Ernst Cassirer on the History and Philosophy of Chemistry

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From Duhem to Bachelard, reflections on chemistry played a central role in French philosophy of science, whereas German-speaking philosophy of science, from Mach to the Vienna Circle, remained predominantly oriented toward physics. This paper presents Cassirer as an overlooked exception to this tendency. In his 1910 *Substanzbegriff und Funktionsbegriff*, he engaged closely with contemporary debates on chemistry and regularly returned to the subject in his subsequent epistemological writings. Despite growing scholarly interest in Cassirer's historiography and philosophy of mathematics and physics, his reflections on chemistry have received little attention. Addressing this gap, the paper illuminates overlooked aspects of his philosophy of the natural sciences by situating his account of chemistry within his debates with Meyerson and Rickert. It thus seeks to recover a neglected episode in the early history of the philosophy of chemistry.

Keywords: Ernst Cassirer • Chemistry • Émile Meyerson • Heinrich Rickert

Introduction

On September 30, 1909, during a visit to Paris, Hermann Cohen, the founder of the Marburg school of neo-Kantianism, sent Émile Meyerson a postcard asking whether he would be available to meet the following afternoon. In early 1908, Meyerson, a trained chemist without an academic position, published his first philosophical book, *Identité et réalité*, which brought him almost overnight prominence in Parisian intellectual circles when he was nearly fifty years old (Fruteau de Laclos 2009). In the same postcard, Cohen mentioned that one of his former students, Ernst Cassirer, was also in Paris and would join them for the meeting. Although the three spent only a "few hours" together (Meyerson to Cassirer, Nov. 2, 1909[1]), a month later, Meyerson received a copy of *Das Erkenntnisproblem in der Philosophie und Wissenschaft der neueren Zeit* (Cassirer 1906a, 1907a), Cassirer's two-volume work, in which he famously traces a linear historical development of modern science from substance-concepts to function-concepts, a distinction he had already begun to articulate systematically in his *Habilitationsvortrag* (Cassirer 1906b; see also Cassirer 1907b).

[1] ECN, Vol. 18, Doc. 121. The numbering of the Meyerson–Cassirer letters follows the DVD attached to Vol. 18 of the edition of Cassirer's *Nachlass* (ECN). However, the letters are not transcribed. Scans of the originals are available online at Hamburger Kulturgut Digital; last consulted on November 11, 2026.

By late December 1909, Meyerson had contacted Xavier Léon, the editor of the *Revue de métaphysique et de morale*, with the intention of drafting a 'critical review' of *Das Erkenntnisproblem* (Meyerson to Cassirer, Dec. 23, 1909[2]). From the outset, Cassirer welcomed Meyerson's proposal with great enthusiasm, as he was about to start working on the second edition of the book (Cassirer to Meyerson, Jan. 1, 1910[3]). Furthermore, between late April and early May 1910, Meyerson visited Cassirer in Berlin (Meyerson to Cassirer, Apr. 18, 1910[4]). Their correspondence sheds no light on what they discussed. Nevertheless, it seems plausible that Meyerson anticipated the criticism that would later appear in his published review (Meyerson 1911), where he reproached Cassirer for neglecting the role of chemistry in the epistemological debate of early modern science. This omission, according to Meyerson, led Cassirer to overstate the importance of function-concepts at the expense of the substance-concept.

By the time of Meyerson's visit to Berlin, Cassirer was also in the final stages of drafting *Substanzbegriff und Funktionsbegriff* (Cassirer 1910; see Heis 2014), a book originally conceived as a systematic counterpart to *Das Erkenntnisproblem*. In July 1910, Meyerson received at least part of the galley proofs of *Substanzbegriff und Funktionsbegriff* (Meyerson to Cassirer, Jul. 17, 1910[5]), but the complete book only much later, when the review was already in press (Meyerson to Cassirer, Oct. 21, 1910[6]). Had he had access to the book, he would have realized that, far from neglecting chemistry, Cassirer (1910, 270–92/203–20)[7] had devoted a rather well-informed twenty-page discussion to the subject. Cassirer's choice is by no means obvious. The word 'chemistry' is absent from the subject index of Paul Natorp's (1910) contemporaneous 'Marburg' monograph on the foundations of the 'exact sciences.' For Cassirer, by contrast, chemistry has a peculiar epistemological status with respect to physics. In both cases, scientific concept formation proceeds from substance-concepts to function-concepts; however, while physics foregrounds the movement toward increasingly general laws, only chemistry brings into view the complementary movement toward increasingly determinate individuality (Cassirer 1910, 270–72/203–5; 289–93/217–21).

Meyerson's review finally appeared in January 1911. Cassirer read it immediately and conceded that, from a *historiographical* perspective, *Das Erkenntnisproblem* had devoted less attention to the history of chemistry than it deserved. As a result, he added to the second edition a new section addressing Meyerson's complaints. From a *systematic* perspective, however, Cassirer integrated this material into a conceptual framework very different from the one Meyerson had in mind. On Meyerson's account, the history of chemistry unmistakably shows that scientific explanation tends toward a form of 'acosmism' (Meyerson 1911, 129), progressively eliminating distinctions until matter is asymptotically reduced to an undifferentiated unity (see Meyerson 1908, ch. VII). For Cassirer, by contrast, the history of chemistry shows more clearly than the history of physics that the 'generality' of scientific concept formation aims at an asymptotic increase in individual determinacy. The discussion of chemistry in section 4.VIII of *Substanzbegriff und Funktionsbegriff* is not merely an appendix to the preceding sections on physics. Rather, it lays the groundwork for section 4.IX, in which

[2] ECN, Vol. 18, Doc. 132.
[3] ECN, Vol. 18, Doc. 134.
[4] ECN, Vol. 18, Doc. 141.
[5] ECN, Vol. 18, Doc. 148.
[6] ECN, Vol. 18, Doc. 157.
[7] The number following the slash indicates the corresponding page in the English translation given alongside the original edition in the bibliography.

Cassirer draws on chemistry to challenge Heinrich Rickert's (1902) distinction between the 'generalizing' natural sciences and the 'individualizing' historical sciences. The case of chemistry thus enables Cassirer to bring together the arguments developed in the first part of the book and situate them within the broader debate between the two major neo-Kantian schools of the period.

As has been noted, reflections on chemistry, from Duhem to Meyerson, played a central role in early French philosophy of science (Bensaude-Vincent 2009). By contrast, German philosophy of science, perhaps influenced by Kant's own denial of chemistry's status as a 'science' (see Carrier 2001), developed primarily in relation to physics.[8] In this context, Cassirer's reflections on chemistry are all the more remarkable. However, despite the increasing attention given to Cassirer's historiography and philosophy of mathematics (Schiemer 2018, Reck 2020) and physics (Ryckman 2005, French 2014), these reflections have received little scholarly attention (see Brakel 2012, 30). Against this background, the present paper examines Cassirer's engagement with chemistry, reconstructing its historical context (section 1) and exploring its role in his confrontation with Rickert (section 2) and Meyerson (section 3). In doing so, the paper aims to shed light on overlooked aspects of Cassirer's philosophy, particularly his attitude toward atomism, while also recovering a neglected episode in the prehistory of the philosophy of chemistry. Whereas Meyerson's interest in chemistry left a lasting legacy in France, extending from Hélène Metzger to Gaston Bachelard, Cassirer's philosophy of chemistry appears to have had little resonance, not only within neo-Kantianism but also in German-speaking philosophy of science, which remained largely focused on physics.

