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Paracelsus: the measurable and the unmeasurable*

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A perennial tension of scientific investigation is the divergence between what can be measured and what ought to be measured, as illustrated by the anecdote of the drunkard who dropped the keys to his house late one night. As he was vainly scrabbling around beneath a lamp post, a sympathetic passer-by stopped to assist. "Where exactly did you drop the keys?" he inquired. "Over there," replied the drunkard, pointing towards a rather forbidding looking wall, where inky blackness reigned. "Then," exasperatedly, "why are you searching beneath the lamp post?" "Because there is more light here!"

With the recent proliferation of sophisticated measurement devices, often of the black box variety, the tension has become even more acute. An expensive apparatus has been acquired, and at the push of a button it will pour out a string of numbers, to which some mathematical functions built in to the memory of the apparatus may then be fitted automatically. Is it not tempting to be satisfied with this, regardless of whether it actually means anything? One is possibly aware that a different kind of measurement would be far more revealing, but its practical realization would mean weeks, if not months, of laborious work building new apparatus, and hours of tedious calculations for evaluating the hard-won data. It is no wonder that the average researcher often succumbs to the temptation of convenience and is content in due course to fill yet more of the increasingly precious shelf space in libraries by publishing spuriously quantitative data.

"It amazes me that you use a dead body in order to understand the living," wrote Paracelsus [1], vainly trying to stem the tide of eager dissectors who were busily emptying graveyards with all the zeal of newly-won converts. He did not, of course, mean that the serious study of anatomy was an idle pursuit for the medical aspirant; on the contrary, in his Basle lectures to the students of medicine, and elsewhere [2], he emphasizes its indispensability. His call was, however, a warning to recognize the limitations of anatomy, and a spur to including physiology and psychology in medical curricula.

But the warning turned out to be largely in vain. In 1542, a year after the death of Paracelsus, Andreas Vesal arrived in Basle, began lecturing at the University, and in 1543 published his book "De humani corporis fabrica", the first systematic (and correct) anatomy text based on observation [3]. In that respect, it is actually very Paracelsian in concept: one of Paracelsus' maxims, which he was especially at pains to inculcate into his undergraduate audience, was the primordial place of observation in science. But in the implicit reduction of medicine to anatomy, Paracelsus would have seen (as he already saw in his lifetime) regressive impoverishment. Yet that is how medicine chiefly developed thereafter. In our own time, this reductionism is exemplified by belief in drugs as a universal panacea (and, under the guise of 'molecular medicine', pharmacology is itself practically reduced to listing possible receptors for drugs), and the even more extreme foreseen reduction of medicine to the enumeration of all the genes in the human genome.

Paracelsus was not the first to lay emphasis on observation as the foundation of medicine; his professors Nicolo Leoniceno and Giovanni Manardo at Ferrara (where he obtained his doctorate [4]) were known for holding such heretical views. At that time, most medical students were taught that "the great Master Galen said . . . ", or "Magister Avicenna has stated . . . ", etc. The statutes of the medical faculty at Basle explicitly specified that the interpretation of Hippocrates' aphorisms was a compulsory part of the final examinations. In contrast to this unquestioning reliance on the old authorities, Paracelsus emphasised the necessity for *Erfahrung*, experience, i.e. experiment (insofar as it was possible in medicine) and observation. His response to the statutory obligations was to organize undergraduate seminars on Hippocrates, which were later written up as a new style of critical commentary [5].

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Placing experience at the centre was in itself such a decisive break with the past that Paracelsus was dubbed Lutherus Medicorum, an appellation that he appears to have disliked, however, knowing full well that this step, of basing knowledge on experience, could only be the beginning. Restricting knowledge to that what can be measured is to echo in paraphrase the immortal words attributed to William Jowett, "I am the master of this College / What I don't know isn't knowledge." All scientists risk falling into this beguiling trap. The risk is already rather obvious in most branches of biology, and becomes glaringly so in medicine and economics [6].

Unfortunately, science has developed in such a way that it is extremely wary of admitting the existence of phenomena beyond measurement, because that appears to allow licence in opening the floodgates to the most outrageous "phenomena" into the fold of science—occultism, magic, parapsychology, perpetual motion machines, etc. Yet why should one not allow nature to rule as the supreme arbiter? Science should have nothing to fear from pseudoscience masquerading as science: dispassionate investigation will quickly sort the wheat from the chaff. The most elementary criterion of what constitutes a scientific phenomenon—that under a given set of conditions, an event will recur with a probability tending to a constant limit (greater than zero) as the number of observations is increased—seems to be perfectly adequate for arbitrating the claims of what is commonly known as pseudoscience. The only genuine argument for standing strenuously aloof from pseudoscience is that it adds noise to and therefore hinders the efficient running of the real scientific enterprise [8]. Clearly not every improbable claim can be investigated, but a dogmatic and absolute veto would be even worse—and contrary to the spirit of openness which lies at the core of true scientific investigation.

