Acta Baltica Historiae et Philosophiae Scientiarum
Vol. 12, No. 2 (Autumn 2024)
DOI: 10.11590/abhps.2024.2.01

What Does 'φ-Scientificity' Mean? II. Measure

Ave Mets

University of Tartu
Ülikooli 18
Tartu 50090, Estonia
ave.mets@ut.ee

Abstract: Following the first part of this article series, I will examine the notion of φ-sciences' φ-ness on the example of Vihalemm's early chemical studies on affinity and both early and later accounts of the periodic table. I analyse these cases as instances where he applies the term 'measure' or 'qualitative quantity' to denote a numerical assignment, presumably attained by some measurement procedures, that capture the essence of the studied phaenomenon. I will draw conclusions about measurement scales, the numericity and mathematicity of these case studies and, more generally, make a further attempt to theoretically clarify measurement in φ-sciences.

Keywords: *chemical change, essence, mathematicity, models, numericity, periodic table of chemical elements, Rein Vihalemm, thermal energy*

Introduction

In the first article (Mets, 2024) of this series, I inquired what Vihalemm means by φ-scientificity, while he references his primary inspirations: Kant, Heidegger, and most importantly Galileo. Borrowing some missing specifications about hypotheses from Taagepera (that Vihalemm did not oppose) about models proposed by Giere (that Vihalemm explicitly supported), and hints from Vihalemm's early articles (from the 1960s and 1970s), I arrived at the following meaning of φ-ness. In this view, the theoretical account of a phaenomenon is assumed to be mathematical—the phaenomenon itself is assumed to have a mathematical essence. That means that it can be assigned numbers (through measurement) that meaningfully afford mathematical operations.

This mathematical essence, and the numbers and operations characterising the phaenomenon, are hypothesised prior to material experiments. It has remained ambiguous, though, whether making empiria-based adjustments to a hypothesised mathematical formula is consonant with φ-ness.

While these accounts could primarily give clues about models in φ-sciences, but the empirical nature of these sciences, as implied, necessitates measurement of material systems to link their mathematical models to those systems, I studied ideas about exact-scientific measurement and Galileo's measurements to determine what kind of measurement could be considered φ. I asked whether the measurement procedure itself can be regarded φ, and whether certain measure(ment)s, particularly measurement scales, are more characteristic of φ-sciences as represented in Galileo's scientific practices.

In this paper, I extend beyond the limits of Galilean science and consider those questions more broadly, using examples from Vihalemm's early and later works. In his later writings, Vihalemm specifically mentions the periodic system of chemical elements as a φ chunk of chemistry, though not necessarily mathematical. Thus, in the first section, I discuss the notions of exactness that he apparently applies differently in different contexts of the periodic law and of φ-ness in general, and argue for mathematically numerical exactness as necessary for φ-sciences.

In his early works, Vihalemm at times uses the term 'measure,' or 'qualitative quantity,' which may give us some idea about his take on measurement in the context of sciences, primarily exact sciences, their theories and models. Thus, in the second section, I discuss the notions of measure and essence in general, using, in subsections, examples from his early articles and try to discern what exactly did he mean by measure, or the numerically mathematical model that captures the essence of the phaenomenon. These examples are from the many studies about chemical substances and change. I will try to identify some features of φ-ness, particularly mathematical projection and exact-scientific measurement as extensive in the phaenomena and attributes that the examples might demonstrate. I conclude with a philosophical discussion regarding these assumedly φ aspects of measures and phaenomena, and hence their numericity and mathematicity.

1. Two meanings of exactness

The sciences called 'exact' and Vihalemm's 'φ-science' seem to nearly coalesce. This raises the question of why he would need to introduce a distinct term in addition to the one already existing. The exact sciences use mathematical formulations for their theories, precise measurements and calculations, and their predictions concerning the phaenomena in their purview are correspondingly awe-inspiringly exact. This appears to be the feat that practitioners of other sciences may and often do try to emulate. An example of this is the excessively precisely provided statistical data in social sciences (see Taagepera, 2008, for a criticism of this strive towards excessive and meaningless precision). As we saw in the first article of this series (Mets, 2024), Vihalemm considers Galileo's way of doing sciences as exemplary of φ-ness and that Galileo, in his publications, omitted the numbers he obtained as results of his physical measurements (in contemporary terms, these numbers would be considered the empirical evidence of his theory). Instead, Vihalemm stresses the importance of 'Galilean idealisation' for φ-science. He often cursorily mentions point masses and frictionless planes as examples of the 'Galilean idealisation,' though he does offer a tiny commentary on it in relation to the periodic system of chemical elements.

In (Vihalemm, 2003a, p. 12), he quotes Eric Scerri and Lee McIntyre (1997, pp. 221, 223) about the exactness of the periodic law: namely, it "is not exact in the same sense as are laws of physics"; instead, "[t]he law expresses an approximate [i.e., not numerically exact] trend among the properties of the elements and their compounds." Vihalemm regards the lawness, and hence φ-ness, of the periodic law to stem not from its relation to (measured or calculated) numbers, but from idealisation:

> When I say that the periodic law is exact in the same [philosophical] sense as are the laws of physics, what I have in mind is not the exactness of the statements about the world or mathematical equations. Exactness of a law here means that it involves the *construction and application of idealized objects construed as models of real systems*. (Vihalemm, 2003a, p. 13, emphasis added; see also Vihalemm, 2015, p. 11)

According to Vihalemm, the periodic law is certainly a real law of nature, though not quantitative or mathematically formulated. The defining aspect of an element, its place in the periodic system, "was reached through a fundamental idealisation substantiated by experimental chemistry." Mendeleev's starting

point for idealisation—that experimental chemistry—did measure quantities of substances in a precise manner, obtaining knowledge about elements' atomic weights and exact atomic compositions of compounds (molecular formulae). Before Mendeleev, characteristics of each element were derived purely empirically, ad hoc. Mendeleev arranged them into a system and "constructed" a new systematic characteristic—the place in the system (Vihalemm, 2003a).