1 Chemical Concept-Formation

Cassirer referred to chemistry throughout *Substanzbegriff und Funktionsbegriff*, but devoted section VIII of the fourth chapter, on concept formation (*Begriffsbildung*) in the natural sciences, specifically to chemical concept formation. Chemistry had initially developed as a purely 'descriptive science,' much like zoology or botany. However, by the time Cassirer was writing, the emergence of physical chemistry in the late nineteenth century had firmly established chemistry among the 'constructive sciences'.[9] In particular, chemists increasingly turned to thermodynamics to investigate chemical processes, analyzing reaction equilibrium conditions in terms of macroscopic variables such as temperature, pressure, and energy. As Cassirer points out, from this point of view, chemistry's "fundamental laws, as for example the law of phases (*Phasenregel*) of Gibbs or the law of chemical masses (*Massenwirkung*), belong to the same purely mathematical type as the propositions of theoretical physics" (Cassirer 1910, 271/204).[10] The difference between physics and chemistry thus lies not in their status as 'exact

[8] This is somewhat surprising since chemistry had become one of Germany's most successful scientific disciplines during the nineteenth century (Rocke 2021).

[9] Cassirer refers to Nernst (1896), which uses the same terminology.

[10] While the 'phase rule' determines the number of independent intensive variables compatible with the coexistence of phases, and the 'law of mass action,' in its equilibrium form, specifies the equilibrium relations among reacting species, both find a unified treatment within the thermodynamic framework developed by Gibbs, Helmholtz, Duhem, and Planck through the use of thermodynamic potentials. Alongside this program of determining the conditions of chemical equilibrium, molecular and ionic accounts of chemical phenomena were already being developed, notably by van 't Hoff and Arrhenius, without yet relying on a theory of the internal electronic structure of atoms.

sciences,' but in the historical paths by which they attained that status.

Physics had the advantage of dealing with relatively simple systems, such as planetary motion, in which bodies could be treated as 'structureless' mass points. It could therefore replace the thing-concept (*Dingbegriff*) with the concept of law (*Gesetzesbegriff*) at an early stage. Chemistry, by contrast, had to begin with the problem of the individual thing (*Einzelding*), that is, with the specific properties of elements and compounds in all their complexity (Cassirer 1910, 271/204). Cassirer therefore asks whether chemistry requires a different form of concept formation from that of physics. He argues that this question can be answered only "if we follow the concrete historical development of chemical doctrines themselves" (272/204). Given the book's systematic aims, Cassirer does not attempt to trace the history of chemistry in detail, but seeks instead to identify "the great logical lines of direction" along which it developed (272/204). Cassirer does not appear to draw directly on the original sources, relying instead on Wurtz (1879), Meyer (1884), Berthelot (1885), Ladenburg (1902), Duhem (1902), and Ostwald (1906) as his principal historical accounts of the development of chemistry. Cassirer reorganizes this material to fit his own philosophical narrative.

1.1 From Definite to Multiple Proportions

Cassirer emphasizes that concept formation in early chemistry followed the logical presuppositions of the Aristotelian system, which moves from the genus-concept (*Gattungsbegriff*) to its metaphysical counterpart, the substance-concept (*Substanzbegriff*). Medieval natural science, particularly alchemy and old chemistry, can be understood only in light of the Aristotelian model, which treats qualities as independent entities that can, at least in principle, be transferred from one body to another (Cassirer 1910, 204/154). The hypothesis of phlogiston shows how slowly this conception was abandoned in chemistry (205/155[11]): combustibility, a property that we seem to perceive directly in various bodies, was conceived as a distinct substance admixed with those bodies: "and from this assumption, the whole structure of chemistry before Lavoisier follows with inner necessity" (205/155). In a footnote, Cassirer refers to the "excellent presentation" in Meyerson's (1908) book, which assigns Lavoisier's establishment of the law of 'conservation of mass' a pivotal role in the quantitative turn in the history of chemistry. Cassirer may well have added this reference at a late stage of revision. Indeed, his account immediately diverges from Meyerson's by assigning a central role instead to the German chemist Jeremias Benjamin Richter, whom Meyerson, by contrast, does not discuss (see Duhem 1902, II.III; Ladenburg 1902, lect. 4; Wurtz 1879, I.I; Ostwald 1906, 44–49).

In Cassirer's view, Richter's 'law of definite or constant proportions' constituted "the starting-point of modern chemical *theory*" (Cassirer 1910, 273/205) and marked a decisive break with the alchemical tradition. Richter observed that definite masses of different bases were required to neutralize a fixed mass of a given acid, and that the ratios between these masses remained constant for other acids. His discovery thus established not merely the *definite* proportions characteristic of chemical compounds, as opposed to the *variable* proportions of physical mixtures, but also fixed quantitative relations between different chemical combinations. According to Cassirer, as in physics, "[t]he demand for strict numerical determination here also forms the decisive turning

[11] Translation modified.

point" (272/205). What matters for Cassirer is therefore not merely the conservation (*Beharrung*) of a quantity, as in Lavoisier, but the establishment of a coordination (*Zuordnung*) between distinct ordered sequences of numbers.[12]

Indeed, these laws could be established by measuring the masses of substances involved in chemical reactions "entirely independently of any conception of the constitution of matter, and in particular independently of the atomic hypothesis" (273/205). Richter determined the masses of different bases neutralized by a given mass of sulfuric acid, hydrofluoric acid, and other acids, arranging them into numerical series. Conversely, he determined the masses of different acids required to neutralize a given mass of a base. Following Duhem (1902, 70), Cassirer introduces a series of acids and a series of bases:

$$A_1, A_2, A_3, \ldots \qquad B_1, B_2, B_3, \ldots ,$$

and establishes a correspondence between these substances and two series of characteristic numbers:

$$m_1, m_2, m_3, \ldots \qquad n_1, n_2, n_3, \ldots ,$$

so that every acid A_i is assigned a characteristic number m_i, and every base B_j a characteristic number n_j. If sulfuric acid is assigned $m_1 = 100$, neutralization ratios yield $n_1 = 82$ for sodium hydroxide and $m_2 = 74$ for hydrochloric acid. Once m_p and n_q are known, the combining ratio of any acid A_p and base B_q is uniquely determined, without further measurements: "The manner in which an element of the first series combines with an element of the second is definitely [*eindeutig*] determined by these numbers; the two weights according to which an acid A_p combines with any base B_q are related according to the corresponding numerical values m_p and n_q" (Cassirer 1910, 273/205).

In the conventional rational reconstruction, Richter's scheme faced a difficulty: two elements can combine in different ratios. Thus, 12g of carbon combine with 16g of oxygen in carbon monoxide and 32g in carbon dioxide. From a logical point of view, it can be said that John Dalton provided a solution by formulating the 'law of multiple proportions.' Instead of abandoning the idea of characteristic masses (p_i), he retained them as fundamental proportional numbers and introduced integer multipliers (λ, μ, ν). The mass ratio of any compound is then no longer simply $p_1 : p_2$, but

$$\lambda p_1 : \mu p_2 : \nu p_3 : \cdots$$

where p_i is the characteristic proportional mass of an element (e.g., $p_C = 12$, $p_O = 16$, using modern values), and λ, μ, ν are positive integers $(1, 2, 3, \ldots)$. In carbon monoxide, the mass ratio is $1{\cdot}12 : 1{\cdot}16$, so that $\lambda = 1$ and $\mu = 1$; in carbon dioxide, it is $1{\cdot}12 : 2{\cdot}16$, so that $\lambda = 1$ and $\mu = 2$. Berzelius's chemical notation subsequently provided a symbolic representation of these combining proportions. On a purely quantitative reading, a formula such as

$$\mathrm{H_2O} \quad \text{or} \quad \mathrm{CO_2}$$

can be interpreted as an algebraic shorthand for the corresponding integer multipliers. The letters designate elements associated with characteristic proportional masses (p_1, p_2), and the subscripts indicate their multipliers (λ, μ).