In Paracelsus' own time, the scientific enterprise was in its infancy, and clear ideas as to what constitutes a proper scientific investigation were still inchoate. Medical doctors, astrologers and soothsayers, alchemists trying to turn base metals into gold, and others all abounded. Paracelsus firmly dismisses these areas of activity. He was scathing about the numerous 'authorities' who asserted that the stars influenced terrestrial phenomena, and his only interest in gold was in its medicinal uses—potable or colloidal gold; his chemical recipes concerning gold are not for transmuting base metals, but for producing colloidal gold from gold salts [9]. The bane of progress was then, as now, eloquent arguments and unqualified assertions being substituted for conclusive evidence.

The rationalist alternative

So how did Paracelsus deal with the problem of the unmeasurable?—and how are his ideas of importance to us today? The issue at stake is how to comprehend the whole nature of a living being—above all, Man—without having recourse to more or less vague theories of vitalism, and its successor, organicism. Currently, the opposing reductionist view is mechanism, and it is instructive to look at what Descartes, sometimes considered to be its father, and often set up as a rationalist opponent of Paracelsus, propounded. In passing, note that although both of them shared the experience of having travelled widely in Europe, whereas Paracelsus studied medicine, Descartes studied philosophy and mathematics. In the Discours de la Méthode [10], he elaborated his notion of proceeding step by step, starting from the simplest and easiest to know, to more complex knowledge (precisely as geometers proceed), and "attention was to be restricted to things about which we can attain a certitude equal to arithmetic and geometry".

Descartes had an unbounded faith in a priori conclusions, and failed to recognize the decisive nature of even the simplest experiment. Hence it is not surprising that his greatest achievements were in geometry. The negative side was that "toute ma physique n'est que geometrie" —a view which led him into severe error in formulating the laws of motion, of which a couple of examples concerning the fate of two colliding bodies B and C will suffice [11]; the reader may care to verify their correctness or otherwise by means of simple tabletop experiments:

> If B and C are equal, but B's speed is greater, however slightly, than C's, C alone will be reflected and both will together move to the side whence C came, and B will transfer to C half its excess of speed.
>
> If C, which is at rest, is greater, however slightly, than B, no matter with what speed B approaches C, never will it have the force to move it, but it will be reflected to the side whence it came.

Descartes' reliance on his immortal maxim, "Cogito, ergo sum," led to a separation of body and mind which persists widely to this day, and while he was aware of the unsatisfactory nature of this state of affairs, he left no clue as to how their union was to be brought about. In grappling with such issues, mathematics and geometry, especially during the epochs of Paracelsus and Descartes, offered great security. In these disciplines one could indeed proceed step by step from the simple to the complex, and the circumstance that this method appeared to lead to errors (as in Descartes' laws of mechanics) was, curiously enough, not held to be significant. It is fortunate for the subsequent progress of science that Isaac Newton, only a few decades after Descartes, instinctively found a middle way between the extremes of Cartesian rationalism and Francis Bacon's empiricism. Newton's work appears as *the product of a truly inventive intellect pondering on the witness of the senses* [12], and in it we see a beautiful consummation of what has been called the heart and soul of science—the search for causes in layers beneath the surface, and their generalization in terms of universal concepts. A century and a half before Newton, we find Paracelsus working along the same lines, in a field—medicine—which demanded it even more urgently, but whose fruits could not be condensed into a handful of laws expressed with beautiful mathematical economy.