Now, there is a serious shortcoming in Vihalemm's assertions concerning this matter: he never gives the reader a formulation of 'the periodic law' or 'the periodic system.' What exactly are the periods? What do they consist in? How do they form? Does he have in mind the system that Mendeleev conceived or the contemporary one? Mendeleev formed the periods by sequencing elements in increasing order of their atomic weights and placed fractions of the sequence so that chemically similar elements formed groups. In this manner ,their valencies, or chemical properties (but also physical properties), formed periods in this sequence; that is, valencies and chemical (and physical) properties changed periodically with the increase of atomic weights. He was not the first to observe this. The change is not exact—the same values of most properties do not repeat themselves exactly as atomic weights increase, but trends do. Finding atomic weights was an arduous task for many a chemist over decades, and it could only be determined statistically in the sense that the number obtained represented an arithmetic average of collections of atoms. Nowadays, the sequence follows the atomic number, which is an exact integer.

Thus, the measurement—and, specifically, exact measurement (of "atomic weights")—was indeed the bedrock of the periodic system, as Vihalemm claims. By "exact," I here mean relative exactness: the statistical collections were measured in the manner appropriate for them, obtaining adequate scale and accuracy. The scale—a quasi-ratio scale with hydrogen representing the unit—enabled laboratory operations with chemical substances (weighing, supplying necessary bulk into a reaction). The accuracy was reached through meticulous measurements. However, according to Vihalemm, the exactness or φ-ness of the system (or law) does not consist in numerical determination but, instead, idealisation. What might exactness of idealisation mean here? I suspect that it means building an idealised model that exactly captures those aspects of the ("pure") phaenomenon (periodicity) that provide the desired end result—that is, a representation of the phaenomenon that enables accurate enough description and prediction of it, whatever the accuracy (it can vary in different cases, and need not be numerical).

However, playing all one's cards of φ-ness on idealisation is insufficient and even erroneous for at least two reasons, which I argue Vihalemm should have realised. Firstly, due to the nature of scientific theories as consisting of abstract models—an idea popularised by Ronald Giere (e.g., 1988) that Vihalemm strongly supported. According to Giere, all sciences are engaged in building models about their studied phaenomena, the core of scientific theories are the abstract, idealised models obtained thereby, and all models are idealisations of their modelled object in that they only aim to capture certain aspects of the phaenomena or objects and leave out most other aspects.[1] This is what Galileo did explicitly: he included height and angle of descent of the body in his model of free (or obstructed) fall, and stated that he disregards material circumstances such as imperfections of the inclined plane and others which are there in the real setup. Giere (1988) shows the abstraction from irrelevant (with respect to the aim at hand) circumstances in case of geology, a non-exact science. A well-known idealisation is the perfectly rational and optimising agent in economics that calculates their costs and benefits and always chooses the most optimal option, while it is also well known that such hardly ever exist in real life. This model neglects the true "imperfections" of real human agents like emotions, informational or perceptual hindrances. And let us not forget that Vihalemm understands his notion of φ-science as a model obtained through the Galilean idealisation procedure. Hence, idealisation in Galilean sense exists in all sciences irrespective of their being φ or non-φ.

Secondly, Vihalemm emphasises the empiricism of φ-sciences, arguing that they are about the material world and thus their mathematical models must be tested against material systems, mostly through experimentation. Considering this, if the mere idealised object itself constituted φ-ness, remaining indefinitely far from matter, then any idealisation, however unrealistic and unassociable with the material world, could qualify as φ. This is certainly not the intent of an empirical science, nor of Vihalemm. Mendeleev's implied hypotheses about yet undiscovered elements relied not only on their physical properties but on numerical determinations (atomic weights and valencies) to justify their inclusion in his table or grid. On the other hand, he made predictions, based on his table, and more so on the renewed 1905 table, that were just as idealised but utterly inadequate and even ontically wrong (the coronium and aether, for

[1] Already early in his career (e.g., in Vihalemm, 1979, pp. 178–180), Vihalemm analogously argued that scientific mathematical laws, or theoretical schemata, are not directly about the material world but about idealisations, which, just as Giere conceptualises them, have similarity with the material world.

instance). Also, any speculative thought experiments with contrived numbers, of the sort that Galileo held for the earlier stage of his conceptualisation of free fall, would suffice.

In one of his early papers, Vihalemm gives crucial credit to quantitativeness: "Discovery of the essence becomes possible through a quantitative approach, by determining the measure of the phaenomenon (and this, in turn, becomes possible on the basis of a distinct structure)" (Vihalemm, 2024, p. 131). This is said in the context of the study of chemical affinity, where answers regarding the nature of this phaenomenon were finally found by what Vihalemm would later have included under φ aspects of chemistry. Qualitative study, discerning a phaenomenon from all others, is necessary for delimiting it and making it a focus of inquiry, and in chemistry it is indispensable as the core of that science, but the inquiry itself must proceed quantitatively (Vihalemm, 2019, pp. 77, 81–82).

Thus, I conclude that, firstly, numerical mathematicity and exactness in the sense of numerical calculability and measurability are indispensable for a science to be demarcated as specifically φ; and, secondly, that the mathematicity stands for substantive numericity, meaning the measurements feeding into it should have a true measurand.

Does this imply that the periodic law is not really a law of nature in Vihalemm's sense, contrary to his own claim? I will address this question below.