[12] On the notion of coordination, see Ryckman (1991).

In this sense, Cassirer could point out that the compositional formula has a purely macroscopic quantitative content, independent of its interpretation in terms of atoms. The goal of the 'law of constant combining numbers' (*Verbindungszahlen*) was initially to establish a characteristic equivalent number for each element (*Äquivalenzzahl*), such that whenever two or more elements enter into a compound, their masses stand to one another "as whole multiples of these numbers" (Cassirer 1910, 274/206). In principle, these ratios can be established by measuring the macroscopic masses of substances involved in chemical reactions. In Dalton's work, however, this rule of 'multiple proportions' becomes associated with a particular interpretation: "The concept of combination-weight [*Verbindungsgewichts*] is transformed into that of atomic weight [*Atomgewichts*]" (274/206). Although the law does not itself require matter to be discontinuous, the occurrence of simple integer ratios receives a natural explanation if chemical elements consist of discrete units with fixed masses. Dalton interpreted such regularities by assuming that substances consist of indivisible atoms, each element possessing atoms of a characteristic mass, with hydrogen = 1 as the unit standard. Different elements possess atoms of different masses, while all atoms of the same element possess the same constant mass: "In place of the empirically gained proportion-numbers (*Proportionalzahlen*) of the individual bodies, assertions appear regarding an essential property of their ultimate constitutive parts" (274/206).

In Cassirer's rational reconstruction, Dalton's hypothesis gives rise to a fundamental difficulty: it leaves relative atomic weights underdetermined by composition alone. Taking hydrogen as the unit, the experimental facts of composition alone cannot decide between $O = 16$ and $O = 8$, if formulas are adjusted accordingly; likewise, $S = 8$, $S = 16$, $S = 32, \ldots$ remain possible without further constraints (274–75/206–7). Rather than accept this ambiguity, chemists sought independent relations to determine atomic weights unambiguously. Following Meyer's (1884) account, Cassirer shows how the *univocal determination* of relative atomic weights emerges progressively, not from a single measurement, but from the mutual confirmation and correction of results obtained through independent physical laws.[13] He mentions three particularly important ones: Avogadro's rule,[14] relating molecular weights to gas volumes and vapor densities; the Dulong–Petit law, relating atomic weights to specific heats[15]; and Mitscherlich's law of isomorphism, relating crystalline form to chemical composition and structure[16] (Cassirer 1910, 275/207). No single rule can univocally determine all the relative atomic weights: "It is only the totality of all these different points of view, mutually confirming and correcting each other, that finally after many experiments gives a unitary table of atomic weights, and thus lays the basis of a definite system of chemical formulae" (275/207).

Here the conditions of "scientific *production*" must be distinguished from those of "critical *reflection*" (279/210). A modern chemist might maintain that "[t]he objective existence of the different types of atoms is presupposed; it is only necessary to discover their *properties*, and to define them more exactly" (275/207). Although scientists may take atoms as their starting point, Cassirer insists that the empirical basis of atomic theory reveals the reverse. Inquiry begins with experimental laws (conservation of

[13] See Norton (2024) for a modern account.

[14] Equal volumes of gases at the same pressure and temperature contain equal numbers of molecules.

[15] The product of a solid element's atomic weight and its specific heat is approximately constant.

[16] Equal numbers of atoms similarly combined exhibit the same crystalline form.

mass and definite, reciprocal, and multiple proportions) that establish invariant mass relations in chemical reactions and distinguish compounds from mixtures. The concept of 'combining weight' is then reinterpreted as the 'atomic weight' of discrete constituents whose combinations explain the observed whole-number ratios. Determining atomic weights, however, requires coordinating further independent empirical relations. Thus, "[i]t becomes clear that the atom is never the given *starting-point*, but always only the *goal* of our scientific statements" (Cassirer 1910, 276/208).

As expected, Cassirer rejects Wurtz's 'naive' atomism. However, he does not embrace Ostwald's or Duhem's militant anti-atomism either.[17] For Cassirer, the alternative itself is ultimately misleading. The decisive question concerns not "metaphysical assertions regarding the *existence of atoms*", but "the characteristic *logical function of the atom-concept*" (276–77/208[18]). If one confines oneself strictly to observational data, one might simply *accept* as an empirical fact that elements combine in several distinct ratios. Daltonian atomism, by contrast, introduced the problem of *resolving* the ambiguity by establishing a unique system of atomic weights, a task that ultimately required recourse to independent physical laws see Ladenburg 1902, lect. IV. Although chemistry initially appears to investigate the properties of atoms as *bearers* of constant atomic weights, closer examination reveals that it employs the *series* of atomic weights to establish univocal correspondences between otherwise unrelated domains of experience. The Avogadro–Cannizzaro method, for example, establishes a relation between the vapor densities of gaseous substances,

$$\rho_1, \rho_2, \ldots, \rho_n \,,$$

and their molecular weights. Since the relative molecular weights of gases are proportional to their densities at the same temperature and pressure, the atomic weights of their constituent elements,

$$a_1, a_2, \ldots, a_n \,,$$

can be determined by comparing the molecular weights and chemical compositions of different compounds. The Dulong–Petit law, in turn, establishes a correspondence between these same atomic weights and the specific heats of solid elements,

$$b_1, b_2, \ldots, b_n \,,$$

such that the product of an element's atomic weight and its specific heat is approximately constant. The same series of atomic weights thus mediates between two apparently unrelated empirical domains: the behavior of gases and the thermal properties of solids (Cassirer 1910, 276–77/208).

The question of the reality of the 'atom' is thus displaced by the question of the heuristic role of the atom-concept in establishing univocal correspondences between otherwise unrelated series: "The atom functions here as the conceived unitary center of a system of coördinates, in which we conceive all assertions concerning the various groups of chemical properties as arranged" (277/208). The initially heterogeneous numerical series are brought into univocal coordination (*eindeutige Zuordnung*) by relating each of them to the mediating series of atomic weights. The atom with its determinate atomic weight is not simply an *underlying substance* bearing independently

[17] Needham (2008); for the nineteenth-century debate, see, e.g., Rocke (1984).

[18] Emphasis mine.

discovered properties. Rather, the series of atomic weights serves as the common "*comparison sequence*" (254/191)[19] through which different numerical series are related to one another: "In truth, we are concerned not so much with relating the diverse series [*Reihen*] to the atom as with *relating them reciprocally to each other* through the mediation of the concept of the atom" (Cassirer 1910, 277/208).

The law of multiple proportions expresses a regularity in the macroscopic combining weights of elements, considered pair by pair. The atomic hypothesis introduces a further demand: each element must be assigned a characteristic 'atomic weight' that applies consistently across its compounds. This demand prompted chemists to extend their investigations, drawing upon further empirical laws governing different domains of chemical and physical phenomena. As this determination progresses, the range of empirical relations itself expands accordingly: "If we conceive this progress as completed, then in the 'absolute' atomic weights all possible *relations* that the particular series could enter into with one another would be expressed", or, more precisely, in the determinate values of the *relative* atomic weights (277/209). On the one hand, by attributing observations concerning vapor density, heat capacity, isomorphism, and so forth to the same subject, we organize disparate known empirical laws into a system. On the other hand, in the attempt to determine the atomic weights, we discover previously unknown empirical laws. Cassirer can thus conclude with a characteristic neo-Kantian move: the atom should not be conceived as the 'substantial unity' from which scientific investigation begins, but rather as the 'projected unity' toward which it strives: "Thus the atom of chemistry is an 'Idea,' in the strict meaning Kant gave this term" (280/210).

