, 2002, in particular pp. 16f. (Vapors, little worms and eggs): M. Cobb, *The egg & sperm race*: *The seventeenth-century scientists who unlocked the secrets of sex, life, and growth*, London, 2006.

Lister, that had been published in September 1698 in the *Philosophical Transactions* with the title “An objection to the new hypothesis of the generation of animals from animalcula in semine masculino”. However, Leibniz’s line of thought here might also be connected with two communications, which he received from Johann Bernoulli, in Gronningen, during the second half of 1698. In a letter of August 2, Bernoulli, in contemplating the infinite and the infinitely small in mathematics – like in the coexistence of lines and surfaces, of surfaces and bodies, or of differentials and integrals – drew parallels to the ongoing dispute between ovists and animalculists, in the theory of preformation, and he alluded to works by William Harvey (for example, *Exercitationes de generatione animalium* of 1651) and by Leeuwenhoek (for example, *Observationes de natis e semine genitali animalculis* of 1677-1678). In a second letter of November 18, where the relationship between infinity and the infinitely small was likewise at issue, the mathematician Bernoulli – alluding to his discussions in 1697 and 1698 with Pierre Varignon on these issues – referred to the micro-cosmos, and the world of the animalcula observed by Leeuwenhoek, and he suggested that those animalcula might in turn, if provided with appropriate microscopes, observe a further micro-cosmos within their own, and so forth. Referring then to Leeuwenhoek’s observation of animate beings or little animals in water interfused with pepper (*Observations ... concerning little animals observed in rain- well- and snow-water, as also in water wherein pepper had lain infused* of 1677), Bernoulli envisaged yet another sub-cosmos within the greater one.

The interest of Leibniz, and of his correspondents, in botany and zoology is also reflected in other correspondences between 1696 and 1698. Although chemistry was the main focus of the correspondence with Johann Andreas Stisser in Helmstedt, botany was also an interest of this correspondent. Stisser had set up a botanical garden in Helmstedt, in 1692, and he was the author of a work, entitled *Botanica curiosa* (1697). Zoology, and in particular the anatomical investigation of large mammals, was likewise an important topic in Leibniz’s correspondence at this juncture. It was stimulated by reports of the study of the skeletons of dead or extinct animals.

The more general context of Leibniz’s interest in the anatomy of large mammals was, however, his commitment to natural history and, in particular, regarding the history and form of the earth. On January 3, 1697, for example, Caspar Büssing asked Leibniz about the excavation of bones of an elephant-like creature at Gräfentonna (Tonna in the territory of Thuringia), an event that had been reported by Wilhelm Ernst Tentzel in his journal *Monatliche Unterredungen*, in April 1696, and in an open letter addressed to Antonio Magliabechi, entitled *Epistola de sceleto elephantino Tonnae nuper effoso*, published in Latin and German in the same year. Tentzel, for his part, hoped to obtain a report from the addressee of his *Epistola* about the skeleton of an elephant in Florence. In a letter to Leibniz on April 22, 1696 – to which the official judgement of the 'Collegium Medicum', in Gotha, concerning the discovery at Gräfentonna was attached – Tentzel referred specifically to two additional publications, namely Allen Mullen's twin tracts entitled *An anatomical account of the elephant accidentally burnt in Dublin on Fryday June 17 in the year 1681 ... Together with a relation of new anatomical observations in the eyes of animals* (1682), which were addressed to William Petty and Robert Boyle, respectively,[107] and John Ray's *Synopsis methodica animalium quadrupedum et serpentini generis* (1693). Tentzel's letter to Leibniz, of April 22, thus reveals that, fifteen years after the event, Mullen's dissection of the elephant was still attracting attention. Similarly, in a report on Tentzel's *Epistola de sceleto elephantino*, in the *Journal des Sçavans* four months later, on August 20, 1696, the reviewer commented on Mullen's autopsy of the elephant and he drew comparisons with the more recent discovery at Gräfentonna. In addition to the autopsy of the elephant, the physician Mullen had recorded his observations on the eyes of fowl and of fish, as well as on the ears of fowl, drawing inferences between the organs of animals and of humans.

Whale hunting, and the import of exotic animals from distant lands, offered yet another means of studying the anatomy of the largest mammals. On September 28, 1697, Georg Franck von Franckenau – then personal physician to the king of Denmark – reported to Leibniz that he had received precious minerals, as well as coral, or coral algae, from the mining official Heinrich von Schlanbusch in Trondheim, Norway. In addition, the remarkable

[107] cf. K. T. Hoppen (ed.), *Papers of the Dublin Philosophical Society 1683-1709,* Dublin: Irish Manuscripts Commission, 2008, 2 vols, in particular vol. 1, nos. 184-189, pp. 399-413 and vol. 2, pp. 959f.

penis, as well as the mandible or lower jaw – commonly known as boning or 'Fischbein' – of a whalebone or baleen whale had been received. The same correspondent also reported that he had obtained specimens of exotic animals, like a large spotted civet cat and tiger, a long-tailed monkey and a brown squirrel, from East India.

After he had learned of the impending return of the Jesuit priest, Joachim Bouvet, to China, the president of the Leopoldina, Lucas Schröck, commenced a correspondence with Leibniz, on January 16, 1698. As an attachment, Schröck sent a non-sealed letter addressed to Andreas Cleyer – who was originally from Kassel and had become a physician, botanist, pharmacist and respected figure in the Dutch East India Company's Batavian society – as well as a questionnaire, also intended for Cleyer, about, among other things, the musk plant and the Levant wormseed ("semen sanctum"). Two weeks later, on January 30, Leibniz forwarded Schröck's letter (and questionnaire) for Cleyer to Joachim Bouvet, together with an accompanying letter. As is evident from Bouvet's reply – sent from La Rochelle on February 28 – the correspondent intended having Schröck's letter copied and gathering relevant information himself. Cleyer had already published *Specimen medicinae Sinicae, sive opuscula medica ad mentem Sinensium* (1682), about heartbeat or cardioplegia, and had edited the edition of Michael Boym's *Clavis medica ad Chinarum doctrinam de pulsibus* (1686). In a letter to Leibniz, of July 17, 1698, Schröck also made reference to Georg Eberhard Rumpf from Hanau. Like Cleyer, the latter had gone as a physician to East India and had become consul and senior merchant of the Moluccan Island Ambon.[108] In the service of the Dutch East India company, he wrote a number of works about the natural history, and the natural science of the Moluccan Islands, and devoted himself to the study of botany. Schröck, in this letter to Leibniz, referred to another letter of Rumpf, from September 1696, that had duly been published in the *Miscellanea Curiosa* under the title "De caryophyllis regis Ambonicis". In addition, Schröck referred to a joint publication of Cleyer and Herbert de Jager, who had investigated a species of flowering plants called "artemisia abrotanum" (southernwood or southern wormwood) in Persia. Moreover, Schröck provided Leibniz with intelligence, received from

[108] cf. G. Yoo, "Wars and wonders: The inter-island information networks of Georg Everhard Rumphius", *British Journal for the History of Science*, (Special Issue: *Science and Islands in Indo-Pacific Worlds*), vol. 31(4), (2018), pp. 559-584.

Christian Mentzel and Rumpf himself, about a planned six-part botanical opus of Rumpf, the first part of which had, following dispatch, unfortunately been lost in a shipwreck, while en route to Holland in 1692. Alas, following Rumpf's death in 1702, his posthumous multi-volume work *Herbarium Amboinense* was only published decades later, between 1741and 1750.[109]

In the spring of 1701, Leibniz's correspondence with Alexander Christian Gakenholz gained a special significance, particularly in the fields of biology and medicine. Following a discussion with Leibniz (probably in March 1701), Gakenholz composed an open letter addressed to him, dated April 14, 1701, with the title *Ad illustrem atque excellentissimum virum Dominum Godefr. Guilielmum Leibnitium . . . epistola . . . de emendanda ac rite instituenda medicina*. The first printed version, of this *Epistola* on the emendation and correct practice of medicine, was sent as an enclosure to Gakenholz's letter to Leibniz dated April 21, 1701. The correspondent attributed the inspiration for his composition to the discussion he had with Leibniz a few weeks earlier. Leibniz had proposed considering roots as the basis for a system of plant classification. Following up on this proposal, Gakenholz had, in his *Epistola*, discussed various established classification systems, which were based on fruit, seeds and, more recently, flowers. As in his remarks concerning medicine, Gakenholz complained here also about the predominant orientation towards antiquity, where writings were interpreted, annotated and even provided with plant illustrations without any comparison with the real world having been undertaken. That had only begun to change in recent decades, he maintained. However, the new methods, that strove for mathematical exactness, were hardly suitable for general use, since classification on the basis of flowers and fruit made long-term observation necessary. The advantage of roots, as a basis for a classification system, was that they were constantly available. However, the fact that roots did not present any great number of variations made them unsuitable as a sole classification characteristic, although otherwise easy to deal with. The central message of Gakenholz's *Epistola* then was that, besides anatomy and chemistry,

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[109] cf. W. Buijze, *Leven en werk van Georg Everhard Rumphius (1627-1702)*: *Een natuurhistoricus in dienst van de VOC*, Den Haag, 2006, and in particular the second appendix about persons in Rumphius' ken ("Bijlage 2: Personen in Rumphius' Wereld") pp. 214-339, and specifically Andreas Cleyer (pp. 228-246), Herbert de Jager (pp. 282-296), and Christian Mentzel (p. 309).

botany had a particular significance. And a special desideratum in the subject area of botany was the development of a taxonomy, or classification system, on the basis of parts of plants, such as flowers, fruit, seeds or roots.

From Leibniz's reply of April 23, 1701, it is clear that Gakenholz had picked out and developed suggestions, which had been introduced by Leibniz himself at their meeting some weeks earlier, including thoughts about the taxonomy of plants. Thus, from this letter, it is evident that a classification of plants according to a single criterion, such as the form of flowers, fruit, seeds or roots, was for Leibniz insufficient. Combinatorics, and in particular his own dissertation on the combinatorial art – *viz*. the *Dissertatio de arte combinatoria* of 1666 – appeared to offer a way forward.[110] In addition to mathematics, philosophical (and even juridical) categories also seemed to have a certain relevance for the development of botanical systematics and classification systems. That the criteria depended on the focus of the particular discipline, he illustrated by making reference to geometry. Here he alluded to Ramist geometry (based on the teachings of the Parisian pedagogical reformer Petrus Ramus, 1515-1572), which, despite its crudity, had enjoyed popularity in the late sixteenth-century, and in the early seventeenth-century, providing a method of systematizing all branches of knowledge. It did not heed proofs, like those of Euclidean geometry, and it judged figures on the basis of their form, with practical geometry putting the focus on benefit or usefulness. In terms of the organization of learning, the radical innovator Ramus had, in fact, authored innovative treatises on subjects including grammar, dialectic, rhetoric, and of course mathematics.[111]

While the knowledge derived from Ramist geometry was inferior to that obtained from Euclidean geometry, it was of benefit to those not capable of understanding higher mathematics. According to Leibniz, botany found itself on an analogous level, since the internal structures of the machines of nature, *viz*. of plants – founded perhaps

[110] cf. E. Knobloch, *Die mathematischen Studien von G. W. Leibniz zur Kombinatorik*, *Studia Leibnitiana*, (*Supplementa*, vol. 11 and vol. 16), Wiesbaden, 1973 and 1976, respectively; E. Knobloch, "Renaissance combinatorics" and "The originns of modern combinatorics", pp. 123-146 and 147-166, respectively, in: R. Wilson, J. J. Watkins (eds.), *Combinatorics*: *Ancient & modern*, Oxford, 2013.

