trum consequendum opus sit Auri semen ocultissimum manifestare, quod non fit nisi per plenariam omnimodam fixi volatisationem, ac proinde formae istius corruptionem."

25. *Ibid.*, p. 683: "... proprie & exacte loquendo minima pars metalli est semen ..."

26. W. Newman, *The "Summa perfectionis" of pseudo-Geber*, Leiden, 1991, pp. 143-192.

27. Figala, "Newton as Alchemist," reference 9, pp. 123-124.

28. [Eirenaeus Philalethes,] *Sir George Ripley's Epistle to King Edward Unfolded*, MS. Glasgow University, Ferguson 85, pp. 1-80, p. 11.

29. MS. Ferguson 85, p. 13. Cf. also Philalethes, *Introitus apertus*, in *Bibliotheca chemica curiosa*, in Manget, reference 2, Vol. II, p. 664.

30. *Ibid.*, MS. Ferguson 85, pp. 11-12.

31. *Ibid.*

32. *Ibid.*, pp. 15-16.

33. *Ibid.*

34. Figala, "Newton as Alchemist," reference 9, p. 120.

35. [Eirenaeus Philalethes,] *Sir George Riplye's Epistle to King Edward Unfolded*, in *Chymical, Medicinal, and Chyrurgical ADDRESSES: Made to Samuel Hartlib, Esquire* (London, 1655), p. 22.

36. The word "nucleus" is the Latin term for "kernel" or "nut." Philalethes uses it in his unfinished manuscript of the *Vade mecum Philosophicum* (British Library, MS. Sloane 633, 107v).

37. This explanation of corrodibility as a product of porosity in the base metals was a commonplace in the alchemical tradition utilized by Philalethes. Cf. Newman, reference 26, p. 158, again quoting the *Summa*: "Propter enim eorum [i.e. copper and iron] multam terreitatis quantitatem et sulphureitatis adjustive et fugientis mensuram, defacili hoc modo adducuntur in calcem. Et illud ideo, quoniam ex multa terreitate argenti vivi substantie intermixta turbatur argenti vivi continuatio, et ideo porositas in eis creatur, per quam et sulphureitas transiens evolare potest. Et ignis ex causa illa ad eam accedens comburere et elevare potest illam. Per hoc igitur derelinguitur et partes rariores fieri et in cinerem per discontinuitatem raritatis converti."

38. I. Newton, *Opticks*, Dover, New York, NY, 1952, p. 400.

39. A. Thackray, *Atoms and Powers*, Harvard University Press, Cambridge, MA, 1970, pp. 25 and 64.

40. For Newton's distinction between "vulgar Chymistry" and "Hermetick" philosophy, see P. M. Rattansi, "Newton's Alchemical Studies," in A. G. Debus, ed., *Science, Medicine, and Society in the Renaissance*, Neale Watson Publications, New York, NY, 1972, pp. 176-177, and 170.

41. Reference 38, p. 386.

42. I. B. Cohen, *Isaac Newton's Papers & Letters on Natural Philosophy*, Harvard University Press, Cambridge, MA, 1958, p. 252. Also Dobbs, *Foundations*, reference 9, p. 219.

43. Dobbs, *Foundations*, reference 9, p. 220.

44. Figala argues, furthermore, that Newton associated the alchemists' mercury with the presence of "pores" (and hence void) in matter, echoing the Paracelsian view that mercury was the principle of volatility and hence attenuation. Similarly she thinks that Newton viewed sulfur, the traditional principle of coagulation or solidification, as representing "matter." See "Die exakte Alchemie", reference 9, pp. 163-167, 183-186.

45. W. Newman, "Newton's *Clavis* as Starkey's *Key*," *Isis*, **1987**, *78*, 564-574.

46. Philalethes, *Introitus apertus*, *BCC*, II, 663, "... sulphur externum ..."

47. Reference 45, pp. 572-574.

48. Dobbs, *Foundations*, reference 9, p. 218.

49. Figala, "Die exakte Alchemie", reference 9, p. 164.

50. Dobbs, *Foundations*, reference 9, pp. 222-225.

51. Westfall, *Never at Rest*, reference 8, p. 358.

52. Here it will be useful to give both Newton's paraphrase (Cambridge University Library, Keynes MS. 30, f. 22^r) and the original (Philalethes, *Introitus apertus*, in *Bibliotheca chemica curiosa*, Vol. II, p. 663):

Newton: Hoc chaos est terra propter coagulationem suam, et mineralium matrix propter mineralia quae in ipsa occultantur, et tamen aer volatilis, et caelum [sulphureum] in quo astra revolvuntur continet in centro suo, quod centrum astrale est & terram ad usque superficiem illuminat. Introit. apert p. 10.