1.3 From Substitution to Valence

From a logical point of view, one can say that the first stage in the development of chemistry was the ability to determine the relative atomic weights of *individual* elements. In Cassirer's reconstruction, the second stage was arranging them into *classes*. Following his sources, Cassirer points out that "[t]he empirical facts leading to such relative distinctions and combinations within the total system are given in the relations of chemical *substitution*" (281/211). Dumas observed that, when acetic acid is treated with chlorine, each volume of hydrogen removed is replaced by an equal volume of chlorine, yielding trichloroacetic acid, whose chemical behavior closely resembles that of the original compound. Contrary to the dominant theory, it could be shown that even entirely dissimilar substances can replace one another in certain compounds without fundamentally altering their chemical character.[20] By examining how different elements substitute for one another, chemists uncovered basic rules governing these substitutions: "The form of substitution can be determined once for all and expressed by certain *numerical values*, which we attach to each element along with the numerical value of its combination weight" (281/211).

To construct a systematic account of chemical substitution, chemists needed a common unit for comparing the combining capacities of different elements. Just as hydrogen served as the conventional standard for relative atomic weights, its combining

[19] Cassirer is clearly applying here the same procedure he had adopted in the previous section VII in reference to energy.

[20] Berzelius's dualistic theory deemed the replacement of a 'positive' hydrogen atom by a 'negative' chlorine atom physically impossible. Cassirer naturally found it significant that Berzelius's substance-based theory was forced to yield to Dumas's function-based substitution theory(Cassirer 1910, 282/212). On Berzelius, see Ladenburg (1902, lect. VI) and Ostwald (1906, lect. V).

capacity could serve as the unit of valence. Within the classical valence scheme, chlorine, oxygen, nitrogen, and carbon were assigned combining capacities of one, two, three, and four, respectively: Cl $\sim$ 1H, O $\sim$ 2H, N $\sim$ 3H, and C $\sim$ 4H. This establishes a further basis for relating the individual elements to one another, introducing a "new characteristic constant" for each elementary substance: "The 'valency' of the elements is the expression of a definite property in them that belongs to them independently of their chemical affinity" (Cassirer 1910, 281/211). The concept of 'valence' arises from the demand for consistency. Without it, one might merely record individual cases in which one element replaces another in compounds. Valence brings them under the general rule that substitution must preserve the total valence, allowing one to determine a coherent system of substitution relations across different compounds.

Arranged according to this rule, chemical compounds fall into various 'principal types' (*Haupttypen*) (281/211–12). Compounds belonging to the same type can be derived from a common basic form through successive substitutions governed by the valences of the elements involved. Substitution thus becomes an instrument of classification. Methane gas provides a simple illustration. In this bulk substance, carbon exhibits a total combining capacity of four, which is entirely satisfied by a proportional mass of hydrogen. Because chlorine has the same valence as hydrogen, one can progressively react methane with chlorine to generate a series of new substances. Each successive substitution strictly preserves carbon's overall fourfold requirement:

$$\mathrm{CH_4} \longrightarrow \mathrm{CH_3Cl} \longrightarrow \mathrm{CH_2Cl_2} \longrightarrow \mathrm{CHCl_3} \longrightarrow \mathrm{CCl_4}.$$

Although these compounds exhibit markedly different physical properties, they are understood chemically as modifications of the same fundamental 'methane type,' because each step involves exchanging exactly one equivalent of hydrogen for one equivalent of chlorine. The same classificatory principle is illustrated by the water type. Despite their different properties, water, alcohols, and ethers share the same basic pattern of two attachments to oxygen.

Following the logical rather than the historical order, Cassirer could thus regard the concept of valence as a foundation for the concept of 'chemical type.' What interests him is that chemical 'substitution' illustrates a form of classification in chemistry fundamentally different from the one prevailing in the descriptive sciences. Whereas traditional classification groups substances according to properties they share, the chemical type establishes a systematic relation among compounds through rules governing their possible transformations:

> The concept of the 'type' here comes in for consideration not in its significance for the special problems of chemistry, but as a paradigm of certain *logical* relations. In fact, it displays most distinctly a characteristic feature already established in general by the analysis of the exact scientific concept. The chemical concept of type is also not formed on the pattern of the genus-concept, but on that of the sequence-concept. The different combinations falling under a type are not so conceived because of the external similarity of their sensuous properties, or because of the direct agreement in their chemical functions. They belong together in so far as they can be changed into each other by means of the relation which subsists between the valency of the individual atoms, while the remote members of the series need no further *analogy* than is established by this law of derivation itself. (282/212[21])

Dumas still grouped compounds derived from one another by *analogy*, insofar as they retained similar chemical properties; Regnault extended the notion of *substitution* to

[21] Translation modified.

encompass a whole sequence of reactions yielding products whose properties differed completely from those of the initial compound (283/213). The unity of the chemical type rests not on the similarity of the actual substances themselves, but on the rules, grounded in 'valence,' that govern their possible transformations through substitution. Traditional *conceptual abstraction* establishes the unity of a class by identifying properties shared by its members. Chemistry mimics *mathematical abstraction*, which, by contrast, can establish conceptual unity through relations preserved under specified transformations. In projective geometry, two figures, however different in appearance, may belong to the same *equivalence class* if one can be transformed into the other by a collinearity-preserving transformation. Similarly, two chemical compounds, however different in their properties, may belong to the same *chemical type* if one can be derived from the other through a succession of valence-preserving substitutions (Cassirer 1910, 283/213). Whereas mathematical equivalence is constructively stipulated, chemical type is discovered empirically (283–84/213–14). However, the same model of concept formation is at work in both cases.

One might be tempted to explain valence as a "thingly quality", as if each atom possessed a fixed number of 'hooks' (284/214). Cassirer, however, dismisses these mechanical models as *obscurum per obscurius* explanations (285/214, see Wurtz 1879, 175). The real advantage of attributing to each atom its own valence is that it imposes a demand for consistency (Cassirer 1910, 283/213). The different valences must be accounted for within a coherent scheme, rather than assigned independently to accommodate each compound. At the empirical level, different combining capacities can be accepted as separate facts. The atomic hypothesis prevents chemistry from accepting this inconsistency and forces it to organize experience into a coherent system of chemical types: "what distinguishes the concept of valency from all scholastic qualities is the intellectual renunciation which it implies. It does not seek to penetrate into the substantial nature of the connection of atom and atom, but merely to represent the facts of this connection according to universal quantitative principles of order" (285/214).

Cassirer concludes that the implications of this development become particularly evident in organic chemistry, where the theory of substitution acquired greater scope once chemists recognized that groups of atoms (*Atomgruppen*), as well as individual atoms, could function as units of substitution. Although these concepts emerged historically in a different order, Cassirer appears primarily interested in their logical dependence. The conversion of methanol into chloromethane,

$$\mathrm{CH_3OH + HCl \longrightarrow CH_3Cl + H_2O}\,,$$

illustrates how a group of atoms can be treated as remaining unchanged through a chemical transformation. Here, $\mathrm{CH_3-}$ functions as a 'compound radical' (*zusammengesetztes Radikal*), while OH is replaced by Cl. Radicals could replace one or more hydrogen atoms in a compound and were accordingly classified as monovalent, divalent, and so on. For example, methyl ($\mathrm{CH_3-}$) has one point of attachment, whereas methylene ($\mathrm{CH_2-}$) has two. Whereas Laurent conceived of radicals as 'nuclei' persisting within compounds, Gerhardt treated them as 'residues,' emphasizing their role in relating different compounds through substitution (286/215). Once again, Cassirer can argue that this alternative (Ladenburg 1902, 175, 189ff.) rests on a mistaken assumption. For Cassirer, the significance of the 'radical' $\mathrm{CH_3-}$ lies not in its correspondence to an *actual* thing-like entity, but in its function of constraining the range of *possible*

substitutions. Cassirer concludes that here chemistry seems to set aside "the questions as to whether and how the elements continue to exist in the compounds into which they enter" and seeks only to discover the measurable relations "between the initial and final conditions of a process of chemical transformation" (Cassirer 1910, 286–87/215–16).