2. Essence, φ-ness, and measure

In his early papers from the 1960s, through the 1970s, and up to the early 1980s, Vihalemm (2019, pp. 123, 133; 2020; 2022; 2023) understood the term 'measure' or 'qualitative quantity'—"the unity of quality and quantity" (Vihalemm, 2022, p. 150)—as the truthful numerical assignment for a property or phaenomenon, that is, an assignment that reflects the essence of a phaenomenon, "a quantity that has been defined (fixed) for a particular quality" (Vihalemm, 2019, p. 123). As the above quote suggests, Vihalemm (2024, p. 131) links essence explicitly to quantitative theory-building research: the essence is discovered "through a quantitative approach" where the measure of the phaenomenon is determined "on the basis of a distinct structure," and "[a]wareness of measure leads to such quantitative cognition which connects directly with the quality of the object, explores the basis of the quality, conducts

measurements with its own measurement units and formulates quantitative laws" (Vihalemm, 2019, p. 123). In the context of chemical affinity, or the reactive properties of substances, structure refers to the structures, and at once essences, of the different aspects or orders of this phaenomenon: molecular-kinetic, thermodynamic, and the underlying quantum levels of substances that determine their reactive properties (see Vihalemm, 2023 for details). Thus, by the claim "phaenomena are recognised as manifestations of essence" (Vihalemm, 2023, p. 137), he means that chemical affinity as a phaenomenon manifests its molecular-kinetic, thermodynamic, and quantum-chemical essences.

To clarify what 'essential' as an attribute of scientific reasoning might be, his comparison with some other modes of scientific thinking can be given. As to models, he discerns essential models from model conceptions which are qualitative-formal (Vihalemm, 2023, p. 129, n3). From the 13th to the early 20th century, conceptions of chemical affinity were corpuscular-mechanical, electric, or electronic. Those did not afford mathematisation or quantification of the phaenomenon. On the other hand, merely empirical laws, in contrast to essential (or theoretical) laws, may give numerical results and be explanatory in a broad sense of the term (e.g., Guldberg and Waage's empirical studies of chemical equilibrium and rates of reactions obtained; Vihalemm, 2023, pp. 127–128), but they give no essence, that is, no explanation in the narrow sense, answering *why* something is as it is (Vihalemm, 2023, p. 134; see also Vihalemm, 2022, p. 146; 2021, p. 113). He says about chemical affinity: "The truth is that the chemical transformation of substances, the actual chemical process, is a unity of mechanical, physical, and the so-called elementary-chemical processes" (Vihalemm, 2023, p. 126), corresponding to the aspects enumerated above, suggesting his belief in a true nature or essence of phaenomena. His defence of unity, certain monist, paradigm-based approach in physical sciences in (Vihalemm, 2016) alludes that he still held analogous views later, and his defence of the term essence in relation to the terms 'natural kinds' and 'laws of nature' (e.g., in Vihalemm, 2003b; 2011) directly attests of the persistence of this partisanship.

Below is a brief explication of the notions of models or laws[2] that Vihalemm applied in these early papers, and of Giere's notion of scientific model that Vihalemm came to endorse later. Vihalemm's notion of models, appropriately to his context of the evolution of a chemical phaenomenon, represent the different

[2] Vihalemm uses the word 'model' mostly in the expression '(qualitative) model conception,' often also in 'theoretical/essential model,' whereas he applies the word 'law' in 'empirical law' and also in 'theoretical law.' It is clear, though, that he means the same type of thing, thus theoretical law and theoretical model are more or less the same.

stages of this evolution, that is, they appear diachronically. The qualitative model conceptions are analogies of yet (theoretically) unconceptualised phaenomena with known phaenomena that also shape the scientific world picture. An example might be likening reflecting light to bodies falling on surfaces and bouncing back at certain angles, or likening electrons and nuclei to planets and their stars. An empirical law is usually meant as one based on systematic measurements, values obtained thereby, and yielding a mathematical relation between variables (measured properties treated as variables in the mathematical formula). I would extend this notion also to qualitative properties (or intensive properties, as expressed in measurement theory) that are used to systematise knowledge, for instance, the qualitative aspects of chemical substances (e.g., that all metals are similar in certain respects and differ from non-metals in those respects). A theoretical or essential model or law is one that is based on theoretical understanding of a phaenomenon, capturing its true essence or ontology, and enabling mathematical conceptualisation of it ex ante. From a measurement theory perspective, I understand this to mean that the essential properties of the phaenomenon that the essential or theoretical model suggests are correct and thus the model enables correct measurement of the phaenomenon, where measured values pertain to real entities and properties.

Giere's understanding of scientific model, meanwhile, is synchronous; he does not look into the evolution of science in this aspect. His stated view of the nature of science as a set of models refers to a hierarchy of models (he shuns the term 'law' for its historical-theological connotations). His principled models, which he also calls principles or definitions, serve as general (mathematical) definitions or axioms in science, for example, the concept of force as $f = ma$, and have no direct similarity to any concrete spatio-temporal things. Based on these principles, and adding concrete restrictions, representational models are formulated, which do have similarities to concrete things in the world. These can be used to formulate concrete (numerical) hypotheses.[3] Vihalemm's empirical laws are certainly included in this ilk. In other respects, their classifications of models are not in direct and clear correlation, for at least some of Vihalemm's essential models too seem to be representational, though the evidential base of the extension of this term is too limited to draw a conclusive correlation with Giere's hierarchy of models.

In a sense, even though Vihalemm seems to define phaenomenon as a plainly perceivable regularity, since for empirical research also the hypothesised essences must be rendered perceivable in some manner, either directly or indirectly, then

[3] I omit other models in Giere's schema for their non-relevance in this context.