[111] cf. P. H. Smith, *The body of the artisan*: *Art and experience in the scientific revolution*, Chicago, 2004 (and 2012), in particular p. 66; A. T. Grafton, "Textbooks and the disciplines", pp. [11]-36, in: E. Campi, S. De Angelis, A.-S. Goeing, A. T. Grafton (eds.), *Scholarly knowledge*: *Textbooks in early modern Europe*, Geneva, 2008, in particular p. 22 (regarding Ramus).

in René Descartes' natural philosophical approach to the vegetal realm[112] – were not yet known. For Leibniz, therefore, further progress seemed to depend above all on an improved knowledge of the inner workings of these machine-like entities. For him, organic bodies produced by nature, like plants, animals and the human body, represented machines for the fulfillment of certain duties and functions, such as nutrition, reproduction and the preservation and perpetuation of knowledge.[113] Just as one differentiated between theoretical and practical mathematics, one ought to distinguish between theoretical biology, on the one hand, and practical biology and medical practice, on the other hand. To theoretical biology belonged the classification of plants according to one criterion, or several criteria. Plants, animals and humans were, for him, machines that were adapted for certain tasks: humans for contemplation, and plants and animals, among other things, for helping humans in the fulfillment of such tasks. The challenge then was to explain these tasks, as well as the mechanisms involved in their realization.

Leibniz had long been interested in the animate beings of earlier epochs, and in the science of these creatures. It may be recalled, for example, that he had obtained intelligence (in 1696 and 1697) regarding a trove of bones in Gräfentonna. In his letter to Gakenholz, on April 23, 1701, he then employed concepts from the field of comparative anatomy (such as "collatio animalium") and from reproductive, developmental and evolutionary biology (like "plantarum cum animalibus connexio" or "transitus a plantis ad animalia majora per intermedia"). Thus, he spoke of a link between plants and animals on the common basis of respiration, or respiratory organs, and of insects as an intermediate form between plants and

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[112] cf. F. Baldassarri, "The mechanical life of plants: Descartes on botany", *British Journal for the History of Science*, vol. 52(1), (2019), pp. [41]-63.

[113] cf. R. Andrault, "The machine analogy in medicine: A comparative approach to Leibniz and his contemporaries", chap. 7 (pp. 95-114), in: J. E. H. Smith, O. Nachtomy (eds.), *Machines of nature and corporeal substances in Leibniz*, Dordrecht, Heidelberg, London, New York, 2011; F. Duchesneau, "Physiology and organic bodies", chap. 26 (pp. 466-484) in: M. R. Antognazza (ed.), *The Oxford Hanbookof Leibniz*, Oxford, 2018. Regarding the machine analogy / metaphor, cf. the following editions of Canguilhem's works and their English translations: G. Canguilhem, *La connaissance de la vie*, Paris, 1952, and1965, 1992, 2003, respectively, and in particular "Machine et organisme", pp. 124-159 and pp.129-164, respectively; M. Cohen, R. Cherry (trans.), "Machine and organism", pp. 44-69, in: J. Crary, S. Kwinter (eds.), *Incorporations*, New York, 1992, and P. Marrati, T. Meyers (eds.), and S. Geroulanos, D. Ginsburg (trans.), *Knowledge of life*, New York, 2008; O. Fiant, "Canguilhem and the machine metaphor in life sciences: History of science and philosophy of biology at the service of sciences", *Transversal*: *International Journal for the Historiography of Science*, (*Graduate Program in History of Federal University of Minas Gerais* / *Universidade Federal de Minas Gerais*), vol. 4(4), (2018), pp.149-162.

animals, particularly with Jan Swammerdam's *Historia insectorum generalis, ofte Algemeene verhandeling van de bloedeloose dierkens* (1669) in mind.[114]

A further influence on Leibniz thought, in relation to the classification and, in particular, the reproduction of plants, was no doubt the letter sent to him by Johann Heinrich Burckhard, on February 21, 1701, also following a meeting between the two in Wolfenbüttel a few days earlier. In Leibniz's letter to Gakenholz of April 23, Burckhard's reference to the work of the Tübingen professor Rudolph Jacob Camerarius, entitled *De sexu plantarum epistola* (1694), was duly acknowledged. In his letter of February 21, Burchard had provided him with a detailed representation of the sexual organs of plants and, in particular, of the phenomena of monoecy and dioecy, *viz*. of monoecious and dioecious plants. Leibniz, in his letter to Gakenholz of April 23, saw in the reproduction process in plants – described by Burckhard and set in connection with the reproduction of animals – a connecting element between the vegetable and animal kingdoms. Accordingly, the pollen of seed-producing, or flowering, plants corresponded to mammalian sperm. Similarly, the style of a flower corresponded to the vagina in placental mammals, and the ovary at the bottom of the style corresponded to a mammalian ovary. Fertilization occurred when a kind of spirit – a non-physical element, or a vital force, contained by the living organism – coming from the pollen, penetrates the ovary, whereby either the eggs or the seeds are duly fecundated there ("atque ova vel semina illic foecundare").[115]

In this context, Leibniz recalled the rival theories of preformation of Antoni van Leeuwenhoek and of the anatomist

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[114] cf. S. Klerk, "Natural history in the physician's study: Jan Swammerdam (1637-1680), Steven Blankaart (1650-1705) and the 'paperwork' of observing insects", *British Journal for the History of Science*, vol. 53(4), (2020), pp. 497-525.

[115] cf. G. Toepfer, *Historisches Wörterbuch der Biologie*: *Geschichte und Theorie der biologischen Grundbegriffe*, 3 vols, Stuttgart, Weimar, 2011; see vol. 3, pp. 692-710 (Vitalismus) and in particular pp. 693f. (Stahl und Leibniz); F. J. Martínez, "Vitalism in Leibniz: A dileuzian approach", chap. 10 (pp. 159-170) in: J. A. Nicolás, J. M. Gómez Delgado, M. Escribano Cabeza (eds.), *Leibniz and hermeneutics*, (*Cambridge Scholars Publishing*), Newcastle upon Tyne, 2016. Regarding vitalism or vitalists, cf. E. Mayr, 1997 and 2001 (note 105 = 201). Concerning Newton's position with regard to the nature of a vital force, see pp. 12-16 (Vitalism beyond Mechanism) in: I. Leask, 2019 (note 192). Regarding Leibniz's communications concerning sexual reproduction, cf. J. G. O'Hara, ""ova vel semina … foecundare": Sexual reproduction in Leibniz's scientific correspondence", in W. Li, U. Beckmann, et. al. (eds.), *"Für unser Glück oder das Glück anderer": Vorträge des X. Internationalen Leibniz-Kongresses, Hanover, 18. – 23. Juli 2016*, 5 vols, Hildesheim, Zürich, New York, 2016, in particular vol. II, pp. 431-448. Regarding preformationism and the work of Camerarius, cf. L[incoln] Taiz and L[ee] Taiz, *Flora Unveiled*: *The discovery and denial of sex in plants*, Oxford, 2017, in particular chap. 12, pp.322-349 (The difficult birth of the two-sex model).

Theodor Kerckring. In the ovist-animalculist controversy, Leibniz saw here a possible reconciliation, but his own position was close to that of the animalculist Leeuwenhoek and removed from that of the ovist Kerckring. The preformist theory assumed that the entire organism was preformed, either in the sperm (the animalculst position) or in the egg (the ovist position), of the mammal and had only to unfold, or deconvolve itself, in the process of fertilization. Here again Leibniz saw a connection between the vegetable and animal kingdoms.

Following his correspondence with Gakenholz in 1701, Leibniz continued to refer to the theory of preformation in his learned correspondence. Thus, for example, in a letter to queen Sophie Charlotte and John Tolland, in early December 1702, Leibniz explained his views on preformation, referring to Swammerdam's *Historia insectorum generalis* (1669) and Leeuwenhoek's article "Observationes de natis e semine genitali animalculis"(1677/78). Leibniz, referring to Leeuwenhoek in his major philosophical writings composed between 1704 and 1714, admitted his penchant for the latter's interpretation of the theory of preformation, particularly in the *Nouveaux Essais sur l'entendement humain* (1704), in the *Essais de theodicée sur la bonté de Dieu, la liberté de l'homme et l'origine du mal* (1710), and in the *Lehr-Sätze über die Monadologie* (1714 and 1720). In the *Nouveaux Essais*, he expressed the view that Leeuwenhoek had enhanced the status of the male sex, and accordingly degraded the female sex, which merely provided a nutrient medium for the seed. Finally, on August 5, 1715 – almost forty years after their meeting in Delft in November 1676 – Leibniz commenced a direct correspondence with Leeuwenhoek, and a total of eight letters were exchanged between the two before Leibniz's death on November 14, 1716. A final letter of Leeuwenhoek, dated November 17, was written before he learned of Leibniz's passing.[116]

11) Medicine

"Wolte Gott daß Medicinalia und dergleichen concreta so wohl in potestate wären. Gleichwohl ist gewiß, daß auch diese dinge, in so

[116] [= note 212] cf. L. Palm, et al. (eds.), note 95 [= note 95]; J. G. O'Hara, note 95 [= note 95]; A. Becchi, "Between learned science and technical knowledge: Leibniz, Leeuwenhoek and the school for microscopists", pp.47-79 in: L.Strickland, E. Vynckier, J. Weckend (eds.), *Tercentenary essays on the philosophy and science of Leibniz*, Basingstoke, 2016.

weit sie rationi unterworfen, auch in calculum zu bringen. Denn calculus nichts anders als aptissima et compendiosissima ratiocinationum expressio".[117]
Leibniz to Rudolf Christian von Bodenhausen. February 20, 1690.