1.4 The Periodic System

Establishing a consistent scale of relative atomic weights was itself a major achievement of chemistry. As Cassirer put it, each element thereby acquired, in Leibniz's expression, a 'characteristic number' that implicitly expressed its distinctive empirical character (Cassirer 1910, 287/216). The real advance represented by concepts such as atomic weight was that the properties of atoms could now be assigned univocal positions within numerical series. Qualitative differences could thus be translated into numerical relations, with each element occupying a determinate position: "[T]his demand henceforth is extended to all physical and chemical determinations, such as are known to be dependent on certain numerical values [*Zahlwerten*]" (287/216). Here the "methodological advantage of the field of number" (*Zahlgebiet*) becomes apparent (287/216). Chemistry undergoes the same process of arithmetization that characterizes the history of physics, a process that culminates in the establishment of the *periodic system*.

Cassirer credited Lothar Meyer[22] with publishing a systematic table of elements arranged in order of increasing atomic weight and grouped according to their valence (see, e.g. Arnesano and Natile 2025). Meyer famously plotted the atomic volume V of the elements (calculated by dividing atomic weight by density in the solid state) against their atomic weight A. Connecting these points produced a striking, wave-like periodic curve $V = f(A)$. Elements occupying analogous positions on this curve, whether on its ascending or descending branches or at its maxima or minima, also exhibit analogous chemical and physical properties (valence, volatility, ductility, electrical and thermal conductivity, and so on). As Cassirer emphasizes, Meyer (1884, 176) himself observed that 'matter' had now passed from the domain of the constants of natural science into that of variables. Instead of regarding the characteristic properties of each element as independent *constants*, chemists could now treat them as functions of a common *variable*. This ordering relation is scientifically meaningful regardless of whether atoms are understood as physically existing entities: "The qualitative nature of the particular material is made mathematically conceivable by discovering a point of view from which the material can be arranged in series with a definite law of progression" (Cassirer 1910, 289/217).

To clarify the philosophical significance of the periodic table, Cassirer takes a rather lengthy detour through Locke's concept of 'substance,' which Locke develops "in connection with the example of chemical knowledge of the fundamental elements and their properties" (289/217–18). For Locke, we can know the 'nominal essences' of substances, but their 'real essences' remain inaccessible to us (see also Cassirer 1929, 505/433). The substance we customarily call 'gold' possesses a yellow color, a certain hardness, a certain specific gravity, and so forth, and behaves in a particular way toward other substances. For example, it is soluble in *aqua regia*. However many characteristics of gold we may collect, we can only assemble its 'nominal essence'; we cannot derive these properties from its 'real essence,' the ultimate metaphysical nature

[22] Mendeleev is not mentioned.

of gold (see Cassirer 1907a, 6.III). For Locke, this constitutes a fundamental limit of scientific knowledge.

According to Cassirer, the establishment of the periodic table shows that modern chemistry has moved beyond the mere determination of 'nominal essences.' It does not, of course, claim thereby to have grasped the 'real essence' of a chemical element. Yet modern chemistry does not abandon the possibility of establishing "conceptual connections" among its various empirically given properties: "Science today collects the plurality of elements into a fundamental series, whose members succeed each other according to a definite principle, and then determines the individual properties of bodies as functions of their position in this series" (Cassirer 1910, 290–91/218). This yields less than knowledge of Locke's real essence, but more than knowledge of a nominal essence. Why particular atomic weights correspond to particular properties remains unexplained. Nevertheless, these systematic dependencies allow chemists to calculate and predict specific properties: "We penetrate no deeper into the absolute being of bodies by this means; but we grasp the rules of their systematic connection more definitely" (291/219).

At this stage, the relative atomic weight of each element was still treated as an ultimate, immutable, discrete numerical constant (*starre Einzelwerte*). As long as atomic weights remained fixed, discrete constants, science had to accept them as unexplained empirical 'givens' (291/219). Yet there was no reason to regard their constancy as ultimate.[23] Indeed, Cassirer could point to the recent discovery of phenomena such as radioactivity, which seemed to suggest that the indivisible chemical atom might resolve into "a system of electrons" (214/162). Measurements of the electron's charge and mass yielded increasingly precise values, and in this convergence toward new numerical constants, science might have found a new "relative resting-point" (292/219). The achievement (*Leistung*) of the atom-constant is preserved even when its material properties change, as when "the atom of matter becomes the atom of electricity" (280/211). The atom-concept, Cassirer tentatively concludes, is a 'form-concept' (*Formbegriff*) (280/211) defined not by its particular content but by its capacity to relate different contents.

2 The Polemic with Rickert: the Case of Isomerism

Our reconstruction of Cassirer's discussion of atomic weight, valence, etc. should convey the considerable effort Cassirer devoted to familiarizing himself with contemporary chemistry. Despite this wealth of historical detail, the central argument of section VIII is straightforward. Cassirer's aim was to show that chemistry follows the same procedures of 'concept formation' (Cassirer 1910, 289/217) that he had examined in the preceding sections of the fourth chapter on the natural sciences. Like the history of physics, the history of chemistry can be understood as a process of progressive 'arithmetization,' in which qualitative differences are replaced by purely numerical differences. Yet, as Cassirer explicitly points out at the opening of section IX, the chemistry section was not merely an appendix to the previous physics sections: "The real *methodological* interest of the construction of the concepts of chemistry lies in the fact that in it the

[23] Cassirer (1910, 516/442–43) later noted that successive radioactive transformations revealed isotopes, atoms with the same chemical properties but different masses. Atomic weight thus yielded its role to a different *Ordnungszahl*, the 'atomic number,' corresponding to the nuclear charge. See also Cassirer (1936b).

relation of the universal to the particular is set in a new light" (292/220). Physics seeks general laws and treats individual things as instances of those laws. Chemistry, by contrast, appears from the outset to be concerned with determining the distinctive properties of an individual element or compound (*Einzelding*) (271/204). The case of chemistry, according to Cassirer, shows that these two directions of concept formation in the natural sciences are compatible and, indeed, inseparable.

The expression 'concept-formation' (*Begriffsbildung*) plays no role in the other works of the Marburg school. For example, the term does not appear in Natorp's contemporaneous 1910 book. By contrast, the term was given prominence by the competing Southwest school. In particular, Rickert's (1902) work had initiated a debate in contemporary German philosophy concerning the 'limits of concept formation' in the natural sciences in relation to the cultural sciences. The more universal a scientific law or concept becomes, he claims, the further it moves from actual reality. To grasp reality in its individuality, human knowledge must adopt a different, complementary methodology: the individualizing method of the historical and cultural sciences. By framing his work in terms of the debate over scientific concept formation, Cassirer clearly sought to expose the inadequacy of Rickert's sharp distinction between the *generality* of the natural sciences and the *individuality* of the historical sciences. However, it was only after treating chemistry that Cassirer could launch a direct attack on Rickert, thereby concluding the first part of the book.