Although he made important contributions to the science of extraction of metals from ores, Paracelsus considered himself above all to be a medical doctor (indeed his work on extraction subserved his medical interests, since he considered minerals to be an essential source of pharmaceutical materials). His father was a medical doctor, he studied medicine at several European universities, he spent the rest of his life both deepening his medical knowledge and practising medicine, and nearly all his books are on medical topics. Inevitably this focus strongly coloured his thought, for already at the very beginning of his studies the medical man is confronted by an immensely complex system (the human body), and it is futile to begin with the simple and move step by step to the complex. As a practising doctor Paracelsus was very successful, and his Basle appointment was made on the strength of his reputation. For the rest of his life he was highly sought after, especially by those pronounced by medical tradition to be suffering from "incurable" diseases. With his motto "morbus est incurabilis, . . . doctor non est irrefragabilis" [13] he recognized that to declare a disease incurable was one of the greatest disservices a doctor could do for his patient, who then lost hope, whereas if he could inculcate a fighting spirit, the patient stood a genuinely better chance of survival. This is considered to be a very modern view in contemporary medicine—it is the ethos of the successful Bristol Cancer Centre in England, for example—and yet Paracelsus had already recognized the powerful interaction between mind and body and the medical consequences thereof more than half a millenium earlier, and was putting this recognition into practice in the treatment prescribed for his patients. This was quite apart from the fact of his finding that many illnesses conventionally declared to be incurable could be cured by the proper observation of hygienic principles, and with the help of suitable medicines extracted from minerals and plants.

The four pillars of medicine

Paracelsus actually had a double battle on his hands, not only against a priori rationalist reasoning and its epigone, reductionism, but also against the unquestioning acceptance of ancient authorities [14]. Against both enemies he had a single powerful weapon, his maxim "ex cura nascitur theoria, non contra" [15]. The importance of Erfahrung, experience, is one of the two great themes running through the lectures he held in Basle. It forms the basis of the first of Paracelsus' four pillars of medicine [16]—natural philosophy, i.e. knowledge of minerals, plants, the human body, etc., but also including the unseen things, the underlying causes. His aim is "die unsichtbaren Sachen, sichtbar zu machen" [17]. Paracelsus saw this process of discovery as a process of which man was symbiotically a part, i.e. discovery was an integral part of the system of creation. Nature was not to be conceived as a static, closed thing, but as a dynamical process, illustrated by the picturesque image of a pear which begins to grow in the spring until it ripens in the autumn, and is then a pear—but not before [18]. And the dynamical challenge for man is to discover the mysteries of which he is a part. One has the impression that it was not easy to find the words with which to adequately describe these concepts. Paracelsus introduces the image of the "Licht der Natur"—the light with which the unseen, the Herz der Dinge or the Quinta Essentia, will be made visible [19]. In developing this idea of dynamic symbiosis, Paracelsus was doubtless influenced by the notions of microcosmos and macrocosmos then prevailing in the scholarly world. The latter was the universe at large, and the former the human being, into which, in some sense, the entire macrocosmos was concentrated [20].

The larger universe is the focus of Paracelsus' second pillar of medicine, astronomy [16]. This is by no means restricted to knowledge of the stars, and is not concerned with the notion of their possible astrological influence. In modern terms, Paracelsus' astronomy is about information flow between sources and sinks, a concept which is incompatible with that of a world whose evolution is completely deterministic, and which could be predicted forever into the future if at any instant the positions and momenta of all its constituent particles could be specified. This deterministic concept is vitiated not only microscopically—quantum mechanics ensures that phase space is divided into blocks of finite size, within which all knowledge of the trajectories upon which particles arrived at a given block is lost—but also macroscopically, through turbulent motion (sources) constantly expanding microscopic, thermal noise up to macroscopic expression, and the existence of dissipative structures acting as information sinks. The ubiquitous "$1/f$ noise", whose origin is still mysterious but which is possibly linked to these flows [21], with its absence of a characteristic scale, really vindicates the mediaeval idea of microcosmos and macrocosmos, of the world existing as a homogeneous whole; for the clock to have subsequently become the symbol of a universe considered to be ordered and deterministic must be considered as a regression of thought [22].

Paracelsus' third pillar of medicine is alchemy. His definition of alchemy is so forcefully different from the common notion that it is worth quoting in full [23]:

> Dann die Natur ist so subtil und so scharff in ihren dingen / das sie ohn grosse kunst nicht wil gebraucht werden: Dann sie gibt nichts an tag / das auss sein statt vollendet sey / sondern der Mensch muss es vollenden: Diese vollendung heisset Alchimia.
>
> Dan ein Alchimist ist der Becke in dem / so er Brodt bacht: Der Rebman in dem / so er den Wein macht: Der Weber in dem / das er Tuch macht. Also was auss der Natur wachst dem Menschen zu nutz / derselbige der es dahin bringt / dahin es verordnet wirdt von der Natur / der ist ein Alchimist.