"phaenomenon manifests its essence" must mean that the studied phaenomenon manifests another phaenomenon which is considered its essence, more basic and general. There are, however, different ways to consider something as manifesting something else, as it already cursorily shimmered in the first article, in which Vihalemm only hints at it. Something can be a manifestation of its causes, as Aristotle (allegedly) saw (speed of) motion as a manifestation of the moving cause; or something can be a manifestation of what it consists in. Vihalemm writes about the chemical bond and reactive properties of chemicals as a manifestation of the quantum-level properties of particles (atoms, ions). Both meanings of manifestation may be present here since chemical bond and chemical affinity *consist* in the interactions between electronic shells of particles (which are themselves manifestations of interactions between nuclei and electrons); also, the structure of electron shells co-causes particles to interact, in one way or another (there are other conditions at play, too, that affect the interaction).

Indeed, essence is linked to the cause of the phaenomenon too, since Vihalemm (2024, p. 134) positively quotes Nikitin (1963): "the cause of the origin or change of a thing usually determines its essence to a great extent. […] Overlooking the cause of a phaenomenon usually makes it impossible to establish its essence, its intrinsic nature," even though knowledge of cause is not the knowledge of essence. Determining the essence of a phaenomenon provides a firm grounding to the "empirical relations between the results and conditions (or causes—R. V.)" found in purely empirical research (Sagatovskii, 1965, cited in Vihalemm, 2024, p. 134). This suggests that in the above example of chemical affinity, the "truest" essence should be understood to lie in the quantum-level account, while the molecular-kinetic and thermodynamic accounts present models of more generalised or summarised aspects, with additional influencing circumstances (such as heat energy) taken into account. The given citations also imply that the cause of the phaenomenon is assumed to be mathematisable or conveyable in a meaningfully (representationally and calculably) numerical form. The latter is expressed in Vihalemm's summarised characterisations of φ-sciences, where he states that they adapt the world to fit their (mathematical) cognition and study only those aspects of the world that do submit to mathematical treatment.

Let us examine some important differences between him and other authors quoted in these specifications of exact scientific mode of reasoning. Neither Taagepera, quoted in the first article of this series on the kind of hypothesis appropriate for physical sciences (substantively quantitative principled hypothesis), nor Giere make crucial distinctions between essential and merely empirical mode of research or models. Giere, for sure, mentions that representational models

can be obtained from measurement results, that is, from purely empirical study, according to Vihalemm's early accounts, but he treats these as equivalent to models derived from higher-order, principled models. Giere's principled models, on their part, do not exactly entail what Vihalemm would have counted as theoretical models, since the latter include models that do refer and are no mere definitions (such as the periodic system of chemical elements, as will be discussed below). Taagepera's hypothesis, even if commissioned to take into account the logically possible values of variables, which on their part are determined by the variable's (phaenomenon's) essence, are by themselves not necessarily about the essence of the phaenomenon as Vihalemm understands it. For instance, the molecular-kinetic and thermodynamic accounts of chemical affinity should consider its quantum account to avoid erring into impossibilities.

In an attempt to bring more clarity to the essences and measures of phaenomena as Vihalemm likely intended them, I will examine his own examples. He mentions measure in three examples: units of chemical substances and change (Vihalemm, 2020; 2023); thermal energy as 'a *measure* of thermal motion' (Vihalemm, 2023, p. 130); and essence, yet with the periodic law of chemical elements (Vihalemm, 2022, p. 148 and n27). The first two examples are also relevant to the periodic system, since they form the foundation of that system, which is systematised and determines its form—a regular grid. I will discuss these separately and thereby try to establish the specific ontology that Vihalemm refers to, both in comparison to non-essential measurements as well as to what kind of empirical relational system (ERS) is meant.

We will see that, perhaps predictably, the idea of essence is complex and ambiguous, for it is not always entirely clear why Vihalemm considers something to be the essence of a phenomenon, and something to be its measure. Nor is he always consistent in leaning on the quantum-chemical level when pursuing his account of essences and measures in chemistry. He is even terser about his third example of measure, the thermal energy. Thus, it is necessary to dig deeper into those cases and offer some critique and my own suggestions from measurement-theoretic perspectives.

2.1 Chemical substance

Chemical affinity is the subject of many of Vihalemm's early studies (Vihalemm, 2020; 2021; 2023; 2024). The focus is on the conceptualisation of chemical substances' reactive properties. In (Vihalemm, 2020), he differentiates, first, between quantitative and qualitative inquiry in chemistry: the phlogistonist

systems were qualitative in their core, observing the qualitative properties and changes of substances (see also Vihalemm, 2019, p. 102). The advent of measurements of masses and volumes at once introduced quantitativeness into chemistry. The reacting substances and the resulting substances of reactions came to be weighed. The units used, however, were still physical-mechanical, such as grams for weight, characterising substance "as such," as physical substance not distinct chemical substance, importantly (and primarily) distinguished also by their qualitative properties that chemistry is interested in, such as type (metal, non-metal, gas), reactivity, colour, odour, etc. The aim was to quantify substances' affinity, or reactive properties (reactivity) toward each other, and thus to find units that underlie this phaenomenon.

Vihalemm (2020) discerns two steps in quantifying essentially chemical units of affinity: firstly, substance's bulk versus number, also expressed as mass versus (chemical) amount (Atkins & de Paula, 2009, p. 8), or "how many active agent's units are there (in a bulk)," as I would understand it—atoms and molecules. Secondly, the capability of reaction of a unit of substance—its valency. Both units were non-trivial and cognisance of them was achieved through considerable efforts of chemists. Here, I focus mainly on the first step. The next subsection will address chemical reactivity, or affinity, in relation to valency.