For Cassirer, Rickert's conclusion is the consequence of a misunderstanding of the nature of concept formation in the mathematical sciences. Here, generality is not achieved through the progressive omission of individual differences, but through the transformation of individual differences into numerical variables. Initially, we might describe, say, a volume of gas in terms of its perceptible characteristics. Referring to Duhem (1906), Cassirer points out that physics first replaces the real gas with an idealized model whose behavior is characterized by only a few numerical variables (Cassirer 1910, 189–90/143–44): pressure p, volume v, and absolute temperature T, connected by a functional relation, the ideal gas law:

$$pv = RT\,.$$

Like many other concepts in physics, the ideal gas is a "limit-concept" (*Grenzbegriff*) (304/228), an idealized representation of a real physical system: it describes how a gas *would* behave under idealized conditions in which additional physical effects are neglected. At this point, Rickert's objection might still have force. In this model, all gases are treated as equivalent; their individual characteristics are disregarded. It seems that, to recover more specific detail, we must sacrifice the generality of the ideal gas law.

According to Cassirer, however, concept formation in physics proceeds in precisely the opposite direction. To account for the differences between 'real' gases and the 'ideal' gas, physics moves to a more 'general' functional relation that encompasses the ideal gas law as a special case. The van der Waals equation,

$$\left(p + \frac{a}{v^2}\right)(v - b) = RT\,,$$

introduces two additional empirically determinable substance-specific constants a and b, whose values differ from one gaseous substance to another (see Cassirer 1936a, 107–08/85–86). The ideal gas law is recovered by setting $a = b = 0$. The more general mathematical

framework thereby permits a more differentiated empirical characterization of particular gaseous substances: "it appears that the scientific concept is in no way denied the establishment of the individual" (Cassirer 1910, 306–7/231). The movement toward greater systematic generality is simultaneously a movement toward the more precise determination of the particular.

Rickert might still object that the goal of physics is the search for general laws, and not the determination of individuality. According to Cassirer, however, this objection loses much of its force once we move from the *laws* of physics to the *formulas* of chemistry. Indeed, the goal of the formula is precisely to identify an individual compound and its properties, as distinct from those of other compounds. Nevertheless, here too, chemistry must turn to a more general determination to grasp more particular cases. To establish this point, Cassirer appeals to the phenomenon of 'isomerism' (see Ladenburg 1902, 122–24, 274–78, Duhem 1902, chap. VII, Wurtz 1879, II.III, Ostwald 1906, lect. IV). Before the recognition of isomerism, chemists generally assumed that two substances sharing the same empirical or *compositional* formula, such as

$$C_2H_6O\,,$$

were 'indistinguishable' in terms of their elemental percentage composition. However, compounds were discovered that shared the same compositional formula but exhibited markedly different chemical properties. If chemistry followed the traditional logic of concept formation, grasping the individual difference between these 'isomers' would require adding more *concrete* sensory descriptions (color, boiling point, etc.). Chemistry, however, proceeds in the opposite direction, introducing more *abstract*, two-dimensional *constitutional* or structural formulas

$$CH_3 — O — CH_3 \qquad CH_3 — CH_2 — OH$$

which specify how the atoms are bound together through valence units to form a molecular framework (Cassirer 1910, 276/208):

> Thus if the chemical "concept" of a certain body is given by its *constitution-formula*, in which it is grasped as a particular material in its characteristic structure, it is at the same time brought under the various chemical "types," and is thus set in a definite relation to the totality of the remaining bodies. The ordinary chemical formula only gives us the composition in general, but not the type of construction of the individual elements; here it is enriched by a wealth of new relations. The general rule now in our possession enables us to trace how and according to what law the given material is transformed into another; the rule involves not only the form of the existence of the material at a definite moment, but the totality of its possible spatial and temporal phases. The further the chemical construction of concepts proceeds, the more sharply the particulars can be *distinguished*. Materials which were called similar because "isomeric," from the standpoint of the undeveloped concept are clearly separated and distinctly defined in character from the standpoint of the developed concept. (298–99/224)

Of course, Cassirer resists the idea that these formulas depict the *actual* spatial arrangement of atoms within a molecule; rather, he insists that introducing additional degrees of freedom makes it possible to represent a wider range of *possible* reactions that the compound might undergo under different conditions: "Since the constitution-formula represents this *connection*, this formula is indeed the real scientific expression of the *empirical* reality of the body; for it means nothing else than the thoroughgoing

objective connection between an individual 'thing' or particular event and the totality of real and possible experiences" (285/214).

Rickert might rightly object that an individual chemical compound is a repeatable chemical kind rather than an unrepeatable individual in the strict sense. However, according to Cassirer, this objection would amount to conceding that his real concern is not that scientific concepts fail to capture the 'individuality' of objects (*Einzelheit*), but that they fail to capture their concrete 'thinginess' (*Dinglichkeit*) (Cassirer 1910, 305/229). These, however, are distinct problems. What counts as an 'individual' is not given to theory as an external 'thing,' but is determined within the theory itself by its own 'general' concepts. Different forms of inquiry—chemistry, biology, history—employ different criteria for individuating their objects. In this sense, and only in this sense, the integration of these different forms of 'individuality' can never be completed; it remains an infinite task: "Here, in fact, the 'individual' reality shows its fundamental character of inexhaustibility. But it is the characteristic merit of the true scientific relational concepts that they attempt this task in spite of the impossibility in principle of its completion" (309/232).

3 The Debate with Meyerson: a Battle over the Substance-Concept

Just after the book was completed in July 1910, Cassirer asked his publisher to send Meyerson part of the galley proofs of *Substanzbegriff und Funktionsbegriff* that contained some short remarks on Meyerson's philosophy (Cassirer 1910, 430–431/324) (Cassirer to Meyerson, Jul. 15, 1910[24]). Cassirer hoped that their "battle over the substance-concept" (Cassirer to Meyerson, Aug. 27, 1910[25]) could be fought on equal footing before Meyerson completed his review. However, by the time Meyerson received the complete proofs, he wrote to Cassirer: "[t]he (very long) article on your *Erkenntnisproblem* has for some time been lying corrected at the editorial office, but, as I was recently informed, it may not yet appear in the next issue" (Meyerson to Cassirer, Oct. 21, 1910[26]). Meyerson was aware that, without having read Cassirer's book, he might not have been able to fully appreciate his theoretical stance. With this in mind, he added a cautionary footnote to the review (Meyerson 1911, 123; fn. 1).

3.1 Meyerson's Review of Das Erkenntnisproblem

The nearly thirty-page review appeared in January 1911. As Meyerson rightly emphasizes, Cassirer himself cautions the reader that the book "is a history only in appearance. At bottom, it is a systematic book" (100; see Ferrari 2015). For Meyerson, it is precisely this unifying perspective that gives the book much of its appeal (Meyerson 1911, 100). Cassirer's integration of the history of science with the history of philosophy was hardly new to a French audience (101). In Germany, by contrast, the separation between philosophy and science "has long been almost a tradition".[27] Notable exceptions were Friedrich Albert Lange (1882) in the previous generation and Kurd Lasswitz (1890) in Meyerson's own generation. Yet the separation "seems to be in the process of disappearing, under the persistent influence of the school of Mr. Hermann

[24] ECN, Vol. 18, Doc. 147.
[25] ECN, Vol. 18, Doc. 153.
[26] ECN, Vol. 18, Doc. 157.
[27] On this point, see also the lecture Meyerson delivered on January 25, 1911, at the École des Hautes Études Sociales (Meyerson 2011, 195–197).

Cohen" (Meyerson 1911, 101), whose students had recently produced a series of studies in this spirit (e.g. Portu 1904; Buek 1904). In this context, *Das Erkenntnisproblem* was "the most important work that a disciple of the master of Marburg has produced to date" (Meyerson 1911, 101). Given the book's enthusiastic reception by German critics, Meyerson expected it to shape the future course of philosophical thought in Germany (101).

