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Newton, Goethe and
Die Wahlverwandtschaften
 - On the Virtue of
 Contradictory Hypotheses* -

Dieser Aufsatz geht auf ein Grundproblem der klassischen Physik Newtons ein – die Frage nach dem Wesen der Kraft – und zeigt, welche Methode Goethe entwickelte, um naturwissenschaftliche Probleme dieser Art zu beleuchten. Es erweist sich, daß der Roman *Die Wahlverwandtschaften* produktiv in die Naturwissenschaften eingriff, namentlich in die Geschichte der Chemie von Newton bis Macquer und Bergman. Goethe wandte hier seine >Theorie der Vorstellungsarten< an, um entgegengesetzte Auffassungen von Materie bzw. Affinität zu verbinden.

With some reason, critics often treat Goethe's *Die Wahlverwandtschaften* (1809)¹ as one of the first >modern< novels: it is told by a third person narrator in a predominantly realistic if symbolic mode; it has a highly-wrought, almost symmetrical structure; it presents not just one central figure or couple, but a group of four, the central characters, through a study of whose ethical and psychological entanglement the author depicts >social relations in symbolic form< (*HA*, p. 639); it elevates the act of interpretation into a central literary problem; and, moreover, much of its narrative strength and novelty derive from an alliance with science. The title is a scientific term. The process it designates provides a pattern for the plot, in that a disturbing >double attraction< occurs between a married couple, Eduard and Charlotte, and their friends, Otilie and the Captain; the attractions dominate and ruin their lives, resulting in the tragic death of Otilie, whom Eduard shortly follows to the grave. Other novels, for instance Rousseau's *La nouvelle Héloïse* (letters 11 and 13), had used scientific images for love, but *Die Wahlverwandtschaften* is probably the first to use science so thoroughly and prominently; and indeed, as Goethe saw it, to show that there is >only one Nature< (*HA*, p. 639). If radical differences between human and chemical behaviour emerge, the analogy

* The material in this paper is taken from the book I was able to complete at the Wissenschaftskolleg: »Eine fast magische Anziehungskraft« - Goethes >Wahlverwandtschaften< und die Chemie seiner Zeit, Verlag C. H. Beck, München, 1986.

as suggested by the title and explained in the fourth chapter lies at the heart of the novel.

Surprisingly, the novel's relation to chemistry has received almost no attention. Scholars have sought analogues in Goethe's own science, e.g. his unifying concepts of >polarity< and >intensification<,² his colour theory,³ or his biology.⁴ But accepted knowledge regarding chemistry rests only on two pages in Walzel,⁵ who noted that >Wahlverwandtschaft< translates Torbem Bergman's >attractio electiva<, and (wrongly) held that an example in Bergman's *De attractionibus electivis*⁶ was the source of the central experiment of the novel, i.e. limestone + acid gypsum, water, + aerial acid. Walzel's basic error, still accepted, was to believe that Bergman was translated as *Von den Wahlverwandtschaften*, though the title is *Von der Attraction*.⁷ Using only Walzel, later Germanists overlook the extent of Goethe's borrowings, the large number of possible sources, and the historical importance of affinity theory. Conversely, historians of science believe in another source: the textbooks of J. F. A. Götting.⁸ Accepting this source, Partington's *History of Chemistry* magisterially concludes that Goethe's views were >out of date<.⁹ It remains to be seen how thoroughly Goethe's novel absorbs affinity-theory. Moreover, I wish to suggest that just as Goethe attacked Newton's *Opticks* in his *Farbenlehre*, so in his novel, more modestly, he approaches a central problem of Newtonian >attraction; and, unwittingly, comes closer to Newton's views than he could possibly have known.

In large part, the 18th. concern with >affinity< was Newtonian:¹⁰ the successful concept of >attraction< was applied to chemistry (even when other words were used) to oust the animistic idea of >sympathy<. Newton himself urged the study of affinity. Scholars traditionally cite the 31st Query of the *Opticks* (1717) to show this, but Newton first made the point in his Preface to the *Principia* (1687):

I offer this work as the mathematical principles of philosophy ... by propositions mathematically demonstrated ... I derive from the celestial phenomena the forces of gravity ... I wish [!] we could derive the rest of the phenomena of Nature by the same kind of reasoning from mechanical principles, for I am induced ... to suspect that they may all depend upon certain forces by which the particles of bodies, by some causes hitherto unknown, are either mutually¹¹ impelled towards one another, and cohere in regular figures, or are repelled ...