Anatomy, Physiology

In the field of medicine,[118] questions arising included those regarding the circulation of the blood, and the form of blood vessels, and were an important consideration in Leibniz's correspondence with the professor of Medicine in Helmstedt, Heinrich Meibom, in the early 1680s. Following a meeting with Meibom in Hanover, in September or early October 1681, Leibniz wrote to him, on January 23, 1682, referring to Meibom's observations of triangular vascular formations discussed at their meeting. Here Leibniz took an anatomical observation of the correspondent – whose exact investigation and verification with the aid of a microscope he considered to be essential – as a starting point for a lengthy theoretical consideration about the form of blood vessels. Assuming the blood vessels to be elastic, and to have a polygonal cross section, they represented what he termed a most simple hydraulic machine, which, notwithstanding the irregular entry of the blood, guaranteed a regular rate of flow. Thus, resorting to trigonal prismatic geometry to describe the shape of such blood vessels – whose cross section was represented by a circumscribed polygon that might range from a triangle (the best case), through multi-faceted polygons, to a circle (the worst case) – he imagined a hollow triangular prism, or tube, filled with water and continually supplied through an orifice, as the most simple hydraulic machine to emulate blood flow. However, the experiment entailed a mechanical problem of reconciling the intermittent, or pulsed, intrusion with the continuous extrusion of the fluid, and the solution of this mechanical problem did not seem to Leibniz to be at all simple. Immediately following this line of thought, Leibniz elaborated a further consideration in which elasticity emerged as an explanatory principle

[117] A III,4 N. 236, p. 462; Translation: [May it be that] God wanted that medicinalia, and the like, exist both concretely and potentially [*viz*. be both concrete and abstract]. Nonetheless, it is certain that these things, in as far as they are subject to reason, can also be reduced to calculation. For, indeed, calculus is nothing other than a most appropriate and compendious expression of reasoning or rational thought.
[118] cf. J. E. H. Smith, "Medicine", chap. 27 (pp. 485-499) in: M. R. Antognazza (ed.), *The Oxford Hanbook of Leibniz*, Oxford, 2018.

in anatomy, while adhering to his triangular prism or tube model for the form of blood vessels. The longer and fewer the sides of the circumscribed polygon were, the more flexible they would be.

He then proceeded to present his views on acoustics, and he concluded that something must exist in the hearing organ which can be of uniform tension or tonus, *viz.* be homotonic (and thus belong to the same gamut or pitch range) with every sonorous body. He encouraged Meibom, in the letter of January 23, 1682 – as he had done previously with Günther Christoph Schelhammer in a letter of February-March 1681– to pursue this outstanding anatomical problem of identifying the missing entity. Otherwise, Leibniz considered the main questions of acoustics to be essentially solved.

New observations about kidneys, and urinary tracts, were reported or discussed in various correspondences in the early 1680s. Sebastian Scheffer had good contacts in Padua and he forwarded, on May 23, 1682, an anatomical discovery of Domenico Marchetti – reported also in the June number of the *Journal des Sçavans* – which Leibniz in turn passed on, without comment, to Friedrich Schrader a couple of months later. Likewise, Scheffer's letter, of January 1681, reveals that Leibniz had acted as an intermediary between him and Henri Justel, regarding the publication, in the *Miscellanea curiosa* in 1678-1679, of his description of an extremely enlarged kidney. Schelhammer's investigations in this area were initiated following his acceptance of a medical professorship in Helmstedt, in November 1680. In relation to medical science, it was an anatomical investigation of the sexual organs of the mole that became the starting point of a discussion between Schelhammer and Leibniz, and that was continued over several letters in 1680 and 1681. The overture to this discussion was a brief meeting between the two in Hanover. Following Leibniz's first letter, of June 2, 1680, and Schelhammer's reply on June 14, the topic of discussion was extended in Leibniz's next letter, of September 24 and the focus moved from the anatomy of the mole to the question of sexual reproduction in general. In the contemporary controversy about the constituent parts of mammalian semen – in particular, between the Dutch physicians and medical professors Johannes van Horne (Hoorn), Reinier de Graaf, and Jan Swammerdam – Schelhammer, writing to Leibniz on November 18, expressed his belief that he had identified the existence of three separate constituents of the seminal fluid which were being continually produced in testicles, prostate or prostatic glands and seminal vesicles, and then effused into the urethra for removal from the body. On December 16, Leibniz then expressed his skepticism and interjected that it should be investigated whether all three constituents were equally necessary for animal reproduction. However, the question could not be answered by the correspondent in his reply on January 10, 1681, and, notwithstanding his knowledge of medical literature and the considerable thought he had given to the matter, he readily conceded that Leibniz's objection was valid.

A veritable sensation among scholars was caused by the arrival of Denis Papin's digester, in which animal bones could be rendered soft and made edible. Papin first presented his pressure pot at the Royal Society, in May 1679, and the first publications regarding it came from Robert Boyle, in his *Experimentorum novorum physico-mechanicorum continuatio secunda* (1680), and from Papin himself, in his work entitled *A new digester, or engine for softning bones* (1681), and reviews were published in the newly-established *Acta Eruditorum* in April and October 1682. Furthermore, Mariotte informed Leibniz, on June 4, 1681, about a presentation of the digester at the Académie des Sciences. Leibniz had previously been informed, in a letter of July 18, 1680, by Frederick Slare following which he negotiated with Slare, in the early months of 1681, about the purchase of such a digester. While Schelhammer was curious to learn what was causing the softening of the bones, and thought the invention might have useful applications in medicine, Friedrich Schrader saw in Papin's steam digester an analogy to rachitis, or rickets, which likewise made bones soft. However, he was more interested in the opposite problem, namely as to how one might petrify, and indurate, the parts of animals and innards so that they would retain their form and position, and he informed Leibniz accordingly, on December 8, 1681. The knowledge which Schrader had gained on his journeys about the embalming of corpses, and related matters, as well as through reading and experiments, was greeted with acknowledgement by Leibniz, in a letter of July-August 1682.

A pronounced interest in anatomy, and in new anatomical insights, on Leibniz's part was also apparent in the 1690s. In the early months of the year 1695, the surgeon Jacques M. B. Bouquet accompanied prince Maximilian Wilhelm of Hanover on a tour to Italy. On March 3, Bouquet reported to Leibniz from Padua that discussions about anatomy were very much in vogue in his circles there. In Padua, Bouquet had assisted a dissector with the postmortem examinations of a series of corpses. Two of these autopsies, Bouquet considered particularly worthy of mention. In the first case, in carrying out the postmortem examination of a corpse, they had found a spleen split in two, with one part in the breast area and the other in the abdomen. In the second case, they were seemingly confronted with a corpse having two livers separated from each other. One liver was found in the normal location, and it had normal proportions. The second liver was discovered within the coverings of the diaphragm. According to Bouquet's report, it had the size of two fists, and it weighed about two to three pounds. Furthermore, it had an approximately round figure and a small lobe. Below this second liver passed the vena cava, which led to the remaining veins and numerous arteries, he reported to Leibniz.

After Leibniz had requested further details, Bouquet addressed the two autopsies once again in his next letter of June 11, 1695. First of all, he explained the circumstances of the investigation of the corpse with the two livers. Together with the dissector, he had examined an organ, between the membranes of the diaphragm, that was at first construed to be the heart. Through further investigation, however, similarities with a liver were established. The form and substance of the organ, the path of the vena cava, as well as the distribution of the veins and arteries throughout the whole body, indicated that the organ was indeed a liver. The gallbladder, and the gallbladder passage to the intestines, were found to be missing. Bouquet then elaborated on the special circumstances of this second autopsy. In that, they had been confronted with the corpse of a crippled or maimed man, a school master who had never been able to walk. As a result of his illnesses, and the circumstances of his disability, the organs of the lower abdomen were swollen or overblown, pressed together and pushed upwards. The circumstances of the man's life also provided an explanation for the split spleen in the first corpse. A part of the oversized organ had, in fact, been pressed into the chest, or breast area, by an extension of the diaphragm. For Bouquet, these deformities represented a grotesqueness of nature, from which no new insights into the normal functions, and functioning, of the organs involved could be expected, he told Leibniz.

As regards anatomical studies, Georg Franck von Franckenau emerged as Leibniz’s most important correspondent in the late 1690s. Physicians’ reports about postmortem examinations of corpses, as well as reports about birth deformities, had long been a source of information for Leibniz in the area of anatomy. Both are to be found in a report of Franck von Franckenau, in his letter of September 28, 1697, about a monstrous birth and, specifically, the postmortem examination of the remains of a dead-born two-headed female child. In August of that year, the wife of a schoolmaster near Copenhagen, who was already mother of several children, gave birth to this two-headed girl. The still-born child was brought to the Royal Palace, where the remains were examined by Franck von Franckenau, then personal physician to the king, and the correspondent duly informed Leibniz. His eldest son, Georg Friedrich Franck von Franckenau, had carried out the post-mortem examination, Leibniz was told. It was found that several organs were duplicated, and these including the trachea or wind-pipe with outgrowths, the oesophagus or gullet, the stomach, with the small intestine extending to the middle of the ileus and terminating in an ample or spacious sac, the spine, the lungs and the ribs. The remaining organs were found singly, and these included the heart, the liver, the spleen, the kidneys, the adrenal glands, the urinary bladder, the uterus, the pancreas, the mesentery and the cunt. The body had two arms and two legs, all provided with nails. Finally, following the exenteration, and a public viewing by a large number of visitors at his residence, the remains were laid in a container filled with a fluid of florantibalsam (“spiritus balsamicus”), and then taken to the Royal Museum for preservation, Leibniz was informed.

Following the death of Leibniz’s correspondent and collaborator at the Court in Florence, Rudolf Christian von Bodenhausen, an autopsy was likewise carried out on the remains. Previously, on July 28, 1696, Bodenhausen himself had informed Leibniz about his insistence on self-treatment during illness and his reluctance to seek medical assistance in Italy. Bodenhausen’s reservations were centered on a perceived abuse of phlebotomy there. When his death ensued in May 1698, the corpse was duly dissected. The twenty eight year old

Swedish physician to-be, Magnus Gabriel Block, who assisted during the postmortem examination, availed of the opportunity to commence a correspondence with Leibniz, whom he informed, on May 12, 1698, about the passing three days earlier of his correspondent and collaborator, and about the cause of his death. The autopsy had shown that Bodenhausen died of an abscess of the liver in which, it was reported, four pounds of pus had been found.