It is presumed that the mechanical units and scales—grams and their ratio scales—and their measurement procedures and standards were commonly known and by purely pragmatic logic applied to bulks of stuff, as portions of chemical substances appear to human perception. However, according to Vihalemm, this would yield no more than an empirical model of the phaenomenon. While it may enable insight into some broader features, such as the fixed proportions of elements in compound substances and, correspondingly, in reactions—the weight-based stoichiometric laws and equivalent weights—it did not reveal an essence that would allow extrapolation to yet unobserved instances. Here the essential models of substance and affinity (atoms and valencies) are juxtaposed to merely empirically describe relative weights of reactants in grams as general or unspecific physical units (Vihalemm, 2020, p. 129; 2023, p. 123).

An untoward outcome of merely mechanical determination of substances' quantity would thus be the lack of any guidance about what kind of phaenomenon should be looked for: what makes substances different from each other, what renders them the qualities they have. Some guidance on units of substances (or elements) was provided by the concept of atom, introduced in chemistry by John Dalton at the beginning of the 19th century. Such an idea—of the fundamental

ontology of matter—could only be theoretical and remained speculative for a long time (cf. Chang, 2012, ch. 3, about the operational ways chemists learned to count atoms). I thus consider it a φ hypothesis in the sense of Heideggerian projection, introduced in (Mets, 2024). Basically, it implies that the fundamental units or building blocks of substances (including simple substances, the material counterparts of elements) have a definite size and weight, and thus could be treated as (theoretical) units.

Speaking about units, at this point one must understand the unit of a particular substance, its (theoretical) elementary building block. I add 'theoretical' because, besides atom remaining a non-empirical term for a long time, I simplify the treatment here: mostly substances contain various and varying building blocks, but I only discuss atoms and molecules, omitting ions on this occasion. Thus, the theoretical elementary building blocks of water are H_2O molecules, although it also contains H_3O^+ and OH^- ions (Schummer, 1998, p. 137). The units of oxygen as element are O atoms, the units of oxygen as pure substance are O_2 or O_3 molecules, etc. In this context, the unit of each substance can only "measure" (in Vihalemm's sense) its own kind, and the designation of hydrogen as the prevailing unit was primarily for operational purposes—for measuring weights of substances in reactions in laboratories and comparing them. Hydrogen was thus assigned the atomic weight '1' and other (pure) substances were assigned numbers that were multiples of it (experimentally determined through weight measurements, stoichiometric equations, etc.).

Vihalemm views atomic weights (and, accordingly, molecular weights), defined in this way, as 'chemical units,' that is, the measure of chemical elements or substances (Vihalemm, 2019, p. 132; 2020, p. 129). Why would he deem this schema to reflect the essence of chemical substances, while it might just constitute another ratio scale with arbitrarily chosen unit, even though this time a naturally existing one based on a chemical idea? This he does not explicate. The question is even more pertinent if we take into account the real alternatives, such as oxygen at value 100, used by Berzelius; the current atomic mass defined based on carbon at value $\frac{1}{12}$ of ^{12}C (the unit dalton), and earlier mass, similarly based on oxygen at value $\frac{1}{16}$ of its atomic weight (Lang *et al.*, 1959, p. 361; Landau, Akhiezer & Lifshitz, 1967, p. 105), which indicates the arbitrariness of this unit. The idea that all elements (and/or their atomic weights) be multiples of that (of the atomic weight) of hydrogen or its fraction, as William Prout and others after him hypothesised, does not hold in this form, as Vihalemm also agrees. That was made clear in the nineteenth-century efforts, where the atomic

weights of some chemical elements stubbornly remained nonintegral multiples of this unit. Vihalemm does not mention atomic number, which is nowadays used to define chemical elements, possibly because of the practical use of atomic weight for chemical practices: atomic number was a latecomer and could not be determined with chemical laboratory equipment, but atomic weight allowed measurement of, and weight-wise comparisons between, combinations with and abstractions from substances just as precise as the extant measuring technology afforded. It constituted the core of the paradigm that rested on the principles of, first, primacy of mass as a property of matter, and second, conservation of matter and, respectively, of mass (Vihalemm, 2019, pp. 134, 97), which provided clear practical guidance in laboratory experiments (initial substances and reaction outcomes had to have equal masses).

Prout's hypothesis, an a priori guide for empirical work, was another φ assumption in two senses: it is a pro-jection of the phaenomenon searched for and suggests a mathematical logic—integral multiplicity of a certain unit of elements' atomic weights. However, it unfolded as non-φ in material sense: firstly, it could not be realised, the atomic weights remaining both overly deviant from this logic as well as imprecise; secondly, the manner of measuring them was of statistical or summarising nature, implicitly averaging over isotopes (unknown back then) and more explicitly dealing with collectives of possibly differing proportions of isotopes. (The contemporary manner, by mass spectrometry, is more appropriately called statistical, since it explicitly averages over known proportions of isotopes with known atomic masses.) A summarising description is deemed qualitative by Vihalemm (2023, p. 126). Purely statistical description, such as in social sciences, is not φ, according to Vihalemm,[4] and would count as an empirical model in his early parlance. The cause of this imprecision was only discovered later with the gradual discovery of atomic structure, particularly neutron and its variable number in nuclei. The statistical-summarising nature or unclarity of the measurand, however, are not the reasons why Vihalemm (2019, p. 140) rejects Prout's hypothesis as the pro-jected theory of chemical substances; instead, it is due to measurement results.