The 31st Query takes up the argument ()Have not the small Particles of Bodies certain Powers, Virtues, or Forces, by which they act at a distance ...?<),¹² and illustrates it with a compendium of chemical examples. As I. B. Cohen writes, this amounted to a >research program< for later students.¹³ In 1718, Geoffroy published the first tables of affinity, avoid-

ing both Newtonian and occult bias by his use of >rapport<.¹⁴ Rationalists were still sceptical about the ontology of attraction, as witnessed by Leibniz's attack of the concept, or that in Fontenelle's *Eloge* of Newton.¹⁵ Only after Voltaire's *Lettres Philosophiques* (1734) was it accepted: >l'attraction ... est une chose réelle, puisqu'on en démontre les effets< (Lettre 15).¹⁶ Later, chemists made their Newtonian inspiration clear, e.g. by verbal echoes of Query 31. Yet the ontology of attraction remained an often ignored problem, as Goethe later recognized.

After Voltaire, interest in affinity revived, probably stimulated by Macquer's *Elémens de chymie-théorique*,¹⁷ which reprinted Geoffroy's tables, and the later *Dictionnaire de chymie*.¹⁸ Now, over 40 studies appeared. Macquer gave the first and best typology of affinities; Bergman studied the largest Number, and gave the Latin name of >attractio electiva< to the central reactions upon which the study of affinity depended.¹⁹ The version of the theory which entered Goethe's novel runs from Macquer to Bergman (and back); and thence to the *Physikalisches Wörterbuch* of J. S. T. Gehler,²⁰ and that of J. C. Fischer.²¹ Goethe owned the second German edition of Macquer, knew the other dictionaries, and several other likely sources.

Detailed comparisons show that Goethe used up to ten sources, but followed none slavishly. Ultimately, his presentation rests on Macquer and Bergman. He transfers almost the entire typology of affinity in Macquer to the fourth chapter of the novel, where it forms the basis for an informal discussion between three characters, who illustrate it with (generally) standard examples, human analogues, and an explanatory theory which evolves as the conversation advances. Macquer's types and those in the novel are as follows: 1. >Affinity of aggregation< or >cohesion<, called a >Bezug auf sich selbst< in the novel, and illustrated by water, quicksilver, and oil:

Stelle dir nur das Wasser, das Öl, das Quecksilber vor, so wirst du eine Einigkeit, einen Zusammenhang ihrer Teile finden. (*Wv*, p. 38)

Similarly, the German version of Macquer discusses the >Neigung<:

welche zwey Tropfen Wasser, oder Oel, oder Quecksilber ... gegeneinander äußern.

It was only after Macquer that cohesion was fully distinguished from chemical affinity, but Goethe may have had scientific reasons for retaining it. 2. >Affinity of composition<, treated later in the novel, and there illustrated by acids and alkalis (*Wv*, p. 37), and here replaced by a simpler type represented by the example of wine and water (*Wv*, p. 36). 3. >Com-

pound affinity of composition< is also omitted, and is replaced by an example of two substances which do not mix, namely oil and water (*WV*, p. 36), in preparation for: 4. >*Mediating affinity*<, illustrated by the union of oil and water through an alkaline salt; Goethe's example for this type is not the same as Macquer's, but was common; 5. >*Simple elective attraction*<, the first type of >*attractio electiva*<, which can be symbolized: $AB + C - AC + B$, and which the novel illustrates with the limestone/sulphuric acid example, not in Macquer, but also common; 6. >*Reciprocal affinity*, omitted in the novel, which substitutes the phenomenon of >replacement<, whereby the aerial acid given off in the previous experiment re-combines with water; 7. >*Double affinity*, illustrated in the novel with the letter-symbolism common after Bergman:

Denken Sie sich ein A, das mit einem B innig verbunden ist, durch viele Mittel und durch manche Gewalt nicht von ihm zu trennen; denken Sie sich ein C, das sich ebenso zu einem D verhält; bringen Sie nun die beiden Paare in Berührung: A wird sich zu D, C zu B werfen, ohne daß man sagen kann, wer das andere zuerst verlassen, wer sich mit dem andern zuerst wieder verbunden hat. (*WV*, p. 41)

Macquer does not use letter-symbolism, but there are many analogues, e. g. in Götting:

Es kommt ein zusammengesetzter Körper A+B mit einem andern C+D zusammen, so wechseln sie ihre Bestandteile, und es entstehen zwei neue Körper, A+C und B+D.²³

As can be seen, *Die Wahlverwandtschaften* adopts five of Macquer's seven types, four being left in identical positions. The changes may in part be attributed to the literary purpose: >compound affinity< and >reciprocal affinity< both involve the union of three substances, and this has no real analogue in the human action; but the changes might also have their *rationale* in a simplification of Macquer's typology, through which it ceases to be a classification, and becomes a morphology of types. That the interest seems to extend beyond the literary purpose is suggested by the explanations of affinity included, which turn the conversation into a miniature dialogue on natural philosophy. Here, the novel returns to a problem which, within the context of affinity-theory as used by Goethe, had lain dormant for over half a century. There is much to be gained from detailed comparisons with the chemical texts for an understanding of Goethe's views, but here, there is only space for certain more general observations.

As e.g. Leibniz had argued in 1715 and Fontenelle had reiterated in 1728, >attraction< seemed open to interpretation as an >occult< quality.

Newton argued powerfully against this view in the 31st Query, by distinguishing between causes and explanations through law (>These Principles I consider not as occult Qualities ... but as general Laws of Nature ...<) ²⁴ His view was repeated almost verbatim with regard to chemical affinity in the texts familiar to Goethe, as. e.g. in Gehler:

Schlechterdings aber darf man in diesen Worten [Verwandtschaft usw.] nichts mehr, als Benennungen erwiesener Phänomene suchen. Die Ursache[n] ... bleiben noch immer unerforschliche Räthsel ... [Das Wort Verwandtschaft] bringt nur das Phänomen in Verbindung mit andern ... und giebt also höchstens eine Erklärung aus den Gesetzen, nicht aus den Ursachen ²⁵

Thus chemists opposed animist speculation. Scholars agree with Walzel that Goethe adopts Newton's (public) attitude in the novel. But this is simply false. Moreover, as recent research has shown, e.g. McGuire, ²⁶ Newton himself privately entertained views about the nature of matter which radically diverged from his public pronouncements. In one draft for the original of the 31st Query, he concludes that >we cannot say that all nature is not alive<, ²⁷ and in another, that >all matter duly formed is attended with signs of life<. ²⁸ Such precise and cautious speculation suggests how problematic the concept of matter and the related one of chemical affinity remained for Newton: whilst upholding a firm belief in >laws<, he speculated along paths which his public pronouncements effectively banished from the scientific debate. Yet lacking a >cause<, the concept remained unsatisfactory, and it is just this awkward ambiguity which *Die Wahlverwandtschaften* confronts. To do so, it develops a dynamic epistemology, through which to accommodate mutually exclusive explanations. Thus Goethe employs *both* of the competing hypotheses we may now associate with Newton. This use of contradictory hypotheses is wholly characteristic of Goethe, and is an important contribution to scientific method. It served him as a technique to approach the reality which lay behind a theory.

Characteristically, the novel repeatedly distinguishes between >words< and >things<, to stress the inadequacy of language with respect to experienced reality. As the Captain says of >affinity<:

Man sollte dergleichen ... nicht mit Worten abthun ... Jetzt müßte ich Sie mit schrecklichen Kunstworten hinhalten, die Ihnen doch keine Vorstellung gäben. (*Wv*, p. 40)

Presumably for the same reason, the novel omits classificatory terms, replacing them with descriptions of the phenomena, whereby certain classifications live on in idiomatic phrases, e.g. >Zusammenhang der

Theile< (*Wv*, p. 35), which recalls >Zusammenhang< as a synonym for >Cohäsion<. Explicitly and implicitly, the novel stresses the priority of phenomena over words. In accord with this belief, as Kleinschnieder²⁹ has shown, Goethe trained himself to use competing hypotheses:

da meine Absicht ist, einige Verhältnisse und Wirkungen der Natur in ein helleres Licht zu setzen, so kann mir nicht um *eine* Hypothese zu tun sein. (*WA*, II, 7, p. 8)

Indeed, to grasp the *phenomenon*, and not just an idea of it, he tried to use *all* available hypotheses as aids to understanding (p. 7). Two hypotheses, he considered in his preparatory notes for a *Physiology of Plants* (1790+), can be played off against each other, until the mind grasps them simultaneously. This method, he believes, will enable future researchers to see more than he:

Gewöhnt sich erst das Gemüth daran, diese beiden Hypothesen problematisch zu betrachten, gegen einander abzuwägen, eine mit der andern zu verbinden, oder eine durch die andre zu vertreiben, so gewöhnt sich der Geist vielleicht daran, beide auf einmal zu fassen, und man kann alsdann noch weiter gehen, als ich gegenwärtig nicht denken kann. (*WA*, II, 6, p. 369)

The >understanding< envisaged seems to entail a mental reconstruction of reality, with all the explanatory tools the mind can grasp. It is a related, active understanding of affinity which the Captain urges in the novel.

There, explanations start with a warning: Man is a >Narcissus<, he attributes his own wisdom and folly, his will and arbitrariness to animals, plants, and elements (*Wv*, p. 34). The view seems like that of Robert Boyle:

I look on amity and enmity, as affections of intelligent beings, and I have not yet found it explained by any, how those appetites can be placed in bodies inanimate and devoid of knowledge, or so much as sense ... what is called sympathy and antipathy ... does, in great part, depend on the actions of our own intellect 30

Where the novel differs, however, is in asserting the *inevitability* of anthropomorphism. >Death< is no less a human concept than >life<. The ensuing conversation seeks a resolution. At first, matter is seen as >dead<, when Charlotte notes that >von ganz leblosen Dingen die Rede ist< (*Wv*, p. 31). When she discovers an analogy between wine and water and >old friends<, she elevates these >lifeless substances< into >soul-less beings< (>seelenlose Wesen<, *Wv*, p. 36); later, when moving from physical to chemical relations, the Captain introduces a hypothetical construct (>as if<), not to explain *why* substances react, but to show what they look like:

>weil es wirklich aussieht, als wenn ein Verhältnis dem andern vorgezogen ...< (Wv, p. 38). It is at this point that Charlotte throws in two further explanations: >natural necessity< (>Naturnotwendigkeit<) and mere >chance< (>Gelegenheit<) (Wv, p. 38). In this way, the novel multiplies interpretations, not to produce a single >cause<, but to establish as full a picture as possible.

Advancing from >simple< to >double< elective affinity, the Captain replaces Charlotte's last explanations with more elevated ones, >a higher determination< and >a kind of wanting and choosing<, without seeing a contradiction between them:

In diesem Fahrenlassen und Ergreifen, in diesem Fliehen und Suchen, glaubt man wirklich eine höhere Bestimmung zu sehen; man traut solchen Wesen eine Art von Wollen und Wählen zu, und hält das Kunstwort Wahlverwandtschaften vollkommen gerechtfertigt. (Wv, p. 40)

By adopting the hypothesis with caution (>a kind of ...<), he can use it as an aid to knowledge without prejudice. Then, upon reaching double affinity, he uses his most overtly anthropomorphic terms, arguing that it is precisely the inadequacy of the human senses (>Sinne<) and of reason (>Vernunft<), which lead him to posit equivalents in nature, namely sense (>Sinn<) and understanding (>Verstand<):

Man muß diese todtscheinenden und doch zur Thätigkeit innerlich immer bereiten Wesen wirkend vor seinen Augen sehen, mit Theilnahme schauen, wie sie einander suchen, sich anziehen, ergreifen, zerstören, verschlingen, aufzehren und sodann aus der innigsten Verbindung wieder in erneuter, neuer, unerwarteter Gestalt hervortreten: dann traut man ihnen erst ein ewiges Leben, ja wohl gar Sinn und Verstand zu, weil wir unsere Sinne kaum genügend fühlen, sie recht zu beobachten, und unsere Vernunft kaum hinlänglich, sie zu fassen. (Wv, p. 40)

The modesty of man's equipment places the very observation of Nature almost beyond his reach. The view combines unusual humility with rare methodological sophistication, in that it encapsulates a consciousness of method within the hypothesis itself. Granted the inevitably anthropocentric nature of explanation, one may note how the view does not entail naive animism, but upholds an unequivocal distinction between human and mineral (>Vernunft<: >Verstand<; >Sinne<: >Sinn<). Having begun with a position comparable to Boyle's, or Newton's public pronouncements, the conversation ends with a view more like Newton's private reflections; indeed, it harks back to those subtler distinctions in that *locus classicus* of affinity-theory in Bacon's *Silva Silvarum*, which Whitehead³¹ held up as a model of scientific thinking:

It is certain that all bodies whatsoever, though they have no sense, yet they have perception; for when one body is applied to another, there is a *kind of election to embrace* that which is agreeable, and to exclude or expel that which is ingrate; and whether the body be alterant or altered, evermore a perception precedeth operation; for else all bodies would be like one to another.³²

In the Baconian manner, the chemical discussion examines what Whitehead calls the >immediate occasion of knowledge in its full concreteness<.