According to this definition, all modern scientists are alchemists, insofar as they seek to reveal the workings of nature through unseen causes, described by the universal laws they seek to formulate. The practical, technical work of the alchemist in the service of medicine is to win hidden essences from plants, extract and purify substances from crude ores, etc., these activities in turn forming an image of the great search for the Quinta Essentia. This is not the fabled philosopher's stone beloved of many of Paracelsus' contemporaries; Newton's law is the Quinta Essentia of gravity, Maxwell's equations are the Quinta Essentia of electromagnetism, and so on. Paracelsus was himself apparently unschooled in mathematics, and there is not a single equation to be found in his voluminous writings, but his chosen field of study was such that equations would have been of little use, and even today one would hesitate before proposing an equation to describe human behaviour [24].

Paracelsus' emphasis on the very necessary hard work required for extracting nature's secrets stands in sharp contrast to the effete idea that nature reveals her secrets spontaneously, which held sway in the succeeding so-called Age of Enlightenment. His approach preempted the positivist stress on seeing, counting and measuring, but to then say ne plus ultra would have struck him as absurd.

The fourth and final pillar of Paracelsus' medicine is ethics [16]. This is the second great theme running through his Basle lectures (the first, it may be recalled, was the importance of Erfahrung, experience), and one may infer that these were two ideas he wanted at all costs to be engraved on the hearts of his students. His view on ethics is summarized in the aphorism [25] "Im Herzen wechst der Artzt." This is no vague and sentimental beneficence; on the contrary, it is the keystone of Paracelsus' desire and demand for the total healing of a patient.

Reductionism

Reductionism tends to be associated with a comparatively recent philosophical school. The growing speed and efficiency of data gathering, especially in the twentieth century, the ability to analyse the ultimate constituents of matter, and in some cases to successfully reconstruct the whole from the parts, has given reductionism great impetus. Its most outstanding success remains chemistry, whose illimitable complexity is built upon a mere hundred or so elements. In physics, the picture is less clear, the erstwhile and tractable world of electron, proton and neutron having given way to yet more elementary, albeit putative, entities. In biology, the molecular approach took off spectacularly after its first great success, revelation of the unseen layer (DNA) guiding the origin of species [26]. But assessment of the achievements of molecular biology to date leads to a confused and contentious picture [27]: the more molecules that are discovered, the more bewilderingly complex and intractable does the whole become. The so-called integrative biologists, who deal with whole organisms and ecosystems, lament the abyss which has opened and widened between them and the molecularists.

Nor has physics remained immune from reductionism. It is regrettable that, increasingly, understanding of the measured world is felt to reside in the mechanism of a simulated model of that world. This is fine as far as it goes, and deviations between the predictions of the model and actual measurements may even illuminate understanding, but all too often attention comes to be inexorably focused on the model alone, which may itself display rich and complex behaviour, and in whose brilliance of illumination at close range the light of nature as a whole pales into insignificance.

Although the term 'reductionism' is recent, nevertheless the issue was very much alive in Paracelsus' time. With his emphasis on Erfahrung as the primary source of knowledge, and his considerable expertise in identifying and isolating useful drugs from natural sources, it would have been very natural for him to advocate a reductionist view of medicine. But in fact he did not, and we need to ask, whence came his strong perception that reductionism was not the Ding an sich?

Let us not forget that Paracelsus considered himself first and foremost a medical doctor. Therefore he was an ens agens, not an ens cogitans like Descartes, and for an ens agens concrete realization is the real test of any system of concepts. Following graduation, Paracelsus accompanied several military campaigns as an army doctor and had ample opportunity to observe at first hand the ghastly wounds inflicted in mediaeval warfare. Reductionist medical treatment, which confined itself to the organ needing attention, or prescribed pharmaceuticals without ministering to spiritual needs, had grim consequences with which Paracelsus was only too familiar. In Basle, Paracelsus held a double appointment, as a Dozent at the University and as Stadtarzt [28]. Among his duties as the latter was control of the apothecaries of the city, and he was appalled by the rampant corruption he found among them. Not only were prescriptions frequently improperly made up, but there was widespread collusion with doctors, who often prescribed quite unnecessary medicines. These experiences can only have strengthened his resolve to stress the neglected moral aspects of medicine. The ens agens is confronted with reductionism in ways which the ens cogitans is not. In fact, the reductionism which Paracelsus encountered as Stadtarzt went beyond medicine per se and reflected the mercantilist idea of how society should be organized: the mercantile system is simply reductionism applied to the economic realm, and not too surprisingly it appears to sanction reductionism in other spheres, such as medicine. As Weir has remarked [29], "beneficial undertakings had been proved profitable; [later] it was assumed that a business, as long as it is profitable, does not require to be proved beneficial."