Atomic weight was neither sufficient for establishing the chemical units of affinity, nor could they be determined merely by defining the unit object hydrogen. Further assumptions were required to conceptualise the perceived and weighed reactants into properly chemical units, that is, molecules (for the sake of simplicity, I omit ions): how many atoms of any single constituent

[4] Personal communication, see also Mets, 2009, p. 124.

element compose a certain substance's molecule. Guidance for this came with the idea of fixed proportions of elements in compounds, countering the idea of continuously varying proportions (e.g., Vihalemm, 2019, p. 120); though this was not necessarily operationally easier, as the distinction between solutions and compounds had not been clearly made, which influenced Berthollet's studies supporting the varying proportions (Vihalemm, 2019, ch. V) and Dalton's ideas about structures of substances. Also, based on Vihalemm's claims, the atomic hypothesis was metaphysically insufficient for determining the weights of the atoms of different elements, allowing the idea that all atoms have the same weight (Vihalemm, 2020, p. 127, referring to Berthollet[5]). A direct corollary of this would be that the same mass of all substances contains the same number of their building blocks; for example, 1 g of hydrogen and 1 g of oxygen each have the same number of hydrogen particles and oxygen particles, respectively. This would imply that when hydrogen and oxygen react without residue to build water, it should yield the conclusion that water consists of 1 particle of hydrogen per 8 particles of oxygen, though Vihalemm does not make such conclusions explicit. Neither have I any information about whether such conclusions were ever made, but this is an example of what might happen if the numbers assigned to observables or hypothesised entities notably digress from the real relations, possibly yielding erroneous projections about their ontology and possibilities of observing them, based on misleading theory.

Thus, once the components of a compound were determined, their atom-based, and not merely mass-based proportions were found, thus gradually leading to valency as the main cause for the proportions and reactive properties of elements. These concepts, grounding the measurements, were indispensable for determining the atomic weights of elements, ultimately leading to the formulation of the periodic system.[6]

I suspect that Vihalemm designates the concept of atomic weight a qualitative quantity because it implies the atomic-molecular nature of matter, the measurement scale being discrete as befits and reflects that structure, while the summarising nature of this quantity can be seen as reflecting the true variability of isotopes, even if that was not known until much later. Also, it affords summation

[5] However, I cannot confirm that Berthollet held such a view. Vihalemm could have inferred the indifference of the weights of atoms of different substances from Berthollet's descriptions of his chemical experiments on affinity, where he claims having taken (weight-wise?) equal amounts of the reactants and assumed those to be equal reactive amounts of those substances.

[6] See Chang (2012) about the details of the process of determining atomic weights, in interaction with determining the molecular composition of substances and other properties of stuff; see Eric Scerri's works on the periodic table and its history.

and multiplication, appropriately for an extensive measurement, reflecting a narrow but important aspect of the science of chemistry, of the processes that chemical atoms go through in analysis-synthesis reactions, and corresponding operations carried out in laboratories; unlike atomic numbers whose sum due to concatenated (bound) atoms in molecules does not make any practical sense for chemistry. These measurements and calculations of the persistent aspect of elements enabled determining the constancy of elements while their other properties changed from one state or compound to another. On the other hand, contrary to Vihalemm, in the 19th century atomic weights were not the theoretical knowledge that would provide the essence of the phaenomena, but merely empirical knowledge as discerned in (Vihalemm, 2022), which, as mentioned and discussed further in section 2.3, could lead the conceptualisation of chemical ontology astray.

Another extremely important measure of substance, albeit unexplored by Vihalemm, is the mole, defined by Avogadro's number—a specific number of particles of a substance used to define most standard chemical and physical attributes for characterising substances, for instance heat capacity or ionisation energy. Expressed in this way, extensive properties become intensive or non-summable. On the basis of this widespread use and practical importance one could think that the mole and molar mass are measures of substance, and in laboratory practices they are indeed. They are the macro-level counterpart of numbers of substances involved in reactions and other processes. Nonetheless, this number itself is rather arbitrary, defined on the basis of the number of carbon-12 atoms in 12 grams of that substance, and empirical (in Vihalemm's sense) not theoretical, as it required counting this number of atoms and has thus been imprecise (even though now precisely determined).

2.2 Chemical change

As noted above, Vihalemm considers the different mathematised accounts of chemical affinity to reflect its various true aspects or essences: thermodynamic, molecular-kinetic, and quantum chemical. This implies that, even though Vihalemm (2020) does not go beyond mentioning 'units of affinity,' there must be different units that should be deemed appropriate or essential measures of those several facets of chemical reactivity. Besides valency, though, he does not specify the units. The aspects that he discusses are nowadays not always given the title 'affinity.' The International Union of Pure and Applied Chemistry (IUPAC) does provide a definition of 'affinity of reaction': "Negative partial derivative

of Gibbs energy with respect to extent of reaction at constant pressure and temperature" (IUPAC, 2019), which pertains to the thermodynamic aspect of chemical reaction (also Mills *et al.*, 1993, p. 49). I will briefly discuss just two of the aspects of the vigour of chemical reactions—the quantum level and the thermodynamic notion of free energy, corresponding to the definition conveyed above.

The quantum chemical aspect of chemical affinity refers to formation of chemical bonds, the process whose essence Vihalemm (2021) specifically considers to be on quantum level. This is evidenced by his admissions:

> no specifically chemical forces exist in nature, […] the interatomic bond in a molecule, which is the chemical bond, is explained by electromagnetic forces which can be calculated by means of quantum mechanics,

and

> [t]he specificity of a chemical bond does not emanate from some special chemical forces, but from our dealing not simply with general electromagnetic forces but with specific interatomic electromagnetic forces in a molecule which can only be detected and calculated by means of quantum mechanics. (Vihalemm, 2021, pp. 116, 117)