Philalethes: Chaos etenim Nostrum est quasi Mineralis Terra, coagulationis suae respectu, & tamen aer volatilis, intra quod est Coelum Philosophorum in Centro suo, quod Centrum est revera Astrale, irradians Terram adusque superficiem suo jubare.

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ROBERT MAYER AND THE CONSERVATION OF MATTER

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Robert Mayer (1814-1878) is well known as one of the discoverers of the principle of the conservation of energy. A physician from the kingdom of Württemberg in southwestern Germany, Mayer sailed to the Dutch East Indies in 1840, where he was startled by the brighter-than-expected color of the blood he let from European sailors recently arrived in the tropics. Reflecting on the implications of Lavoisier's combustion theory of animal heat, and of his own failed childhood attempt to construct a perpetual motion machine, Mayer employed a widely invoked analogy between organisms and machines to conclude that there must be a constant numerical relationship between heat and "motion" (1). Two years later he published his first paper, "Remarks on the Forces of Inorganic Nature", in Liebig's *Annalen der Chemie und Pharmacie*. That paper contained his calculation of the mechanical equivalent of heat; as he put it, the fall of a given weight through a distance of 365 meters is equivalent to a rise in temperature of one degree Celsius of an equal weight of water.

Although this essay cannot develop the full context of Mayer's reflections, it is important to recognize that the line of reasoning sketched above yielded Mayer a number, not a general concept of energy (he said "Kraft", or force), let alone of its conservation. Of central importance in the exposition of his theory of force was an analogy between force and matter - the fundamental concepts, he argued, of (respectively) physics and chemistry. Both force and matter are quantitatively invariable and qualitatively variable. Just as matter is, in the normal course of nature, neither creatable nor destructible, so, too, is force neither creatable nor destructible, at least as far as the processes of inorganic nature are concerned. It is thus tempting to suspect that Mayer transferred to the new conceptual entity "force" the well-known chemical principle of the conservation of matter.

The only thing wrong with this explanation is that there was no such principle in the chemistry and physics texts of the first half of the 19th century, at least not in Germany. The substance of the principle was, to be sure, tacitly assumed as a working principle by chemists, but it had no visibility as a fundamental principle, let alone the fundamental principle upon which the science of chemistry is based. In a real sense Mayer had to "discover" for himself the principle we know of as the conservation of matter. Nor was it a simple business for him to settle upon the analogy between force and matter. He first had to define for himself the meaning of force and to decide what its fundamental characteristics were. It was only gradually and with great conceptual difficulty that Mayer concluded that force, too, cannot be created or destroyed under any circumstances. He never doubted the indestructibility and uncreatability of matter, but whether those characteristics apply also to force was precisely the difficult question to answer. A confused application of the parallelogram of forces to central-force motion, coupled with residual uncertainty as to the status of the vital force and attachment to a widely invoked image of the solar system as an "organism," led him to conclude until around 1844 that force is continuously produced in the sun via the neutralization of a portion of the planets' centrifugal force. In other words "organisms," unlike machines, are truly capable of creating force effectively out of nothing.

The nonexistence of an explicit principle of the conservation of matter is as unambiguous as it is startling. The overwhelming majority of German chemistry and physics texts and handbooks of the period contain no explicit mention of anything like the conservation, indestructibility, or uncreatability of matter, mass, or substance. One needn't quibble over terms. I've looked at about 30 works by 17 authors from the 1820s till the early 1840s, including the well-known texts of Baumgartner, Berzelius, Biot, Leopold Gmelin, Kastner, Mitscherlich, Pouillet, and Wöhler. Most list as the general properties of matter things like extension, impenetrability, divisibility, porosity, elasticity, compressibility, inertia, and motility, rarely also weight or gravity ("Schwere"). Some don't even mention mass as an important concept, let alone its conservation.

Robert Mayer

One of the standard reference works of the day was *Gehler's Physical Dictionary*, published in 11 multipart volumes between 1825 and 1845. Neither the short article on "Mass" nor the long one on "Matter" specifically mentioned its conservation or indestructibility (2). To be sure, passing mention of such a principle did occur here and there in the course of particular discussions, quite as Lavoisier's oft-quoted enunciation of it was tucked away in the section of his *Traité* dealing with vinous fermentation. Thus Lamé referred to "the indestructibility of matter and the constancy of the quantity of vis viva" in his discussion of the constancy of the quantity of heat in certain reactions, but he otherwise passed in complete silence over the conservation of matter (3). Interestingly enough, the two other incidental references I've encountered to something like the conservation of matter have to do with reactions involving oxygen - perhaps a faint resonance of the historical association of that principle with Lavoisier.