Of course Paracelsus the scientist sought to make sense of the perceived world by applying reductionist principles. The hidden, underlying layer must perforce be simpler in some sense than the visible world of phenomena, otherwise the underlying laws would be useless for predicting the visible phenomena. But Paracelsus was constantly coming up against the limitations of the reductionism of his day. For example, he found that the postulated four "elements", earth, air, fire and water, were inadequate to characterize the real world, and hence added three more [30]. At the same time, he clearly saw that the Quinta Essentia—of a medicine, of a human being—did not lie in a reductionist residue, but in something far more subtle, which today we would probably call emergent properties. Thus chemistry is not applied physics, biology is not applied chemistry, ecology and social anthropology are not applied biology, and so on, apprehension of which devastates the attempt to reconstruct the world from its reductionist elements. One is perhaps nowhere more conscious of Paracelsus' striving to express these ideas in words as in his writings on the Quinta Essentia [31]. Although sometimes perceived as the ultimate, inner essence, the Quinta Essentia is itself a complex, multilevelled entity.

A way out of the labyrinth

Perhaps Paracelsus' most enduring achievement was to have been able to put the unseen and the unmeasurable on the plane of the objective. His contribution was to show that one can embark upon rational discourse about them, indeed one must, if one is to really understand the seen. To this day we are still searching to elucidate the nature of our laws and of observed "reality", and the relationship between them (purely pragmatically, these laws do enable us to make correct predictions about observed phenomena), and Paracelsus made a contribution to this quest of which it is worth taking note. One of his books is entitled "The Labyrinth of the Doctors who Err" [32], and in it Paracelsus offers a way out of the indeed labyrinthine, chaotic ideas of the mediaeval doctors, and some of his ideas can even today provide inspiration towards understanding the modern biomolecular labyrinth in which medicine finds itself.

References and notes

1. T. von Hohenheim (Paracelsus) Sämtliche Werke, ed. K. Sudhoff, Munich: R. Oldenbourg, 1922, Bd I/6 (Von Blatern, Lähmi, Beulen, Löchern und Zitrachten der Franzosen), p. 333.