Valency, which he discusses in relation to quantifying affinity, is a rather simplified representation of an element's bonding properties, which are more complex due to the specific electron shell structure: "bond formation depends on the electronic structures of atoms" (Atkins & Jones, 2008, p. 57). It can result in different kinds of bonds (e.g., ionic, covalent, metallic) of different strengths, bonding vigour, and required external conditions for bonding (that I see as the other aspects of chemical affinity, e.g., temperature, pressure, reactants' spatial relations such as concentration and surface contact). Let us consider the binding energy of outer shell electrons of an atom that underlies chemical bonding in terms of measurement theory and Vihalemm's idea of essence or measure. For energy, joules or calories are applicable as units, but they are used for bigger quantities of substance, such as the moles. For quantifying the ionisation energy of one atom, the unit electron-volt (eV) is used. In this sense, both are appropriate units of physical chemistry and can be viewed as measures of energy in Vihalemm's sense, taking into account entities relevant for chemistry practice. Electron-volt is an extensive unit in that by taking a mole of a substance, one just has to multiply the amount of eVs necessary for one atom of the substance with Avogadro's

number (and can use conversion into joules or calories), to obtain the number of electron-volts to ionise the entire mole of that substance. In other respect, in this context, the regularity of this property breaks down. On the one hand, the measure 'ionisation energy' does not form a regular, predictable scale across the periodic table, even if in abstraction each electron would behave the same way as the definition stipulates (gain a certain energy passing through a potential difference of 1 volt). Even though first electron ionisation energies change nearly periodically, the periodicity is neither precise nor consistent (in agreement with Scerri and McIntyre in the above quote). On the other hand, ionisation energy is not equal for all electrons in one and the same atom, that is, the next electrons in the atom require more and more energy to be knocked out, and how much more, depends on the electron shell structure, which is different for all elements and thus also is not a mathematically regular feature (see, e.g., Kulman, 1967, pp. 26–27; Landau, Akhiezer & Lifshitz, 1967, pp. 107–109). There is even no similarity to electron shells between elements: for instance, if beryllium loses one electron, its electron number is (and the electron shell structure might be) that of lithium, whereas knocking out the next electron takes more than thrice the energy of knocking out the first electron of lithium. Thus, one cannot really predict those energies from the building-up of electronic orbitals either. They can be found by measurement, for example, with electrostatic potential or light quanta.

The Gibbs free energy, ΔG, used in the contemporary definition of affinity of reaction, given above, is "[t]he thermodynamic function used as the criterion of spontaneity for a chemical reaction" (Atkins & Jones, 2008, p. 294). Mathematically, it is "the difference in molar Gibbs free energies, G_m, of the products and the reactants" (Atkins & Jones, 2008, p. 294). Thus, affinity of reaction is the rate of change in the potential for chemical work with respect to stage of reaction progress. The Gibbs free energy's absolute value is not typically measured; instead, changes in free energy are measured. The zero point of the scale of the standard Gibbs free energy change is defined to be at the "formations of elements in the most stable forms"; thus, for iodine I_2 in solid state in standard conditions it equals zero while for the same in gaseous state it is non-zero (Atkins & Jones, 2008, p. 295). This convention is adopted precisely because of the impossibility to determine the absolute value of free energy (Lewis, 1913, p. 15). Considering Vihalemm's conceptions, this variable is schizophrenic: its scale is defined according to each element or simple substance and thus answers to the requirement of measure of that substance, as it were. On the other hand, this definition seems to stem from our conceptual-technical limitations, rendering

this definition rather pragmatic, adjusting the theory, or assignments of values, to our cognitive capabilities, and not necessarily to theories. Thus defined, they do not necessarily reflect the essence of the reality studied. Vihalemm (2023, pp. 131–132) himself proposes van't Hoff's chemical equilibrium equation as the fundamental thermodynamic essence of chemical affinity, thus linking it to the end state of chemical reactions instead, which, in a sense, is an opposite approach, although also hinting at temperature conditions of reaction vigour. Whichever we take as more basic, the thermodynamic account of reactivity is a higher-level, summarised account concerning macro-properties of affinity, which raises doubts whether it can really be its essence in Vihalemm's sense, even though he so claims.

2.3 The periodic system

Explicitly addressing the essence of the periodic law of chemical elements, Vihalemm (2022, p. 148, n27) only says that it is chemical and physical: "the periodic law of chemical elements, discovered by D. I. Mendeleev, expresses the chemical essence of these elements," and, citing Kedrov (1959), "the discovery of the physical essence of the periodic law" prepared the ground for some earlier conjectures. Vihalemm does not specify what the physical essence of the periodic law consists in. Kedrov (1959, p. 258), also without specifying, enumerates some novel issues that came to be studied in physics on the basis of this physical essence of the periodic law, including the atomic number, or 'the ordinal number' indicating the position of the element in the table. This suggests that they both held Mendeleev's version of the table as the essential one, particularly since his successful predictions of the eka-elements were based on it.

According to Vihalemm (2007, p. 232), a chemical element as a place in the periodic table is the fundamental idealisation in chemistry that Mendeleev based his system upon and that renders it the φ-ness. However, when we look at Mendeleev's 1871 table, the finalised version before his last adventure with it in 1905, we find some elements occupying the same place (iron, cobalt, nickel, copper, for instance, and two other foursomes), the noble gases are obviously missing, some larger gaps predict a slightly off number of intermediary elements, and the periods have more even lengths than they currently do. Therefore, his system does not feature precise one-to-one relation between places in the table and elements, though these deficiencies pale in comparison to his achievement. However, in the 1905 table, we find places that never came to be filled, indicating pre-hydrogen "elements" and their periods, whose suggested

atomic weights have three different calculative bases in Mendeleev's (1905) essay. The reason for these blunders is the basis of ordering the elements—atomic weights, which fail to uniquely determine which kinds of elements exist or define what kind of a phaenomenon chemical elements are, as the elements' atomic weights do not form a precisely regular system or measurement scale. It is the atomic numbers that do. Even though atomic weights and atomic numbers are strongly correlated, and the atomic weights are thus decent representatives of the elements, the correlation is not one-to-one. Using Vihalemm's own ideas, one might understand Mendeleev's system or his periodic law as an empirical rather than an essential one. The contemporary periodic system, based on the number of protons in nuclei, is essential, since this is the feature of elements that theoretically identifies them, dictates their electronic shell structures which, on their part, determine their chemical and many other properties (see also Landau, Akhiezer & Lifshitz, 1967, p. 107). Again, while this latter determination is not simple in all elements, it is the chemical properties that chemistry is about. Atomic numbers are the measure of the phaenomenon and the "distinct structure" necessary for determining its essence that Vihalemm (2024, p. 131) requires. In (Vihalemm, 2021), the quantum chemical level for describing the set of phaenomena deriving from elements' reactive or chemical properties is recognised as the essential one, and Mets (2020) discusses the perils of the atomic weight-based system in a measurement-theoretic setting, supporting the idea that atomic number, not weight, is the measure of the periodic law.