In the novelistic form, and in the context of the dialogue, Goethe lets his character go rather further in his interpretation of affinity than he himself went in his one public comment on the subject. This is in the lectures on *Comparative Anatomy* of 1796, published in *Zur Morphologie* (1820). Here too, he considers more than one explanation, writing that substances look *as if they* possess >a kind of inclination. (or >tendency [to combine]<). For this reason, he writes, chemists attribute a kind of >choice< to them, by which Goethe may mean something approaching >free-will<, or what the chemists meant to mean insofar as they were not ensnared by language, namely a *specific* and therefore elective affinity. Goethe then returns to this view, developing it in cautiously negative terms, saying that he >by no means wishes to deny matter the tender (>zart<) portion of the universal breath of nature which is its right. However, at the same time, he considers that >affinity< may play no part whatsoever in a reaction, which may wholly depend on external factors. It is this *balancing* of views which here characterizes Goethe's methodology:

[Mineralkörper] haben nach ihrer Grundbestimmung gewisse stärkere oder schwächere Verhältnisse, die, wenn sie sich zeigen, wie eine Art von Neigung aussehen, deswegen die Chemiker ihnen die Ehre einer Wahl bei solchen Verwandtschaften zuschreiben, und doch sind es oft nur äußere Determinationen, die sie da oder dort hin stoßen oder reißen, wodurch die Mineralkörper hervorgebracht werden, ob wir ihnen gleich den zarten Antheil, der ihnen an dem allgemeinen Lebenshauche der Natur gebührt, keineswegs absprechen wollen. (WA, II, 7, p. 79f.)

It is important to note that in the context of the 1790's, Goethe's methodology was in agreement with chemical findings within the context of affinity-studies. It was well known that Bergman's theory contained countless anomalies, but Bergman treated them as *apparent* anomalies. The number of these anomalies severely restricted the practical value of the theory. Moreover, on the basis of such anomalies, Berthollet was beginning to refute Bergman's theory altogether, by emphasising the multiplicity of factors apart from >affinity< which could determine a reaction.³³ Thus the method of contradictory hypotheses could encompass not only what was *believed*, but also that which was *observed*. The

contradictions were not Goethe's, but high-lighted the accepted discrepancy between theory and observation, by treating the two as equal hypotheses.

As may be seen, Goethe's treatment of affinity in his novel does not simply express a theory, but demonstrates *how* theories occur,³⁴ and how they may change with the phenomena. Each view in the novel emerges with respect to a specific reaction, and through the interaction between the observed and the observer. Not only do different >observers< give different views; but one and the same person may produce contradictory accounts simultaneously (>higher determination</>choice<). The method does not produce an unequivocal theory. But, by exploiting competing, and therefore reciprocally subordinated,³⁵ hypotheses, it turns >explanation< into an activity. The activity does not cease, but neither is it self-justifying, in that it aims to hold the phenomenon in view *between* and *through* the explanations, and, by developing them seeks ever more clearly and fully to uncover the nature of observable reality.

By such means, Goethe overcomes that logo-centricity which, as he argues in *Zur Farbenlehre*, kills observation; namely when one turns observations into concepts, and concepts into words, and then treats the words as things (*WA, II, I*, p. 285). Underlying his active epistemology, which at every point argues the inadequacy of concepts and words to mediate observable reality, there lies of course an equally active ontology, in which >change< is a central concept:

Betrachten wir ... alle Gestalten, besonders die organischen, so finden wir, daß nirgends ein Bestehendes, nirgends ein Ruhendes, Abgeschlossenes vorkommt, sondern daß vielmehr alles in einer steten Bewegung schwanke. (*WA, II, 6*, p. 9)

It is to grasp this *kind* of reality that Goethe sought to exploit mutually exclusive hypotheses. How readily an enquiring mind entertains more than one theory is revealed, for example, in a closer study of Newton's thoughts on matter. Where Goethe has a contribution to make is in his attempt to *integrate* such conflicting hypotheses into an overall view. If this does not, immediately, lead to mathematical explanation, it is less than clear that it does not produce an understanding of nature.