Medicine – anatomy and physiology in particular – received a critical appraisal in the open letter (dated April 14, 1701) by Gakenholz addressed to Leibniz. In his *Epistola . . . de emendanda ac rite instituenda medicina*, Gakenholz complained that the subject was still in its infancy while other sciences, mathematics in particular, had been making great strides. He put the blame for this on a superstitious veneration for the ancients and wrong priorities in medical studies and training. He propagated an anatomy of fluids, and he pleaded for a reform of the system of anatomical, or postmortem, examination that should be guided by a particular understanding, namely that the body was to be viewed simply in the context of the vessels and organs. One ought, he maintained, to begin with the circulation of the blood, with particular interest being paid to the arteries, veins, and the heart chamber, to avoid incisions, and to pay attention to connectivity and interrelation. He himself had tested injections and re-injuries of vessels in corpses. Experimental infusions, as well as blood transfusions, could be undertaken with animals, he thought. Gakenholz emphasized the role of chemistry in medicine, and he insisted that physicians ought to study this subject in order to understand the processes in nature. At the same time, he criticized the excrescence of chemical pharmacy, which had produced a multitude of salts where, he reckoned, a single specimen might be sufficient. He recommended the study of plants with regard to their powers of healing, but he considered the established methods not to be very meaningful. Besides color, odor, taste and combustion or incineration properties, the reaction of plant sap with blood had been investigated in order to establish the effect on the human body. Gakenholz maintained that there were differences in the reactions with arterial and venous blood. Furthermore, the effectiveness of such a medicament, following intake and digestion, was not at all clear.

On April 23, 1701, Leibniz excused himself for entering solely into Gakenholz's further remarks on botany, being unable to contribute further to the discussion of medicine. He pointed out, however, his special interest in public health and he acclaimed his proposed project with Hoffmann – a project referred to above – for the collection and annual publication of meteorological-medical observational data.

In the same month, April 1701, there appeared a summary and review in German of Gakenholz's work in Leibniz's house journal *Monat*[*h*]*licher Auszug*. In this review the writer (perhaps Johann Georg Eckhart) outlined Gakenholz's criticism of the existing system of medical studies. There the reader learned that the core of medical studies, according to Gakenholz, should be anatomy, the science dealing with the structure of plants, animals and the human body, which was to be considered as a machine or automaton. The heart was the prime mover of the machine, and anatomy served the purpose of the meticulous study of the vessels emanating from the heart in their natural state. Thus, the circulation of the blood would be revealed and, for example, the passage of blood from the heart through the largest artery, the aorta, and then through the body to the kidneys illustrated. Furthermore, the reviewer reported that blood and other body fluids were the focus of the anatomy of fluids, and that here experimental science, and particularly chemistry, had a special role to play. Aspirants in the field of chemistry ought to be mainly concerned with the subject as revealed in the works of nature with, for example, the chemical reactions of life, and the seat of most illnesses, being found in body fluids

Pathology, Therapeutics, Pharmacology

Therapeutic and pharmaceutical topics were likewise not wanting in Leibniz's correspondence in the early 1680s. Regarding the spectacular application of cinchona bark, in particular by the English physician Sir Robert Talbot, Leibniz sought (in 1680) to obtain the opinions of the Royal Society and of the personal physicians at the court in Celle, namely Heinrich Christoph Ebell and Dietrich Conerding. Leibniz's question, about the appropriate use of antimony preparations, was answered in detail by Schrader in letters of August

14, 1681, and April 23, 1682, and Ferguson was able to inform him, in the spring of 1680, about a skin cosmetic, which Leibniz then designated as "Cosmeticum Fergusoni". In January 1681, Scheffer reported the use of sulfur as medication against cough and, on August 18, 1682, he reported that he had concocted an "antepilepticum" (an antiepileptic or epilepsy drug) from the hearts of frogs.

The age-old conflict between physicians and apothecaries also raised its head in Leibniz's correspondence in the early 1680s. Schelhammer complained, in the first half of September 1680, that he, as a medical professor, had to leave the production of medication to the apothecaries. In this dispute, Leibniz endorsed the standpoint of the physicians, as he informed Schelhammer in his reply on September 24.

The Chinese method of diagnosing diseases by pulse observation also aroused Leibniz's interest. In January, 1681, Scheffer answered a query from Leibniz, and he referred to a letter of November 20, 1679, which he had received from the botanist, and physician, Andreas Cleyer, which contained mussels from Jakarta and from which excerpts were later published (in 1685) in the *Miscellanea Curiosa*. Scheffer's letter contained a reference to "Clayers methodo" which involved the diagnosis of illnesses by means of pulse observations, and which was treated by Cleyer in his publications, entitled *Clavis medica ad Chinarum doctrinam de pulsibus* (1680), and *Specimen medicinae Sinicae, sive, Opuscula medica ad mentem sinensium, continens I. De pulsibus libros quatuor e sinico translatos. II. Tractatus de pulsibus ab erudito europaeo collectos* (1682), respectively.[119] In a subsequent letter to Leibniz, on August 18, 1682, Scheffer once again referred to his correspondence with Cleyer, and subsequently, extracts from a letter of December 20, 1683, sent by Cleyer from Malacca to Scheffer, were referred to in a letter to Leibniz of October 23, 1685, and were published in the *Miscellanea Curiosa* in the same year. In the final letter, of December 8, 1685, that Leibniz received from Scheffer – before the correspondent's death on January 20, 1686 – there is a final reference to Cleyer's contributions for the *Miscellanea Curiosa*.

[119] cf. L. L. Barnes, *Needles, herbs, gods, and ghosts*: *China, healing, and the west to 1848*, Cambridge (MA), London, 2005, in particular chap. 3, pp. 72-125 (Model state, medical men, and "mechanick principles": 1660-1736), and specifically pp. 73-75 (The reporters). Regarding Cleyer, cf. p. 75 and pp. 92-99 (Perfect knowledge of the pulse).

In Leibniz's correspondences with Friedrich Heyn and Christian Wachsmuth, in 1686 and 1687, a multiplicity of medicinal products are referred to. Besides medicaments like Peru balsam syrup, smelling salts ("Schlagbalsam"), sweet almond oil, white candied sugar, which Leibniz obtained from Wachsmuth, other products, like medication against dysentery and the pest, Armenian bole (referred to in Heyn's first letter of February 6, 1687) or white Armenian bole, also deserve mention. Herbal remedies too were popular like, for example, an emetic from America, which was referred to (in Heyn's letter of November 30, 1686, to Wachsmuth) as a "Planta aus America so vomitus ohne beschwerung macht". In a letter to Bodenhausen, on January 13, 1690, Leibniz tried to get information about a herbal remedy against podagra or gout. The Jesuit missionary Claudio Filippo Grimaldi had brought the plant in question from China, and it was then to be found in the garden of the grand duke in Florence. The correspondent Bodenhausen then reported, on January 28, that he too had been promised this "curam podagrae", and that he intended to investigate the Chinese plant in question. Several months later (on July 6), however, Leibniz had to remind the correspondent about the matter, requesting details once again of the "plantae chinensis Antipodagricae".

It was also Bodenhausen who, on September 16, 1690, drew Leibniz's attention to a panacea against chronic diseases, which was being claimed by Samuel Ledel from Görlitz, and which had been treated by him in the *Miscellanea Curiosa* in 1688. It was the subject of a note drafted by Leibniz, in connection with his reply to Bodenhausen of November 5, 1690. He had – he told the correspondent – in the meantime tried to obtain further details about this alleged universal remedy, specifically by asking Pratisius to write to a well-known physician in Görlitz on the matter. The fact that Leibniz, and his correspondents, were always interested in remedies and therapies can be seen from a passage in a letter of December 7, 1683, received from Tschirnhaus, in which a method for preventing and treating women's breast diseases was highlighted. Breastfeeding women were often found to have painful breast diseases and breast ulcers which, if not treated, might often lead to malignant diseases, like breast cancer. A common resort for such patients was a painful operation at the hands of a barber-surgeon,[120] which the correspondent now sought to replace with milder treatment methods.

Attached to a letter of December 16, 1695, which Leibniz sent to Ramazzini with collegial greetings to friends and acquaintances in Italy, was a copy of his tract about "Ipecacuanha" – a recently discovered medicinal plant from South America – entitled *Relatio ... de novo antidysenterico Americano* (1696). The healing effect of "Ipecacuanha" had previously been described by the Dutch physician and naturalist Willem Piso, in his opus entitled *Historia naturali Brasiliae … In qua non tantum plantae et animalia, sed et indigenarum morbi, ingenia et mores describuntur et iconibus supra quingentas illustrantur* (1648), but it had subsequently fallen into oblivion. Leibniz had learned about this plant for the first time from a letter of April 8, 1695, which he had received from Christophe Brosseau in Paris. Leibniz's *Relatio* was then conceived as a communication to the Academia Leopoldina. In addition, he arranged for the *Relatio* to be published as an appendix to Martin Lister's *Sex exercitationes medicinales de quibusdam morbis chronicis* (1696).[121] Leibniz also reported to Bodenhausen, in a letter of December 23, 1695, about the new "Antidysentericum Americanum". Besides being a remedy against dysentery, Leibniz envisioned further possible therapeutic applications against other diseases.

In addition to his letter to Bodenhausen, the issue of the new antidysentericum from America was likewise broached in Leibniz's correspondence with Johann Bernoulli in the first half of the year 1696. Thus, in the PS to a letter of February 7, Leibniz elaborated the circumstances of the rediscovery of the new "emetica sine violentia", and he requested information about similar emetics recently introduced in the Netherlands, like the "Cortex Peruviana" (also "Cortex Peruvianus") and "Herba Paraguay", and he expressed his desire that the intelligence be imparted to Johann's brother, the pharmacist Hieronymus Bernoulli. Thereupon Bernoulli made enquiries about the plant, and he conferred with, among others, the medical professor in Groningen, Theodorus van Essen, whereby the

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[120] cf. M. Fishbein, "The barber surgeons and the liberation of surgery", *Journal of the International College of Surgeons*, vol. 27, (1957), pp. 766-779; J. E. McCallum, *Military medicine*: *From ancient times to the 21st century*, Santa Barbara, Denver, Oxford, 2008; regarding barber surgeons cf. pp. 36f.

[121] cf. A. M. Roos, *Web of nature*: *Martin Lister (1639-1712), the first arachnologist*, (Series: *Medieval and early modern philosophy and science*, vol. 16), Leiden, 2011, in particular part 4, chap. XIII, pp. 335-374 (Publication and prestige: The *sex exercitationes medicinales* and the Royal College of Physicians).

two medicinal plants from South America – the “Herba Paraguay” and the “Cortex Peruvianus” – were also considered and referred to in the PS to Bernoulli’s letter of March 3 to Leibniz. A little later, on March 13, Bernoulli then forwarded to Leibniz the report of a renowned apothecary from Amsterdam about “Ipecacuanha” and further medicinal plants.

Leibniz reacted to this, on the March 18, by forwarding a copy of his *Relatio*, as well as a set of notes about medicinal cortices or barks. Furthermore, he enquired about possible sources of supply, and about the usage of “Ipecacuanha” in the Netherlands. Cinchona, or Peruvian bark, was obtainable in Hanover even though not of best quality, he told the correspondent. And he even placed an immediate order for a supply of the Peruvian bark, and added a query about the “Herba Paraguay”. This order Bernoulli was able to fulfill a month later, on April 17. As for “Ipecacuanha”, Leibniz was informed about suppliers and purchase price in Amsterdam. As regards this medicinal plant, as well as the “Herba Paraguay”, Bournoulli could announce that he had obtained supplies for Leibniz, but he still wanted to obtain additional information elsewhere about the application and use. Information from van Essen concerning dosage, and the shortfall, of the “Herba Paraguay” as an effective nauseant, or emetic, was also communicated to Leibniz. Finally, on May 25, 1696, Leibniz dealt with this ineffectiveness of the “Herba Paraguay”, and he addressed in this context the broader issue of adulteration of medication or medicinal remedies.