Such silence is perhaps doubly surprising since not only had Lavoisier enunciated the principle of the conservation of matter in 1789, but in Germany Immanuel Kant had laid down a similar principle in his influential *Metaphysical Foundations of Natural Science* of 1786. For Kant, the first principle of mechanics was that "in all changes in the corporeal world the quantity of matter remains on the whole the same, unincreased and undiminished." Yet Kant also assigned to matter primitive attractive and repulsive forces, and the "dynamical" philosophies of nature which were popular in early 19th-century Germany tended to eliminate matter entirely in favor of its construction out of ontologically more primitive forces; hence there was no matter, let alone mass, to be conserved.

The very notion of the conservation of matter was problematic because of the widespread lack of precision concerning the conception of matter as a distinct entity, especially as it related to the nature of the so-called imponderables, i.e. heat, light, electricity, and magnetism, regarded as weightless fluids. (Recall here that even Lavoisier listed caloric and light among the elements.) One prominent writer, Jacob Friedrich Fries, interpreted ponderable matter and the so-called imponderables as merely different states of aggregation of the same underlying substance (4). This was a notion which held out the implicit possibility of the effective disappearance of ponderable matter and hence cut the ground from under the utility of a principle of the conservation of matter. Heidelberg professor of physics Georg Wilhelm Muncke insisted that the alleged weightlessness of the imponderables had not been proven empirically, and thus he held open the possibility that they were only tenuous states of matter, again blurring the concept of ponderable matter and rendering its conservation less than obvious (5). As he observed, the imponderables would only have to be as light with respect to hydrogen as hydrogen is with respect to platinum in order to escape detection by our most sensitive balances. One of Mayer's professors of medicine at Tübingen, the then-prominent Johann Heinrich Ferdinand Autenrieth, concluded his discussion of phenomena of electricity, galvanism, magnetism, chemical reactions, heat, and light with the judgment that "imponderable substances" differ only in degree from "ordinary heavy bodies: They do not constitute a class of entities wholly different from the other material substances, and between the magnetic fluid and rigid flint there is an almost continuous transition" (6). In other words, it would be hard to insist on the conservation of matter as a principle if one's conception of ponderable matter was such that there was nothing in principle to conserve. It took the clarification of the concept of energy and the abandonment of the time-honored but vague notion of the imponderables before the concept of matter was distinct enough to make its conservation a meaningful principle of science.

At issue is not chemists' routine acceptance (after Lavoisier?) of the fact that the weight of the chemical reagents before and after a reaction must be unchanged, but rather the explicit enunciation of a particular principle and the kinds of assumptions which finally made that enunciation reasonable in ways it hadn't been before. The parallel and explicit formulation of both conservation principles as fundamental principles of the sciences of chemistry and physics was in the first instance the work of Robert Mayer. Lavoisier notwithstanding, it appears to me that, for the larger scientific community, the general recognition of the principle of the conservation of matter went hand in hand with, and was only made possible by the general acceptance of the principle of the conservation of energy during the second half of the 19th century.

References and Notes

1. Details about Mayer's work can be found in my book, *Robert Mayer and the Conservation of Energy*, Princeton University Press, 1993. That work also contains a more fully documented review of the chemical literature referred to here.

2. H. W. Brandes and G. W. Muncke, "Masse" and "Materie," in H. W. Brandes et al., *Johann Samuel Traugott Gehler's Physikalisches Wörterbuch*, 11 Vols. in 20 pts., Leipzig, 1825-45, Vol. 6, pt. 2, 1836, pp. 1392-1393 and 1393-1472, respectively.

3. G. Lamé, *Cours de physique de l'Ecole polytechnique*, 3 pts. in 2 Vols., Paris, 1836-37, Vol. 1, 1836, p. 428.

4. J. F. Fries, *Lehrbuch der Naturlehre*, Jena, 1826, p. 75.

5. G. W. Muncke, "Imponderabilien [sic]," in reference 2, Vol. 5, pt. 2, 1830, pp. 765-769.

6. J. H. F. Autenrieth, *Handbuch der empirischen menschlichen Physiologie*, 3 Vols., Tübingen, 1801-1802, Vol. 2, 1802, pp. 189-190.

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PRIDE AND PREJUDICE IN CHEMISTRY

Chauvinism and the Pursuit of Science

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Imbued as they are with the ideal of scientific objectivity, scientists and their historians can forget or neglect an important truism: scientists are just as susceptible as their fellow human beings to chauvinism, bigotry, greed, ambition, and all the other faults to which humanity is prey. Two news articles published in *Science* in 1989 are relevant to the first sin in my