Notes

- 1 All quotations follow *Die Wahlverwandtschaften*, ed. Helmut Praschek, Berlin, 1963 (Akademie Ausgabe) (= *Wv*). Quotations from Goethe's other works follow *Werke. Herausgegeben im Auftrage der Großherzogin Sophie von Sachsen*, 4 Parts in 133 vols, bound in 143, Weimar, 1887-1919 (*Weimarer Ausgabe*)

- (= WA); *Werke*, 14 vols, ed. Erich Trunz, 14 vols (1948-1964), Munich, 1981 (*Hamburger Ausgabe*) (=HA).
- 2 Hubert J. Meessen, >Goethes Polaritätsidee und die *Wahlverwandtschaften*<, *Publications of the Modern Languages Association of America* 54 (1939), pp. 1105-1123.
 - 3 Grete Schaeder, >Die Idee der *Wahlverwandtschaften*< in G. S., *Gott und Welt*, Hameln, 1947, pp. 276-323.
 - 4 Robert T. Clark jr., >The Metamorphosis of Character in *Die Wahlverwandtschaften*<, *The Germanic Review* 29 (1954), pp. 243-253.
 - 5 Oskar Walzel, >Goethes *Wahlverwandtschaften* im Rahmen ihrer Zeit<, *Goethe Jahrbuch* 27 (1906), pp. 166-206; see pp. 196-8.
 - 6 Torbern Olof Bergman, *Disquisitio de attractionibus electivis* (1775), in T. O. B., *Opuscula physica et chemica*, 6 vols, Uppsala etc., 1779-90; vol. 3 (1783), pp. 291-470.
 - 7 Torbern Olof Bergman, *Von der Attraction*, in T. O. B., *Kleine physische und chymische Werke*, übersetzt von Heinrich Tabor, Frankfurt a. M., 1782-90; vol. 3 (1785), pp. 360-602.
 - 8 See Herbert Grünbaum, >Die chemische Verwandtschaftslehre in Goethes *Wahlverwandtschaften*<, *Chemiker Zeitung* 32 (1908), pp. 1173-74.
 - 9 James Riddick Partington, *A History of Chemistry*, 4 vols, London, 1961-70; vol. 3, p. 604.
 - 10 On the pervasive influence of Newton's concepts on 18th. notions of chemical attraction and affinity, see the classic studies by Hélène Metzger, *Les doctrines chimiques en France du début du XVIIe à la fin du XVIIIe siècle*, Paris, 1923; *Newton, Stahl, Boerhaave et la doctrine chimique*, Paris, 1930; *Attraction universelle et religion naturelle*, Paris, 1938; and Arnold Thackray, *Atoms and Powers. An Essay on Newtonian Matter Theory and the Development of Chemistry*, Cambridge (Mass.), 1970. On the history of chemical affinity theory see Hermann Kopp, *Geschichte der Chemie*, 4 vols, Braunschweig, 1843-47; A. M. Duncan, >Eighteenth Century Theories of Chemical Affinity and Attraction<, Diss., London, 1971; Trevor Harvey Levere, *Affinity and Matter: Elements of Chemical Philosophy 1800-1865*, Oxford, 1971.
 - 11 Sir Isaac Newton, *Mathematical Principles of Natural Philosophy* (1687), translation by Andrew Motte, revised by Florian Cajori, Berkeley, 1934, p. xviif.
 - 12 Sir Isaac Newton, *Opticks*, with a Foreword by Albert Einstein and an Introduction by I. Bernard Cohen, reprint of the 4th Edn. (1930), New York, 1952, p. 375 f.
 - 13 I. Bernard Cohen, *Franklin and Newton*, *Memoirs of the American Philosophical Society* vol. 43, Philadelphia, 1956, p. 5f.
 - 14 Etienne François Geoffroy, >Table des différents rapports observés en chimie entre différent substances<, *Histoire de l'Académie Royale des Sciences, Mémoires*, Paris, 1718 (1719), pp. 202-212.
 - 15 On the whole problem of attraction, see the classic essays by Alexandre Koyré, *Newtonian Studies*, London, 1965; see pp. 58, 144, 147 ff
 - 16 Voltaire, *Lettres Philosophiques*, in *Oeuvres*, Edition Moland, 50 vols, Paris, 1883-85; vol. 22, p. 440.
 - 17 Pierre Joseph Macquer, *Elémens de chymie-théorique*, Paris, 1749.
 - 18 Pierre Joseph Macquer, *Dictionnaire de Chymie*, 2 vols, Paris, 1766; second, Paris, 1778.
 - 19 The English term >elective attraction< was first used by William Cullen and Joseph Black in 1749 or after. See Cullen papers, Glasgow University Library, Box I, No. 18, p. 17; No. 26, p. 5r; Joseph Black, *Experiments on Magnesia Alba ...* (1755; printed 1756), Alembic Club Reprint No. 1, new edition, Edinburgh 1963, pp. 12 and 46.