Leibniz’s involvement in a discussion of pharmacology, and pharmacological advances, was surely derived only in part from an academic interest in advances in medical science. His commitment was likewise influenced by his own health and therapy requirements and, in fact, in the years 1693 to 1695 he was often indisposed. Thus, for example, he wrote on May 12, 1693 to Otto Grote, the Chamber president in Hanover, about a feeling he had of health deterioration. Thus, a subjectively-felt pressure of work, or overwork, in connection with the history project in particular may have contributed to his illness pattern – with possible psychovegetative disorders *viz*. physical or vegetative dysfunctions on the basis of a neurotic or high-strung development – at this juncture.[122] On October 24, 1694, we find him

[122] cf. E. Görlich, *Leibniz als Mensch und Kranker*, Doctoral dissertation, Hanover: Medical faculty

enquiring in the PS to a letter to Johannes Teyler about “une Herbe des Indes qui fait vomir sans effort”, about which Robert Boyle had once informed him, and which he thought might be similar to one then obtainable in Amsterdam. Likewise, in a no longer extant letter to Bodenhausen, Leibniz had complained about health problems. And so, in his reply of November 17, 1694, the correspondent commented and attributed Leibniz’s indisposition to a lifetime of overwork. He recommended that Leibniz rest himself, observe a diet, and get more exercise. Likewise, in Bodenhausen’s letter of May 26, 1695, we find the correspondent assuming that Leibniz was suffering from a biliousness that was revealed though external inflammation (phlogosis), painful urination, and in the effects of medical drinks. In fact, he saw part of Leibniz’s problem in the medication he had taken, like lemon juice, and he recommended instead mild acids in fruit drinks (“acida … welche nicht zu starck agiren”). Bodenhausen recalled a well-known case he was familiar with, in which drops of vitriol had been successfully employed against an infectious dysentery epidemic in Italy, and he recommended among other things the intake of this remedy about which he informed Leibniz. Considering Leibniz’s symptoms, Bodenhausen recommended, furthermore, that he take a vitriolic emetic under the supervision of a physician, and he described the mode of operation of the emetic, but he advised caution at the same time. Above all, Leibniz should not delay the treatment and he ought to avoid every form of exertion, he was told. Leibniz’s reaction to Bodenhausen’s proposals is to be found in his letter of June 24, 1695. As far as the acidic and vitriolic remedies were concerned, he was not averse to trying them out. As regards the application of an emetic or vomitive, as suggested by Bodenhausen, he hesitated and wanted to think the matter over first. All in all, Leibniz enjoyed good health for most of his life but, in his last twenty years and at the end of his life in particular, he suffered from lower limb, or foot ulceration (‘ulcus cruris’), as well as articular or joint trouble like gout,[123] the consequences of which probably ultimately led to his death in 1716.[124]

(*Medizinische Hochschule*), 1987; regarding Leibniz’s psychovegetative complex of complaints around the year 1695, see pp.110ff.

[123] [= note 219] cf. E. Görlich (note 122 [= note 218]), pp. 118-120 (Das Ulcus cruris-Leiden), pp. 162-166 (Die Therapie der Ulcera cruris), pp. 120-126 (Die Gelenkbeschwerden) and pp. 166-177 (Die Therapie der Gelenkbeschwerden).

[124] cf. also pp. 199-221 (Leibnizens letzte Krankheit-Tod und Begräbnis).

Leibniz also regularly received reports about the health problems and conditions of his correspondents, or indeed queries regarding medication and medicinal products as, for example, on April 16, 1696, from Johann Sebastian Haes regarding “la teinture aperitive du D^{r} [Gottfried] Moebius et spiritum Martis volatile striatum, du D^{r} [Friedrich] Hoffman [senior]”. Johann Daniel Crafft complained again and again about his gout pains, and he sought the right medication to relieve his suffering as, for example, on September 20, 1694, when he referred to two letters of Christoph Fahrner, written to Jonas Zipffell and published in Zipffell’s work *Podagrischer Triumph* (1659).

Just like gout, which was known as the ‘Patrician Malady’,[125] the topic of phlebotomy, or bloodletting, arose again and again in Leibniz’s correspondence as, for example, in Bodenhausen’s letter of July 28, 1696. In his letter of May 1698 to Franck von Franckenau, Leibniz told that he had received a work hostile to bloodletting, written by Dominico La Scala and entitled *Phlebotomia Damnata* (1696). Leibniz himself, however, favored the moderate application of bloodletting, the value of which was evident from application with animals, he told the correspondent. In his letter to Block, on July 30, 1698, Leibniz justified his standpoint with the following argument: bloodletting might work in the same way that arsenic could act as an antipyretic. Thus, nature reacts to the artificially-produced health threat and reverses the path previously taken. In these letters to Franck von Franckenau and Block, from the summer of 1698, Leibniz referred to the positive effects of the method in treating animals. Block, in his letter of October 30, agreed with Leibniz, and he wrote that with fever, blood heat, unconsciousness or disturbance of consciousness, or with blood congestion in the lungs or heart, bloodletting could indeed be applied. Bloodletting was, however, the last resort of the Galenists and, in France, Spain and Italy, there was an enormous abuse of the method in evidence. Finally, the fact that Leibniz was fully aware of this abuse is evident from his letter to Ramazzini of April 22, 1699, in which he once again referred to La Scala’s opus, and requested the correspondent’s judgement on the issue.

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[125] cf. for example, W. S. C. Copeman, *A short history of the gout and the rheumatic diseases*, Berkeley, Los Angeles, 1964; D. P. Mertz, *Geschichte der Gicht*: *Kultur- und medizinhistorische Betrachtungen*, Stuttgart, New York, 1990; R. Porter, G. S. Rousseau, *Gout*: *The patrician malady*, New Haven, London, 1998.

By 1699, accounts of autopsies had long been a source of information for Leibniz in the field of anatomy. The post-mortem examination of corpses was important, however, not only for obtaining new anatomical knowledge, but it also served for the development of examination and treatment methods for physicians, and even for obtaining medicaments and medicinal or pharmaceutical products. In this context then, Leibniz came into contact with medical cannibalism that was then in widespread use.[126] Thus, on October 30, 1699, he requested information from Papin about the so-called "king's drops", which he had learned about from a traveler, namely an unnamed English musician, who had been to Muscovy and had shortly before come from Kassel. He related that the Electress Sophie, at the court in Hanover, had also heard wonderful, or miracle-like, stories about this medicament. The basis of these drops was a recipe for the liquefaction of material taken from the inside of human skulls, often from executed prisoners. The distillate has found a place in the history of medicine under the name 'Goddard's drops' – after the discoverer Jonathan Goddard – or otherwise as "king's drops" after the Stuart king Charles II, who carried out such distillations in his private laboratory. Whether or not Leibniz knew what kind of medicament was involved is not clear. At all events, Papin's response, on December 3, 1699, was short and decidedly skeptical about what he termed "ces sortes de remedes".

Also the remedy "mumia" – a substance obtained from pulverized Egyptian mummies – is referred to in Leibniz's correspondence. Wagner related, on March 15, 1701, that he had, as a result of clumsiness, suffered a breast injury and then obtained, as a remedy from the apothecary, the following substances: crab's eyes, dragon's blood, prepared mumia, prepared native cinnabar and diaphoretic antimony.

A note which the surgeon Jacques Bouquet handed to Leibniz, on August 5, 1701, provides an example of the use of parts of corpses for therapeutic purposes. A woman from the French émigré community, then living in the town of Hameln, had in the past suffered from a wart, or a swelling, on her hand over a period of time. After a variety of plasters had proved useless, it was recommended

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[126] cf. R. Sugg, *Mummies, cannibals and vampires*: *The history of corpse medicine from the Renaissance to the Victorians*, London, New York, 2011, and in particular chap. 2, chap. 8 and the conclusion.

that she rub the swelling, or growth, with the fingers or hand of a corpse, where the person had died following a lengthy illness. Some years earlier, while resident in Hamburg, a neighbor of a general, whom she had served there as a governess, died. This first opportunity for her to test the proposed treatment method proved unsuccessful. Later, however, the general himself died, and she tried the procedure again of rubbing the swelling with the hand of the corpse and was on this occasion – according to the note Leibniz received – permanently cured in a short time.

Both in the use of medicaments derived from human remains (such as the “king’s drops”), and in the application of corresponding therapies (like in Bouquet’s communication), the death struggle and the mortal agony of the deceased was an essential aspect of the presumed medicinal benefit. The agonal state of tortured and executed prisoners, of soldiers in their death throes on the battlefield, or of long-suffering patients could lead to the production of substances having curative, or immunizing, effects, and which might serve as ingredients for medication. The prevailing positive attitudes towards phlebotomy, or bloodletting, were perhaps akin to those relating to medical cannibalism. Thus, bloodletting might contribute to improved defense mechanisms of the body under attack.

Leibniz received regular reports from Wagner, who also worked as a physician, concerning both his own ailments, as well as illnesses he was confronted with, and the therapies which were applied. In the spring and summer of 1701, Wagner reported about a female patient of his, from the town of Halberstadt, who had a swelling or tumor on the cheek, and which he illustrated in a drawing. He was able to provide relief at first and the swelling declined. However, an accident, or mishap, had led to an undermining of the recovery process, according to the correspondent.

In 1699 and 1700, several university professors at Helmstedt died in quick succession, whereas others suffered from chronic illnesses. Thus, Wagner reported, on April 21, 1699, to Leibniz about the recurring hemorrhages experienced by Johann Andreas Schmidt, a hemophiliac who had to observe a strict diet. A little later, Wagner assisted the medical professors Heinrich Meibom and Friedrich Schrader in the treatment of a fourteen year old, who complained about hoarseness, coughing, intense headache as well as the accompanying fear of asphyxia. On May 5, 1699, Wagner elaborated for Leibniz his explanation of the course of the disease, and he explained that an opening of the temporal artery had brought little relief. Then, on May 16, Leibniz recalled, in this context, a new treatment method for headache involving the opening of the temporal artery, and about which he had been previously informed by Johann Gebhard Rabener.