Nevertheless, Meyerson identifies a glaring "sin of omission" in Cassirer's historical reconstruction: "The author has not, it seems to us, paid sufficient attention to the history of chemistry" (Meyerson 1911, 102). This omission is especially striking in a German book, given that German scholarship had produced Hermann Kopp's (1843–1847) monumental four-volume history of chemistry.[28] For Meyerson, Cassirer's 'sin of omission' is not a mere oversight; Meyerson seems to suggest that it reflects his tendency to downplay evidence that might challenge his functionalist conception of scientific knowledge. Meyerson concedes that Cassirer might argue that, until the second half of the eighteenth century, chemistry exerted much less influence on philosophy than physics did. The sole exception would be Boyle, both a chemist and a physicist, whose work Cassirer had indeed discussed extensively (Meyerson 1911, 102).

However, in Meyerson's view, Cassirer's treatment of Boyle in the second volume of *Das Erkenntnisproblem* is, at the very least, tendentious. Cassirer considers Boyle's contribution to epistemology solely in terms of his having replaced the Renaissance organicist conception of nature with a conception of nature as a "system of rules" (Cassirer 1907a, 312–313). For Meyerson, this reading overlooks the fact that Boyle was not merely an advocate of a lawlike conception of nature; he was "a rigid atomist, assuredly one of the most rigid that the history of science has ever known" (Meyerson 1911, 122–123). Had Cassirer examined Boyle's work from this perspective, Meyerson argues, he would have recognized the indispensable role not only of functional *lawfulness* (*légalité*) but also of the concept of *substance*. This conclusion can be avoided only by resorting to the familiar positivist "subterfuge" of claiming that Boyle proceeded *as if* atoms existed (123). To be sure, Cassirer does not resort to this "rather crude device"; instead, he adopts the strategy of Marburg idealism, in which the specific form of physical hypotheses is justified by the application of the "concept of function" (123). For Meyerson, however, the result is ultimately the same.

Meyerson takes the omission of Lavoisier's work from *Das Erkenntnisproblem* as further evidence of Cassirer's disregard for the history of chemistry (103). If Boyle could be included in the book as a physicist, treating Lavoisier would inevitably have forced Cassirer to address the entire development of chemistry, to which Lavoisier's doctrines remain "indissolubly linked" (103). For Cassirer, the development of science involves a progressive replacement of 'things' of common sense by a mathematical system of functional 'relations.' However, for Meyerson, Cassirer's account is historically untenable. When science destroys a 'thing,' "it immediately creates another, or rather it creates before destroying, for it can destroy only by creating" (129). The fate of phlogiston illustrates the point (see Meyerson 1908, 203). Its rejection did not reduce chemical reality to mathematical functions; it was accompanied by the positing of new entities, such as oxygen, to explain the phenomena: "The concept of a purely phenomenal reality, of a world of relations without a support, is entirely foreign to science; science imperatively demands a world of objective realities" (Meyerson 1911, 129).

[28] Meyerson followed Kopp's lectures in Heidelberg (Bensaude-Vincent and Telkes-Klein 2016, 31).

3.2 Chemistry in the Second Edition of Das Erkenntnisproblem

Had Meyerson been familiar with *Substanzbegriff und Funktionsbegriff* when he reviewed *Das Erkenntnisproblem*, he would presumably have tempered some of his critical remarks. Cassirer not only devoted an entire section to concept formation in chemistry, alongside his discussions of physics, but also attributed to chemistry a distinctive "methodological interest," directly contradicting what Meyerson seems to suggest (Cassirer 1910, 292/220). From Cassirer's perspective, Meyerson's philosophical position was not a consequence of his historical investigations into chemistry. Rather, Cassirer could have turned Meyerson's accusation against him, arguing that Meyerson's interpretation of the history of chemistry was itself shaped by a mistaken conception of scientific concept formation. If Cassirer had neglected Boyle and Lavoisier, Meyerson, Cassirer might have objected, was equally guilty of downplaying the contributions of Richter and Dalton. Nevertheless, Cassirer took Meyerson's criticism seriously: "Of course, you already know that I cannot agree with you on everything, but your critique contains such a sharp and concise formulation of the contrast between us that it already contributes significantly to a mutual understanding" (Cassirer to Meyerson, Feb. 21, 1911[29]).

At the time Cassirer wrote this letter, the second edition of the first volume of *Das Erkenntnisproblem* had already been published, but Cassirer promised to take Meyerson's comments into account in the second volume. After visiting Meyerson in Paris at the end of March 1911 (Cassirer to Meyerson, Mar. 30, 1911[30]), Cassirer wrote to him again just after the second volume of *Das Erkenntnisproblem* appeared: "You will notice for yourself that I have made extensive use of your review, and that it has been extremely valuable to me: for example, I have now added a new section on the development of chemistry[31]" (Cassirer to Meyerson, Oct. 25, 1911[32]). In the new section, devoted entirely to the problem of matter in chemistry, Cassirer makes a concerted effort to atone for his 'sin of omission' by addressing the historical dimension of Meyerson's objections, making systematic use of Kopp's (1843–1847) work. At the same time, however, he skillfully integrates these historical details into his own conceptual framework.

Cassirer now discusses the role of Boyle's corpuscularism in the history of chemistry, but presents it as the first step in a process in which nature is stripped of its "inner qualitative strivings and forces". Boyle conceives of nature not as a separate agent but as a "system of rules" (an expression used by Boyle himself), prescribing how corpuscles act upon and are acted upon by one another (Cassirer 1911, 2:433). Still, Cassirer suggests that the influence of this view on chemistry proper was initially meager. John Freind (1709), for example, sought to reconstruct the entire discipline along Newtonian lines, introducing the concept of attraction as an explanatory principle. Such attempts, however, ultimately remained sterile, since they were still insufficiently supported by experience (Cassirer 1911, 2:434). The first half of the eighteenth century remained dominated by the phlogiston theory, in which "the qualitative conception of natural processes once again comes characteristically to the fore" (2:434).

Cassirer now acknowledges that "only with Lavoisier's reform [...] is the scientific concept of chemistry itself transformed" (2:435). Whereas *Substanzbegriff und*

[29] ECN, Vol. 18, Doc. 161.
[30] ECN, Vol. 18, Doc. 164.
[31] Cassirer (1911, 2:428–441).
[32] ECN, Vol. 18, Doc. 178.

Funktionsbegriff mentions Lavoisier only in passing, the second edition of *Das Erkenntnisproblem* places him at the center of the narrative. While the phlogistonists treated quantitative measurements as secondary, Lavoisier made the quantitative relations between the initial and final states of chemical transformations the criterion for identifying a 'substance.' Once again, however, Cassirer makes this case study work in his favor. Whereas Meyerson emphasized the continuity of explanation in terms of persistent constituents across the transition from phlogiston theory to Lavoisier's chemistry, Cassirer interpreted the same episode as a functional reinterpretation of the concept of substance. 'Substances' in the chemical sense are characterized exclusively by quantitative permanence. Every chemical transformation of one body into another is subject to the condition that certain equations hold between the initial and final states. If anything, Cassirer suggests that Lavoisier was what Meyerson would have dismissed as a 'positivist,' restricting the scope of chemical investigation to what is given in experience: "Nevertheless, Lavoisier's achievement implicitly represents one of the most important steps towards recognizing the logical principles of empirical knowledge itself: for here the concept of substance passes definitively from its ontological into its modern epistemological-critical meaning, being conceived as a pure correlative concept to the idea of quantitative conservation" (Cassirer 1911, 2:440).