- 20 Johann Samuel Traugott Gehler, *Physikalisches Wörterbuch*, 6 vols., Leipzig, 1787-95; see vol. 4, 1791, article >Verwandschaft<.
- 21 Johann Carl Fischer, *Physikalisches Wörterbuch*, 5 vols., Göttingen, 1798-1804; see vol. 5, 1804, article >Verwandschaft<.
- 22 Pierre Joseph Macquer, *Chymisches Wörterbuch*, translated by J. G. Leonhardi, 6 vols., Leipzig, 1781-83; see vol. 5, p. 435.
- 23 Johann Friedrich August Göttling, *Handbuch der theoretischen und praktischen Chemie*, 3 vols., Jena, 1789-1800, vol. 1, p. 7.
- 24 See footnote 12, p. 401.
- 25 See footnote 20, vol. 4, p. 474.
- 26 J. E. McGuire, >Forces, Active Principles and Newton's Invisible Realm, *Ambix* 15 (1968), pp. 154-208.
- 27 University Library, Cambridge, Add. Ms. 3970, fol. 620r, quoted after McGuire (footnote 26, above), p. 171.
- 28 University Library, Cambridge, Add. Ms. 39790.9, fol. 619, quoted after R. S. Westfall, *Force in Newton's Physics*, London and New York, 1971, p. 397.
- 29 See the fundamental discussion of Goethe's theory of conflicting hypotheses in Manfred Kleinschneider, *Goethes Naturstudien. Wissenschaftstheoretische und -geschichtliche Untersuchungen*, Abhandlungen zur Philosophie, Psychologie und Pädagogik, Bd. 75, Bonn, 1971.
- 30 Robert Boyle, *The Works*, ed. Thomas Birch, 6 vols, London, 1772; vol. 4, p. 289.
- 31 Alfred North Whitehead, *Science and the Modern World*, Cambridge, 1926, p.51f.
- 32 Sir Francis Bacon, *Sylva Sylvarum* or *Natural History*, in *The Works*, 2 vols, London 1838; vol. 1, p. 176.
- 33 Claude Louis Berthollet, *Recherches sur les lois de l'affinité*, Paris, 1801.
- 34 Elizabeth M. Wilkinson has shown the way in which Goethe incorporates an awareness of theory into the process of observation. See E. M. W., >The Poet as Thinker. On the Varying Modes of Goethe's Thought<, in E. M. W. and L. A. Willoughby, *Goethe Poet and Thinker*, London, 1970², pp. 133-152; p. 136.
- 35 Elizabeth M. Wilkinson and L. A. Willoughby have analysed Goethe's and Schiller's use of the concept of »reciprocal subordination«. See Friedrich Schiller, *On the Aesthetic Education of Man*, edited and translated with an introduction, commentary and glossary of terms by Elizabeth M. Wilkinson and L. A. Willoughby, Oxford, 1967, pp. 1-lxxxiv. See, too, their article >>The Whole Man« in Schiller's Theory of Culture and Society: On the Virtue of a Plurality of Models<, in *Essays in German Language, Culture and Society*, ed. Siegbert S. Prawer, R. Hinton Thomas and Leonard Forster, London, 1969, pp. 177-210; p. 191. On Goethe's use of the concept see also R. H. Stephenson, >The Coherence of Goethe's Political Outlook<, in *Tradition and Creation. Essays in Honour of Elizabeth Mary Wilkinson*, Leeds, 1978, pp. 77-88.