Then, on March 23, 1700, Wagner reported that Meibom himself had been infected with a pleurisy, through contact with the vice rector of the university, Christoph Tobias Wideburg, whom he had treated. Bloodletting proved to be of no avail on this occasion, and three days later, on March 26, Wagner reported the passing of Meibom on that day, and he elaborated in detail the course of the illness that had led to the professor's demise. Just two weeks later, Ilse Stisser (née Petersen), the wife of Johann Andreas Stisser, died in childbirth (on April 8) leaving her distressed husband with six children. Stisser himself then suffered a collapse, resulting from grief and exhaustion, as Wagner reported to Leibniz on April 10. Furthermore, Wagner reported, on this occasion, that another colleague, Caspar Cörber, the professor of eloquence, had fever and that his sallow complexion was frightening. Cörber survived just a week with this condition. That the news of the death of Stisser himself, on April 21, devastated the correspondent is hardly surprising. Wagner too had been suffering from headache and lassitude, a condition which was then aggravated by hot flushes and states of anxiety. The narrative of his short but intense illness, accompanied also by a fear of dying, was related by Wagner to Leibniz in great detail, as soon as he began to feel better a few days later, namely on April 27. Recovery, he reported, had come following consumption of large quantities of medicinal beer made from Scorzonera, or "Schwarzwurzeln".

The study of diseases was a particular interest of Leibniz's internationally most renowned correspondent in the field of medicine, namely Bernardino Ramazzini. His teaching assignment for theoretical medicine included the area of occupational or industrial medicine.[127] In the course of his investigation of the water springs of

[127] cf. for example, J. S. Felton, "The heritage of Bernardino Ramazzini", *Occupational Medicine*, vol. 47(3), (1997), pp. 167-79; R. B. Añón, "Medical biographies and their historical significance: The figure and the work of Bernardino Ramazzini (1633-1714)", *Medicina y Seguridad del Trabajo*, (*Special issue* / *Suplemento*

Modena, Ramazzini also investigated the working conditions of laborers in the well pits and shafts, and about which he reported to Leibniz on May 4, 1691. He did not hesitate to descend himself into the shafts in order not to have to rely on accounts of others. The knowledge gained in the course of these investigations is to be found in the surely most important, and most renowned, work of Ramazzini that, however, was only to appear almost a decade later, namely his tract on the diseases of workers and tradesmen with the title *De morbis artificum diatriba* (1700).[128] In replying to Leibniz's letter of April 22, 1699, Ramazzini announced, on February 24, 1700, his forthcoming tract about the diseases of workers with the words "Tractatum meum *de morbis Artificum* inter caeteras meas nugas abjeceram". Leibniz for his part, in his letter of March 18 to Ramazzini, referred to works on the ailments of miners and pitmen by Georg Agricola, who himself had been a representative of the medical profession ("qui ipse erat Medicus reique metallariae scientissimus"), and above all by the physician Samuel Stockhausen, from Goslar in the Harz mining district, who had published a work entitled *Libellus de lithargyrii fumo noxio morbifico* (1656). The latter had described the lung diseases that occurred among miners, namely the pulmonary disease "Bergsucht", or occupational lung cancer,[129] – later to be called "Schneeberg disease" – and the pulmonary phthisis, or consumption, known as "Hüttenkatze".

Stisser's open letter, of February-March 1700, addressed to Leibniz – *De variis erroribus, chemiae ignorantia in medicina commissis dissertatio epistolaris* (1700) – was a passionate plea for a pronounced inclusion of chemistry in medicine, and in the study of medicine. To those who professed to be enemies to chemistry – whom he characterized as "misochemists" – he pointed out the omnipresence

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extraordinario, no. 2), (2014), pp. 34-41; G. Franco, *Meglio prevenire che curare - Il pensiero di Bernardino Ramazzini, medico sociale e scienziato visionario*, 2015 (eBook).

[128] cf. B. Ramazzini, *De morbis artificum diatriba*, Modena, 1700; B. Ramazzini, [E.] W. C. Wright (ed., trans.), *De morbis artificum diatriba*: *Diseases of workers … The Latin text of 1713, revised with translation and notes*, (*History of Medicine series*), Chicago, 1940; B. Ramazzini, [E.] W. C. Wright (ed., trans.), G. Rosen (Introduction), *Diseases of workers. Translated from the Latin text De morbis artificium of 1713*, (*New York Academy of Medicine, History of Medicine series*, no. 23), New York, London, [c. 1964]; P. Di Pietro, "Le fonti bibliografiche nella « de morbis artificum diatriba » di Bernardino Ramazzini", *History and Philosophy of the Life Sciences*, vol. 3(1), (1981), pp. 95-114; A. Gils, *Bernardino Ramazzini (1633-1714)*: *Leben und Werk, unter besonderer Berücksichtigung der Schrift "Über die Krankheiten der Künstler und Handwerker"* (*De morbis artificum diatriba*), Doctoral dissertation, Göttingen (Universität Göttingen), 1994.

[129] cf. P. D. Blanc, "Historical perspective of occupational and environmental lung disease", chap. 1 (pp. 1-26), in: Y.-C. T. Huang, A. J. Ghio, L. A. Maier (eds.), *A clinical guide to occupational and environmental lung diseases*, New York, Heidelberg, Dordrecht, London, 2012, in particular pp. 6-8 (1500-1750).

of the subject. Foodstuffs, like bread, beer or wine, were prepared with the help of chemical processes, just as with the pretended non-chemical medicaments. His argumentation was founded, on the one hand, on Hippocrates and numerous other deceased and living authorities and, on the other hand, on case studies in which wrongly prepared medication had brought about undesired reactions.

Leibniz – in his last letter to Stisser (probably) of April 25, 1700 – complained about the enormous multiplicity of pharmaceutical products, but he was otherwise in agreement with the correspondent. To abstain from using chemical medicaments, would be tantamount to forgoing great advantages of the natural world. More effective medication against illnesses, that affected the body fluids, could, in Leibniz's opinion, be found, either simply by accident or as a result of advances in chemistry.

Epidemiology, Demography

Pestilence and epidemics featured strongly in Leibniz's correspondence in the early 1680s. At the end of 1679 the plague afflicted Vienna and spread in the following years via Prague and Leipzig, without however reaching the territories of the principalities of Brundswick and Lüneburg. On May 24, 1680, the physician Crafft wrote that Leibniz should not put off a planned journey to Dresden, and that the rumors circulating about the plague there were false, and possibly even fabricated by surgeons to advance their own financial interests. Leibniz lingered in Saxony in the first half of July 1680. That the pestilence began spreading there at this time is evident, not only from the relief of Christof Pratisius, expressed in his letter of July 20, following Leibniz's return, but also from Crafft's communication of August 6 telling of the spread of the contagion in recent weeks. The plague had, we learn from Crafft's letter of early September, spread almost exclusively among the common people, and there had been scarcely any cases recorded among people who had taken precautions, and been able to care for themselves and their kin.

The outbreak of the plague restricted considerably the movement of travelers within Leibniz's ken at this juncture. Crafft was unable to travel to Berlin from Dresden, as he informed Leibniz on April 4, 1681. Likewise, Christoph Pfautz and Otto Mencke, who were preparing the launch of their journal *Acta Eruditorum* with a journey to the Netherlands, and to England, beginning in at the end of May or early June 1680, had, on their return journey to Leipzig, to linger for some months in the town of Oldenburg, from where Pfautz informed Leibniz on January 18, 1681. Leibniz developed ideas not only for health care policy decisions to combat the spread of the plague – for example his "Vorschläge gegen die Pest" (1681?), addressed to duke Ernst August, and involving the closure of borders – but he also pursued medical deliberations on the matter. In a letter, from the end of September 1680, to Crafft, there is a reference to a "Medicina infusoria" which he thought might be a most efficacious remedy against the pestilence, since he was convinced that the malady resided especially in the body's humors, and above all in the blood. Leibniz concluded his considerations regarding the plague by calling on Crafft to use his good rapport to the Saxon vice chancellor, Johann David von Oppel, to thoroughly investigate the cause of the pestilence and, in particular, the changes in the blood of those afflicted by the malady. Other less formidable suggestions included that of the resident diplomat of the Elector of Mainz in Vienna, Johann Christoph Gedenus, who proposed onions as an amulet against the plague, and which was communicated at the end of a letter to Crafft of August 25, 1680, and then forwarded to Leibniz in early September.

In the field of medicine Bernardino Ramazzini emerged as Leibniz's most important correspondent during and following his Italian journey. In the course of their conversations in Modena, between late December 1689 and early February 1690, Leibniz encouraged Ramazzini to intensify his observations, not only in the medical field but also in areas of science and technology, and to work towards their publication. These efforts soon began to bear fruit when, already in 1690, Ramazzini published his first epidemiological work. At short intervals there then appeared several further works which were to make Ramazzini known far beyond the borders and shores of Italy, especially in the fields of epidemiology and occupational, or industrial, medicine. Leibniz actively supported the dissemination of Ramazzini's writings and significantly contributed to his success, and fame, north of the Alps.

Through the use of the thermometer, barometer and hygrometer, it became possible, at the end of the seventeenth century, to establish a relationship between illnesses, or diseases, and the prevailing weather conditions. In addition, statistical investigations were gaining a foothold in medicine. Accordingly, mortality, morbidity and population development could be quantitatively recorded for the first time. Demography, or the statistical study of population, contributed in turn to progress in medicine. Increasingly, prevention became a principal task for the physician. The causes of diseases were sought and found in almost all areas that affected the lives of people as, for example, in weather and occupational conditions, and in the living environment. Parallel to general preventative measures, physicians began to pay particular attention to the causes, and circumstances, of the occurrence of epidemics. This then was the general background to Ramazzini's achievements in medicine.

In the history of epidemiology in the seventeenth century, Ramazzini stands out following in the footsteps of the English physician Thomas Sydenham (1624-1689). He emerged, like Sydenham, as an epidemiologist of the Hippocratic ilk. Sydenham, who coined the concept and term "Constitutio" – *viz*. the epidemic constitution of a year or season – was the first to strive for the annual publication of such "constitutiones epidemicae".[130] Ramazzini continued these efforts, and he published "Constitutiones" for the years 1690 to 1694, which appeared in three installments. The epidemic constitutions *De constitutione anni 1690 ac de rurali epidemia, quae Mutinensi agri et vicinarum regionum colonos graviter afflixit, dissertatio* (1690) and *De constitutione anni 1691* (1692) – which were dedicated to Antonio Magliabecchi and Leibniz, respectively – appeared separately, whereas those for the years 1692 to 1694 were published together, as *De constitutionibus annorum M.DC.XCII., XCIII., et XCIV., in Mutinensi civitate, et illius ditione, dissertatio* (1695). All five annual constitutions finally appeared in a single collection, almost twenty years, later as *Constitutionum epidemicarum Mutinensium annorum quinque* (1714).