The Meyerson–Cassirer 'battle over the substance-concept' was fought with historical weapons, but the battlefield was ultimately a purely systematic one. Cassirer was ready to accommodate Meyerson's objections on historical grounds, though he entirely rejected their systematic implications. Meyerson contends that scientists continuously appeal to 'things' that remain constant beneath the apparent variety of phenomena (Boyle treats his corpuscles as being as real as tables and chairs). By contrast, Cassirer could easily reinterpret the same episode as confirming his narrative of the progressive reduction of the substance-concept to the function-concept (Boyle's corpuscles move according to mathematical laws). For all their differences, Meyerson found the second edition of *Das Erkenntnisproblem* "considerably improved" (Meyerson to Cassirer, Nov. 15, 1911[33]). Eager to see his work gain recognition, Meyerson likely appreciated that Cassirer, a rising figure in German philosophy, had taken his suggestions seriously, even if he incorporated them into a very different narrative. If the Meyerson–Cassirer debate teaches us anything, it is perhaps the limitations of such a *grand récit*: both Meyerson's and Cassirer's narratives turn out to be at once too narrow to accommodate the full range of historical evidence and so broad that virtually any case can be made to fit them.

Conclusion

In December 1912, Meyerson sent Cassirer two issues of the official organ of the French Philosophical Society devoted to Perrin's lecture on Brownian motion: "I also took part in the discussion and, of course, I attempted to turn the situation to my own advantage. Although you will probably disagree with almost everything, you might perhaps be interested in certain aspects of the whole subject" (Meyerson to Cassirer, Dec. 1, 1912[34]). Because chemical experiments could only measure *relative* atomic weights, some nineteenth-century chemists could treat atoms as a useful mathematical fiction. Using independent methods based on Brownian motion, electrical measurements, and

[33] ECN, Vol. 18, Doc. 180.
[34] ECN, Vol. 18, Doc. 195.

radioactivity, Perrin was famously able to determine Avogadro's constant (Perrin 1910, 281) and thereby calculate the *absolute* weights of atoms in grams. Doubts about the existence of atoms began to seem increasingly contrived. Indeed, as Meyerson argued in his intervention, such doubts had never been seriously entertained. Although physicists were often 'professed positivists,' they were invariably 'practicing realists.' By sending the paper to Cassirer, Meyerson wanted to 'score a point' in their ongoing debate. Cassirer's response to Meyerson's letter has a cordial yet detached tone (Cassirer to Meyerson, Jun. 23, 1913[35]). Indeed, for Cassirer the opposite was the case. The professed realism of scientists about 'substantial' entities is only a tool to achieve a more coherent system of 'functional' relations.

If we consider Cassirer's relatively sparse remarks on the subject in his epistemological writings over the following decade, it becomes clear that his concern was not with the existence of 'atoms,' a question he left to science to decide, but rather with the nature of the 'atom-concept' (*Atombegriff*). By following its history, according to Cassirer, one can see how the constancy of the atom as a thing (*Dingbegriff*) progressively gives way to the constancy of a numerical value (*Maßbegriff*): "fundamentally, such a realization, such a strictly quantitative meaning of the concept of the atom, was only reached in the beginnings of modern chemistry in the law of multiple proportions" (Cassirer 1921, 17/360). Chemistry progressively determined 'relative' atomic weights through the convergence of independent measurements, and finally their 'absolute' weights. For Cassirer, the logical significance of these measurements lies not in the proof of the existence of atoms, but in the fact that assuming the existence of atoms leads to the determination of a universal constant, the Avogadro number. The fact that heterogeneous measurements converge toward a single numerical constant provides the only warrant for the *objectivity* of physical knowledge: "Physical thought is always concerned at first with establishing a characteristic point of view of measurement in an objective physical concept, in a determinate constant of nature" (17/359[36]).

Cassirer appropriated this Planck-inspired move of replacing 'realism' about theoretical entities with the 'objectivity' of measured numerical constants in various forms throughout his subsequent writings (Cassirer 1929, 520/446).[37] However, it was only in Cassirer's (1936) later monograph on the new quantum theory that he found the opportunity to organize these remarks into a coherent form. The question of the reality of atoms has always led to the opposition between 'positivism' and 'realism.' However, for Cassirer, this is a false dichotomy. Those who regard atoms as 'fictions' cannot account for the extraordinary heuristic power of the atomic hypothesis; those who regard them as 'things' fail to account for the constant change of atomic images. This dialectic can be overcome once one recognizes that the ultimate value of the atomic hypothesis lies in its *Spürkraft*, its capacity to uncover previously unknown constants of nature. For example, the kinetic theory of gases leads to the determination of Loschmidt's constant: "These are new universal constants of which the atomic hypothesis gives us knowledge—knowledge possessing the *highest degree of 'objectivity' that natural science can possibly achieve*" (178/143[38]). The model-like representations of the atom may

[35] ECN, Vol. 18, Doc. 203.

[36] Translation modified.

[37] "When asked wherein the strictly objective factor in nature consists, the modern physicist can only point to the universal constants arrived at by investigation and, on the other hand, trace the road leading from these universal constants down to the individual constants, the particular thing-constants."

[38] Emphasis mine.

change while the universal quantitative relations they establish survive (179/144).

Once again, Cassirer resorts to a lengthy historical reconstruction of the development of the 'atom-concept' to make his point (chap. IV.2). Whereas 'physical atoms' were initially conceived as small, impenetrable bodies, Huygens later presented them as a consequence of the conservation of energy and momentum. Similarly, whereas Boyle conceived of 'chemical atoms' as thing-like entities, Dalton presented them as a consequence of the empirically established law of multiple proportions (Cassirer 1936a, 183/147):

> As with Huygens, the atom is here defined strictly substantially; but all statements concerning its nature [*Was*] ultimately merge into statements concerning quantity-definite numerical relations [*Wieviel*]. All the basic concepts and theories of chemistry, the concepts of valence and types, the concept of the radical as well as the theory of compound radicals all point in this direction. The conceptual language of atomism in conjunction with the general symbolic language of mathematics now permits the simple and magnificent development in the language of chemistry that is evident in the progress from simple to structural formulas. Stereochemistry, as established by van 't Hoff, permitted the elucidation, through a complex construction of formulas, of an entirely new group of facts, the phenomena of stereoisomerism; it threw new light on the distribution of atoms in space.[39] Thus the visual picture of the atom is modified and refined, but all these changes serve only the one purpose of circumscribing and representing an increasingly large domain of functional relations. (183–84/147)

The discovery of the electron brought together the previously separate histories of the chemical and the physical atom. The indivisible chemical atom turned into a composite system of electrons (Thomson's 'plum pudding' model) and, after the discovery of the nucleus, into a spatially structured system (Bohr's planetary model) (184–186/148–150). From this point of view, as Cassirer put it, the history of the concept of the atom appears at first sight as a "kaleidoscopic" sequence of disconnected portraits (186/149). On closer inspection, however, this sequence advances "in a single direction" (187/150). What matters is not what each atomic model corresponds to, but the stability of the universal constants toward which the series of atomic models converges: "as long as we are convinced that the progression of 'atomic models' is guided not by mood or caprice but by a definite rule, the atom has all the 'reality' of which it is capable" (187/150).

Abbreviations

ECN Cassirer, Ernst. 1995–2022. *Nachgelassene Manuskripte und Texte.* Edited by Klaus Christian Köhnke et al. 19 vols. Hamburg: Meiner.

ECW Cassirer, Ernst. 1998–2009. *Gesammelte Werke: Hamburger Ausgabe.* Edited by Birgit Recki. 26 vols. Hamburg: Meiner.

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[39] To address the case of optical isomerism, Van 't Hoff replaced the two-dimensional structural formulas with three-dimensional stereochemical formulas.

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