2. Ref. [16], Ch. 1, p. 38.
3. The publisher was none other than Johannes Oporinus, erstwhile student and famulus of Paracelsus (who considered him to have been his best student). Years later he became a printer and publisher.
4. This is not irrefutably proven, due to gaps in the registers of Ferrara University for the years in question. See A. Burckhardt, Nochmals der Doktortitel von Paracelsus, Separat-Abdruck aus dem Corr.-Blatt für Schweizer Aerzte No 28 (1914), for a critical assessment.
5. P.T.B. von Hohenheim (Paracelsus) Commentaria in Aphorismos Hippocrates, Basel: Waldkirch, 1589 (pp. 1–44 of the Appendix of Part 5 of the collected works edited by J. Huser).
6. Griffin, referring to the behavioural approach to the scientific study of animals, remarks [7], "The first step is to measure whatever can easily be measured. This is fine as far as it goes. The second step is to disregard that which can't be measured or give it an arbitrary quantitative value. This is artificial and misleading. The third step is to presume that what can't be measured easily isn't very important. This is blindness. The fourth step is to say what can't easily be measured really doesn't exist. This is suicide."
7. D. R. Griffin, The Question of Animal Awareness, New York: Rockefeller University Press, 1976.
8. In this regard, note that certain processes are actually facilitated by noise!
9. See R. Zsigmondy and P.A. Thiessen, Das kolloide Gold, Leipzig: Akademische Verlagsgesellschaft, 1925. Regarding the transmuters of base metals, it may come as a surprise to learn that at least one 'alchemist', G.T. Tiffereau, was giving lectures on his investigations in Paris as late as 1889 (one has been printed in M. Franck, L'Or et la Transmutation des Métaux, Paris: Chacornac, 1889, pp. 151–166).
10. R. Descartes, Discours de la Méthode pour bien conduire sa raison et chercher la Verité dans les sciences, published in 1637.
11. From Principia Philosophiae (Amsterdam, 1644). The translations are from J.F. Scott, The Scientific Work of René Descartes, London: Taylor and Francis, 1952, p.163.
12. S. L. Jaki, The Road of Science and the Ways to God, Ch. 6, Edinburgh: Scottish Academic Press (1978).
13. T. von Hohenheim (Paracelsus) Sämtliche Werke, ed. K.Sudhoff, Munich: R. Oldenbourg, 1931, Bd I/4, p. 419.
14. His diatribes against the latter culminated in the public burning of the leading medical text by Galen in the market square of Basle. Since his colleagues in the medical faculty based their lectures exclusively on such material, this was considered to be an uncollegial act, to say the least.
15. T. von Hohenheim (Paracelsus) Sämtliche Werke, ed. K. Sudhoff, Munich: R. Oldenbourg, 1931, Bd I/4, p. 120.
16. P.T.B. von Hohenheim (Paracelsus) Paragranum, Basel: Waldkirch, 1589 (pp. 5–97 of part 2 of the collected works edited by J. Huser).
17. P.T.B. von Hohenheim (Paracelsus) Funff Bucher de Causis Morborum Invisibilium, das ist / von den Unsichtbaren Kranckheiten und ihren Ursachen, Basel: Waldkirch, 1589 (pp. 238–327 of part 1 of the collected works edited by J. Huser), especially the Vorrede, pp. 238–244.
18. P.T.B. von Hohenheim (Paracelsus) Opus Paramirum, Basel: Waldkirch, 1589 (part 1 of the collected works edited by J. Huser), Book 1, Ch. 7 (esp. pp. 97–98) and Book 2, Ch. 1 (esp. pp. 106–108).
19. P.T.B. von Hohenheim (Paracelsus) Opus Paramirum, Basel: Waldkirch, 1589 (part 1 of the collected works edited by J. Huser), Book 1, Ch. 1 (pp. 67–72).
20. One cannot help thinking that the macrocosmos/microcosmos notion also influenced the development of humanism. Erasmus of Rotterdam, its founding father, was living in Basle at the same time as Paracelsus, and they were apparently befriended.
21. R. Shaw, Strange attractors, chaotic behaviour, and information flow, Z. Naturforsch. 36a, 80–112 (1981).
22. The clock may nevertheless have been instrumental in enabling mechanized mass production to get off the ground, as suggested by D. Landes in The Wealth and Poverty of Nations, New York: Norton (1998), and this in turn presumably facilitated the manufacture of scientific instruments, and hence immensely important scientific advances.
23. Ref. [16], p. 61. "For nature is so subtle and challenging in her things, that she cannot be exploited without great expertise. There is nothing in our world lying to hand in ready form; Man must complete it. This work of completion is called alchemy. The alchemist is like the baker who bakes bread, the vintner who makes the wine, the weaver who turns threads into cloth. Therefore whatever things there are in nature which are useful to Man, these things must Man the alchemist bring to order and completion."

24. This may be asserted despite there being some aspects of human behaviour which are seemingly well described statistically (e.g. expected annual numbers of births, marriages and deaths), at any rate reliably enough for investment decisions to be made on their basis.

25. P.T.B. von Hohenheim (Paracelsus) De Caducis Liber Secundus nemlich de Caduco Matricis, das ist / Vom hinfallenden Siechtagen der Mutter /so allein den frawen anhangt, Basel: Waldkirch, 1589 (part 4 of the collected works edited by J. Huser), p. 368. See also in Book 1, p. 320, "ist dein Hertz falsch / so ist auch der Artzt bey dir falsch."

26. J.D. Watson and F.H.C Crick, A structure for deoxyribose nucleic acid, Nature (Lond.) 171, 737–738 (1953); Genetical implications of the structure of deoxyribonucleic acid, ibid., pp. 964–967.

27. R. Holliday, Successes and limitations of molecular biology, J. theor. Biol. 132 (1988) 253–262.

28. The modern equivalent would be chief medical officer, or surgeon-general—on a small scale, of course (Basle was then an independent city state).

29. A. Weir, The Historical Basis of Modern Europe, London: Swan, Sonnenschein, Lowrey (1886).

30. These were salt, sulphur and mercury; they were not elements as a modern chemist would understand the term, but rather embodied concepts of the different characters of materials.

31. See e.g. P.T.B. von Hohenheim (Paracelsus) Archidoxis, Basel: Waldkirch, 1590 (part 6 of the collected works edited by J. Huser), especially Book 4 (pp. 24–42).

32. P.T.B. von Hohenheim (Paracelsus) Labyrinthus Medicorum Errantium, Basel: Waldkirch, 1589 (pp. 191–243 of part 2 of the collected works edited by J. Huser).