In these works, Ramazzini described all epidemic diseases that had occurred in the region around Modena in the respective year. They contained exact information, and data, about symptoms and the progression of diseases, about applied therapeutics, and about

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[130] Regarding Sydenham's study of London epidemics and his textbook *Observationes Medicae* (1676), cf. K. Dewhurst, *Dr. Thomas Sydenham (1624-1689)*: *His life and original writings*, London, 1966, and Oakland, CA, 2021, in particular, pp. 30-59 (The Physician) and pp. 71-78 (Sydenham's Original Writings).

assessments of their effectiveness. Ramazzini also analyzed the weather, in the respective years, with regard to possible weather and climatic influences on the occurrence of diseases. He even took account of the welfare of useful, or crop, plants like wheat or vine, as well as of the health of farm animals and livestock. He observed which sections of the population, and in what manner, were affected by a particular epidemic, and he tried to find an appropriate explanation. In the Emilia-Romagna region of northern Italy, there occurred, in the years 1690 to 1694, in particular malaria and typhoid epidemics. Thus, the extreme precipitation in the year 1690, that caused flooding along the Po tributaries – as Ramazzini reported to Leibniz on April 15, 1690 – led to a malaria epidemic, which primarily affected the rural population. In his epidemic constitution for the year in question, Ramazzini described the course of this epidemic in detail in relation to the individual seasons. He also described attending ills, like cereal or wheat rust, and animal diseases. The following year (1691) was in contrast dry and warm. On that occasion, the malaria epidemic primarily affected the poorer urban population, whereas the rural population largely escaped the contagion. In the years 1692 to 1694, notwithstanding very different weather and climatic circumstances, typhoid afflictions dominated Ramazzini's attention. He held the view that the transmission of these infectious diseases occurred through the air, and that the south wind had brought the pestilence from Africa to Italy. An obvious source of danger, arising from the deployment of troops in war time in the region, was, on the other hand, seen as innocuous by Ramazzini.

Like many important physicians of the time, Ramazzini belonged to the iatrochemists (or chemical physicians), so that the diagnostic and therapeutic teachings of the chemiatric school are reflected in his works. Thus, the aetiological theories, and the therapeutic strategies he proposed, show his acquaintance with the iatrochemistry of the seventeenth, and early eighteenth, centuries.[131] Since his "Constitutiones" were very successful, and seminal, in the area of epidemiology, Leibniz was able to persuade Johann Georg Volckamer – the president of the Academia Leopoldina – to reprint Ramazzini's report for the year 1690 as an appendix to the

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[131] cf. B. Cavarra, "Filosofia e scienze nell'opera di Bernardino Ramazzini, Medicina nei secoli arte e scienza", *Giornale di Storia della Medicina, Nuova Serie* (*Journal of History of Medicine, New Series*), vol. 23(2), (2011), pp. 411-423.

Miscellanea Curiosa for the year 1691. The second installment of the "Constitutiones" likewise appeared in the *Miscellanea Curiosa*, and these publications helped make Ramazzini well-known north of the Alps. Again on Leibniz's recommendation, the Leopoldina accepted Ramazzini as its 201st member in November 1693. Leibniz considered Ramazzini's epidemiological works to be particularly important, and he repeatedly recommended them to familiar and well-established physicians, suggesting that they write similar works for other regions and time intervals. A case in point here was Leibniz's letter to Paul Pellisson-Fontanier of December 1, 1692.

In Leibniz's correspondence in the early 1690s, several instances of Ramazzini's epidemiological considerations are to be found. In the accompanying letter, of May 4, 1691, to the consignment of his *De constitutione anni 1690 ac de rurali epidemia*, Ramazzini described the plight of the "Modenese" region at that time. The economic decline, as a consequence of the climatic and epidemic situation in the previous two years, had been aggravated by the threat of war and a possible French intervention. Thus, these three afflictions were referred to in this letter, or to quote the correspondent: "sic jam nobis triplex flagellum imminet". The difficulties and shortages, that had arisen in the provision supply of the Italian and allied Bavarian troops deployed near Modena, were sketched by Ramazzini in a later letter of March 30, 1692. He also suspected a connection between the shortages and epidemics of those years, on the one hand, and phenomena like malformation and mortality of infants, on the other hand. Here, anatomical, physiological, pathological and demographic aspects were combined in Ramazzini's considerations. Specifically, he related the details of a case where a German woman at a camp at Spilamberto, located near Sassuolo (south of Modena), had given birth to stillborn deformed female twins, who were conjoined at their breasts and abdomens, but were otherwise of normal proportions. The remains of the stillborn twins were presented to the ducal authorities in Modena where a post-mortem examination was carried out. Ramazzini explained that the pathologist, who dissected the remains, discovered that the twins had but a single, or shared, heart, a single stomach, and a single liver. Otherwise each individual had its own intestines and internal organs, including a bladder, kidneys, spleen, etc. Finally, the remains were handed over to Ramazzini himself for anointment and conservation among other cimelia. And, he added that he had learned of the ominous occurrence of a similar monstrous birth in Bologna and, finally, he posed a rhetorical question as to what the sum of these occurrences did in fact portend.

Ramazzini was aware of the important role that Leibniz had to play in his scientific life. His esteem for Leibniz was reflected not only in the dedication of his work *De constitutione anni 1691 apud Mutinenses*, but also in his accompanying letter of March 30, 1692. That the reprint of Ramazzini’s *De constitutione anni 1690* in the *Miscellanea curiosa* resulted from a suggestion of Leibniz is evident from the fact that, when he revived his correspondence with Johann Georg Volckamer, on July 26, 1691, this was his principal concern. Already in the years 1681 and 1682, Leibniz had carried on a correspondence with Volckamer in which ideas were exchanged about corresponding terrestrial magnetic observations. And, during his sojourn in Nuremberg (from December 31, 1687 to January 6, 1688) at the outset of his Italian journey, he and the correspondent had met, as is evident from the opening words of his letter to Volckamer from the summer of 1691. In this letter, Leibniz presented his principal request to the president of the Academia Naturae Curiosorum, or Academia Leopoldina. First, he told of his meeting with the learned Ramazzini in Modena, and of his exhortations that the Italian commit his results to print. Then he explained how he had recently received Ramazzini’s *De constitutione anni 1690*, a work which he prized so much. And, above all, as he explained, Ramazzini had committed to continuing his medical ephemerides in the future.

Leibniz hoped that the Academia Leopoldina might follow the Italian example and he emphatically pointed out the importance, and necessity, of collecting medical statistics in Germany also. The Leopoldina should use its influence to promote such undertakings and to collect the results of such inquiries from all over the empire. On November 2, 1691, Leibniz thanked Volckamer for reprinting Ramazzini’s *De constitutione anni 1690*, expressing the hope that, through Volckamer’s influence, similar undertakings might be successful in Germany. An exemplary case that Leibniz was able to announce involved the personal physician of the elector Ernst August in Hanover, Christoph Pratisius, who had promised to publish medical observations soon.

A further topic from the field of epidemiology, which occupied both Leibniz and Volckamer, was the medical treatment of dysentery. On January 15, 1691, Henri Justel had reported from London about the mysterious plant root called Ipecacuanha, mentioned above, that had been used in France as a remedy in the treatment of dysentery. Leibniz, in turn, informed Volckamer about this on August 25, 1691. Since the root in question had found use as a medicament with the French army, Leibniz hoped that this rhubarb-like plant might soon be employed by the allied forces also. Volckamer was pleased about the intelligence regarding the new remedy and recommended, for his part, the treatment of dysentery with vegetable, or herbal, remedies like sorrel, or common or garden sorrel, the recipe for which he was happy to communicate to Leibniz.

Throughout the 1690s, Leibniz continued to regularly receive communications from correspondents regarding the plague and other epidemics as, for example, on March 29, 1695, from Augustinus Vagetius in Wittenberg, who referred to the crawling expansion of the plague and epidemic disease throughout Germany. In the field of epidemiology, however, Bernardino Ramazzini remained his most important correspondent, although the direct correspondence between the two was very much in abeyance in the mid 1690s. In the years that followed the publication of Ramazzini's *Constitutiones epidemicae* for the years 1690 to 1694, Leibniz repeatedly recommended to physicians he knew that they carry out, and publish, similar medical compilations for other regions. At the beginning of 1694, on January 6, he sent such a request to the renowned physician Georg Franck von Franckenau in Wittenberg, lauding Ramazzini's achievements at the outset of his appeal. As things transpired, Franck von Franckenau was certainly prepared to support this call, and to pass it on to medical colleagues in Wittenberg, Dresden, Torgau, Leipzig, Zerbst, Halle, Magdeburg and Berlin, as is evident from his reply almost half a year later, on June 22, 1694. For his own part, however, Franck von Franckenau failed to provide a compilation of the type envisioned, not least perhaps for the reason that he would soon become personal physician to the Danish king, Christian V, in Copenhagen.

The project for the annual publication of medical-meteorological observations pursued by Leibniz and Hoffmann, under the aegis of the Berlin Society of Sciences, referred to above, was of course inspired above all by the ephemerides which Ramazzini had published for the years from 1690 to 1694 and in which he described the epidemic outbreaks that had occurred around Modena in those years. The publications for the years 1695 and 1696 failed to appear which motivated Leibniz to enquire about the continuation of the series, in his letter of April 22, 1699. Replying, on February 24, 1700, Ramazzini justified the interruption on the grounds that the data collection had proved cumbersome for physicians, not least due to the lack of remuneration, but also because there had been no new notable epidemic occurrences in the meantime. In a previous letter, on June 17, 1699, Ramazzini had announced the republication of his collected ephemerides in a single volume which of course only appeared in 1714. Leibniz also advocated data collection even in times when there were no special occurrences. At least one would then know that no change had taken place, he wrote in his letter to Ramazzini of March 18, 1700.

The Medical Profession, Mathematization, Rationalization

The medical profession, including studies and qualification, was of special interest to Leibniz. On two occasions in the early 1680s, the actions of academically unqualified physicians were graphically described in Leibniz's correspondence. On the first such occasion, an individual named Scradetzky had apparently found a cure for gout, and seemed to have worked miracles in Berlin, even curing the elector himself, according to the account of May 7, 1682, that Leibniz received from Crafft. As a reward, the individual in question was granted the right to import wines tariff-free, as Elers reported to Leibniz on August 22, 1682. A similar case involved the vicissitudes experienced by another charlatan, a Roman whose departure from several courts Scheffer characterized (on August 18, 1682) as malodorous. Statements of Leibniz regarding an amulet – which had been presented to the elector of Brandenburg and was referred to by Elers, on August 22, 1682 – against pain caused by stone (kidney, ureter and urinary stone), or indeed regarding the question posed by Schrader, on December 8, 1681, concerning the age-old issue of the influence of the moon on the body humors, have not been found. The blacksmith's laborer, who claimed to be able to diagnose all diseases by urine observation, as reported by Scheffer, on May 23, 1682, was at all events not taken seriously by Leibniz.

Two years before embarking on his grand tour of Austria and Italy, Leibniz received a damming report, sent by Pratisius from Venice on October 26, 1685, about the situation there with regard to medical practice and practitioners. Similar sentiments were expressed regarding the pharmaceutical system, and about the methods of treatment there. Leibniz's Italian journey then provided him with a welcome opportunity for oral discourse on medical subjects with Italian physicians and scientists. Whereas, in Leibniz's exchange of ideas with Ramazzini while in Modena, matters of engineering and technology were predominant, he was particularly impressed in the case of other 'medici' by their mathematical abilities. Thus he wrote to Huygens, on July 25, 1690, about his meetings with Domenico Guglielmini and Francesco Spoleti, who referred to as "tous deux bons Mathematiciens" and "deux Medecins, bien versés dans les Mathematiques". In this context, Leibniz advocated treating medicine as an exact science and he pleaded for its mathematization. Thus, in a letter from Venice sent to Francesco Bianchini, on March 18, 1690, he referred to his high expectations for Spoleti, and he recalled having exhorted him "ut mathematicum in re medica agat, quoad ejus fieri potest". Leibniz's vision of medicine rooted in calculus – essentially an appropriate and precise form of expression in the process of reasoning or in the application of rational thought – was even more pronounced in another letter, sent to Bodenhausen from Venice, on February 20, 1690, which provides the leading quotation for this section on medicine.

Leibniz's deliberations on the medical profession, on medical progress, on medicine as an empirical science, and on the application of mathematics in medicine were topics that continued to be discussed in his correspondence in the 1690s. Thus, he wrote to Huygens on June 22, 1694, that medicine had hitherto been a purely empirical science. Empiricism in itself was no bad thing, he thought, but, since medicine had become a profession, its practitioners were often more concerned with saving appearances. Leibniz even envisaged a religious order of friars, like the Capuchins, embracing medicine as a charitable endeavor. Huygens, in his letter of August 24, signaled his assent to Leibniz's perceptions, but did not enter further into a discussion of them.

The mathematician Johann Bernoulli, who had studied medicine and was author of two works entitled *Dissertatio chymico-physica de effervescentia et fermanttatione* (1690) and *Dissertatio inauguralis physico-anatomica de motu musculorum* (1694), was admonished by Leibniz on July 4, 1694 – particularly with reference to the latter dissertation on the movement of muscles – to continue and maintain his commitment to medicine. More than a year later, Leibniz referred to this proposal again in a letter to Johann's brother, Jacob Bernoulli, on December 12, 1695. In his reply, on March 14, 1696, Jacob then emphasized, in particular, the possibilities and the benefits of applying mathematics in medicine, citing his brother's *Dissertatio ... de motu musculorum* as an example.

Considerations by Leibniz regarding the medical profession, advances in the medical field, and medicine as an empirical or rational science, were continuing themes in his correspondence in the late 1690s. After Block had explained, in a long letter of July 1, 1698, why – following studies in history, law and theology – he had opted for the medical profession, Leibniz, in his reply of July 30, welcomed the decision and expressed the view that medicine had previously been primarily an empirical science, and that most of the theories and hypotheses in the field were hardly reliable or useful. For that reason, it was also the desire of the renowned physician, Heinrich Meibom, that the discipline be established on an empirical foundation. Nonetheless, Leibniz himself welcomed the conjectures of competent physicians.

Writing on October 30, 1698, from Stralsund on his journey home to Sweden, Block, for his part, also desired "istitutioni di Medicina", which would not be speculative, or concerned with occult speculation, but rooted rather in empiricism. He had his doubts, however, that medicine could be built up solely on the foundation of experience. He compared the subject-matter of medicine, namely the human body, to a closed machine, like a clock, that one could not correct without opening it up, and thus risking its destruction. A possible way out of this dilemma, Block saw in the form of a panacea or universal remedy. Leibniz's reply, in his letter of December 2, was that hypotheses and conjectures served as tentative solutions on the way to the establishment of the truth. Above all, it was important to separate certain from provisional knowledge. The mainstay of medicine was empiricism and practice. As regards the possibility of finding a panacea or universal remedy, Leibniz recalled the investigations of the recently-deceased English physician Richard Morton. The renowned Morton had established that, in the case of fever patients, a remission often occurred that makes it possible for the physician to save the patient. In the event of an extreme weakness of the body, on the other hand, such a recovery would no longer be possible. Morton had never been able to find a means for the procurement of such a remission. Leibniz himself chose, nonetheless, to continue to adhere to this idea.

Leibniz advocated a comprehensive scientific training of medical doctors. Writing to Franck von Franckenau, in May 1698, he recalled a meeting in Paris with Gui-Crescent Fagon, the personal physician of Louis XIV. Fagon had arranged – Leibniz told the correspondent – for a law to be enacted that would filter out in advance charlatans and quacksalvers, by requiring that henceforth medics, and persons in the medical profession, should have to produce evidence of their knowledge of anatomy, botany and chemistry. According to Leibniz, Fagon also wanted to get rid of the accusation – disseminated not least by Jean-Baptiste Poquelin, alias Molière, the satirist of seventeenth-century French medicine[132] – that the repertoire of treatment methods of French physicians was limited to the application of clysters, enemata, purgatives or cleansing enemas, and venesection or phlebotomy.

Of significance here is Leibniz's reference to Fagon, Molière and of course to their patron, and enlightened despot, the 'sun king', who consciously used the arts and sciences to assert his own importance and grandeur.[133] Remarkable in particular is the fact that, during the reign of Louis XIV, rational and critical thought came into being revealing two facets – a bright side and a dark side – of his rule. Foreigners with talent in the arts and sciences were enticed to come and work in Paris for the academies, or institutions, set up during

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[132] cf. for example, H. Gaston Hall, "Molière, satirist of seventeenth-century French medicine: Fact and fantasy", *Proceedings of the Royal Society of Medicine*, (*Section of the History of Medicine*), vol. 70, (June 1977), pp. 425-431; A. Calder, *Molière*: *The theory and practice of comedy*, London, 1993, in particular chap. 12 (Medicine).

[133] cf. J. Op de Beeck, *De Zonnekoning*: *Glorie & Schaduw van Lodewijk XIV*, Antwerp, 2018, in particular pp. 449, 452, and pp. 539-541 (with a portrait of Gui-Crescent Fagon, 1638-1718).

Louis' reign. Astronomers, mathematicians and scientists like Giovanni Domenico Cassini (from Genua) and Christiaan Huygens (from The Hague) were invited to lead the royal observatory and the Académie des Sciences, respectively. And, of course, it was in Paris that Leibniz (under his mentor Huygens) first developed the differential and integral calculus.[134] New areas of investigation in the arts and sciences emerged under the 'sun king', which in turn led to an unexpected development of critical thinking. His political communication needed the arts as a medium, and he supported and funded, for example, the dramatist Molière who accordingly gained respectability and fame among an ever wider public. Versailles became the fertile ground for a seldom-seen creative drive in the arts and sciences during Louis' reign. Artistic freedom existed in as far as it served the king's ideals, and the chance of social promotion became an attraction for artists and scientists of various kinds. Molière, in particular, needed the king, not only for royal commissions for court performances, but also for protection against the growing number of social groups, like the physicians referred to in Leibniz's letter to Franck von Franckenau in May 1698, which his plays infuriated and antagonized.[135]

Leibniz's thoughts on the idea of a rational medicine found expression in his correspondence, and above all in his epistolary exchanges with the "medico-mathematicus" Domenico Guglielmini in the year 1697. To the latter, in a letter of January 7, he expressed the hope that mathematics might, with the support of the correspondent, find a place in medicine. Guglielmini, writing on June 18, expressed his intention of attempting to deduce mathematical laws in physiology. However, thoughts about the organization of medicine as an exact science, or the training of "medico-mathematici", Guglielmini considered to be wishful thinking and removed from reality. Medics were, as a rule, not versed in mathematics and would spurn rather than approve such ideas. Leibniz replied at the end of September with a profession of faith in the higher value of rational over speculative thoughts in medicine, whereby plausible hypotheses ought to replace less certain conjectures. As he had previously done with Block, Leibniz stressed here how important it was to keep certain

[134] cf. J. Op de Beeck (note 133 [= note 229]), chapters 5, 7, and 8 (in particular pp. 178f.).
[135] cf. for example the introduction to: R. Bolt (trans.), N. Dromgoole (Introduction), *Molière*: *The school for wives*, *a new translation*, London, 1998, and 2012 (electronic/ digital).

and provisional knowledge separate. Conjectures should be taken into consideration only to the extent to which they were expedient or purposeful. And so, from Guglielmini, he hoped for no mean contribution for the advancement of a rational medicine.

Between 1699 and 1701, it was above all to Friedrich Hoffmann that Leibniz turned for progress in the area of the development of a rational medicine. Hoffmann, in a work of 1699, had picked up on the public part of the metaphysical controversy between Leibniz and Johann Christoph Sturm. Hoffmann's dispatch of his work – in particular the dissertation over which he had presided, entitled *Dissertatio inauguralis physico-medica de natura morborum … mechanica* – to Leibniz, in September 1699, was to be the overture to their correspondence. In his reply, on October 7, Leibniz treated Hoffmann's work in detail and commented on the mechanical world picture, on substance and on the soul. However, he quickly changed over to his ideas on the representation of nature. Since one could not immediately establish the mechanism of nature,[136] from the Cartesian principles of magnitude, figure and motion,[137] one ought to reduce composite principles to simpler ones in the same way that chemists reduced many things to secondary principles. However, he criticized their oftentimes vague terminology, stressing that for principles firm concepts should be chosen. In this sense then, Leibniz desired a contribution from Hoffmann towards the development of a rational medicine, or in his words "Itaque aliquando a Te expecto quaedam rationalis Medicinae elementa". Alas, Leibniz did not live to see the publication of Hoffmann's multi-volume work, entitled *Medicina rationalis systematica* (1718-1734), or its English translation entitled *A system of the practice of medicine* (1783).[138]

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[136] [Continuation = Footnote 232] cf. D. Bertoloni Meli, *Mechanism*: *A visual, lexical, and conceptual history*, Pittsburgh, 2019.

[137] [Continuation = Footnote 233] cf. for example, C. Mercer, *Leibniz's metaphysics*: *Its origins and development*, Cambridge, New York, Melbourne, 2004, in particular Part 2 (Metaphysics of substance), pp. 110-114.

[138] [Continuation = Footnote 234] cf. F. Hoffmann, *Medicina rationalis systematica*, 6 vols., Halle, 1718-1734; English translation: A. Duncan (ed.), W. Lewis (trans.), *A System of the practice of medicine*, London, 1783. Also, cf. S. Naragon, "Friedrich Hoffmann (1660-1742)", pp. 346-348 in: H. F. Klemme, M. Kuehn (eds.), *The Bloomsbury dictionary of eighteenth-century German philosophers*, London, New York, 2010 and 2016.