Why, if the quantum chemical nature of the periodic system is the essential one, as would be the case according to Vihalemm's early views, does he nonetheless suggest that the early Mendeleev's version of it is the essential, the φ, the law of nature version of it? Possibly regarding its essence to be physical, he would risk leaving the system to being hijacked by physics, while it has a central role in chemistry, and important roles in other sciences too, such as geology and biology. Also, as Mets (2020) argues, the qualitative aspects of elements were both logically and chronologically prior to the quantitative aspects, grounding chemists' classification of elements into groups that guided and justified the tabularisation in the first place. The structure of elements and molecules, even if it could be explained by physical means, manifests essentially through chemical phaenomena, through the properties studied by chemistry as the science of stuffs. Possibly for this reason, Vihalemm comes to contradict his views on levels of thinking or modelling in science. The atomic weight-based ordering of elements, although more theoretically grounded than equivalent weight, is still empirical compared to atomic number-based ordering, as it does not take into account

the nature of the phaenomenon (Mendeleev did not even believe in structural divisibility of atoms; Gordin, 2004, pp. 215–216). The numbers assigned do not reflect that nature, they do not discern the basis of chemical distinctions or even the parts making it up (which is especially important regarding the concept of isotopes); they only reflect the phaenomenon in a sort of macro-level summary mode (though Vihalemm, as mentioned, designates a summarised approach qualitative instead; Vihalemm, 2023, p. 126). It also does not ground unambiguous prediction of which elements exist, while atomic number does this in principle. "In principle," because even that is not enough; it dictates a lower boundary of this property of elements (one proton), but no higher boundary. For that, a lower-level theory and experimentation is needed to determine the intra-atomic forces that might deter heavier elements from forming or their sufficient longevity to determine their chemical properties. In this sense, the periodic table, at least its technologically created fillings of cells, is purely physical. Valencies, otherwise defining the groups (in Mendeleev's version), are not empirically defined for those elements at all, only potentially theoretically via the membership of the shell in a group.

2.4 Thermal energy

As in his approach to the periodic system or law, Vihalemm does not explicate what exactly he means by 'thermal energy.' In this case, he is even less explicit, since this is only a side topic of his study due to the effect of heat on chemical reactivity—that is, due to the need to sever the effect of thermal energy from that of chemical energy or affinity. He states that thermal energy is the "chaotic movement of particles," the "*measure* of thermal motion" (Vihalemm, 2023, p. 130). Can we find more clues from the textbooks of the era when Vihalemm attended his studies? A physical chemistry textbook from Soviet Estonia (Kulman, 1967) uses this expression which can seldom be found in contemporary textbooks. However, in physical-mathematical terms, it is not much more specific either. It equates the intensity of thermal energy with thermal potential and claims that temperature characterises it (Kulman, 1967, p. 100). I assume it is the kinetic energy of particles, the form of energy which is the destination of thermodynamic processes (into which all other forms of energy can transform), but no mathematical definition of it is given.

Let us consider a couple of options for interpreting 'thermal energy.' The definition of the term as movement of particles suggests that the essential features of motion might be thought of as constituting the essence of thermal motion. From the

previous article of this series, we gather that (mechanical) motion, essentially, is the change of space in time, hence it has speed and direction. Since thermal motion was already said to be chaotic, we should consider the aspect of speed called 'thermal velocity.' Indeed, this property is conceptualised in the footsteps of classical mechanics—velocities of single particles (e.g., molecules), expressed in meters per second (we are only looking at gases here) (Lang *et al.*, 1959, p. 370). Physically, it can be measured using molecular beams, for instance, with devices with rotating slitted discs in evacuated spaces, allowing particles at certain temperatures enter the space and count those that reached the screen behind the discs, thus determining the ratio or those moving at the particular speed dictated by the discs' rotation (Landau, Akhiezer & Lifshitz, 1967, p. 165; Lang *et al.*, 1959, pp. 377–378). Thus, the measurement process itself is still statistical and indirect. Also theoretical approaches rather use the averaged velocity, since the number of particles is just too large for an individual approach; including linking particle motion to temperature where temperature T (in kelvins) is proportional to the particles' root mean square speed (v_{rms}) and inversely proportional to their molar mass M: $v_{rms} = \left(\frac{3RT}{M}\right)^{1/2}$, R is the gas constant (e.g., Lang *et al.*, 1959, pp. 367 ff, 375). This, of course, seems logical, as temperature is a macro-level property, and thus the kinetic equation links micro-level properties to the observable macro-property of interest (and "statistical mechanics opens the core of [the thermodynamic] process, the elementary processes constituting it"; Vihalemm, 2021, p. 116). This quantity is not extensive: taking twice the temperature does not yield twice the root mean square velocity.

Another possibility is to focus on the term 'energy' as the basic one. In this case, at least two interpretations can be suggested: the kinetic energy of a particle's thermal motion, and the heat part Q of the internal energy U of a system, the other thermodynamically interesting part being work A: $U = A + Q$; or the bound (useless) energy part G of the same, the other being free energy F: $U = F + G$, where bound energy is closely related to entropy (which can be treated as "the measure of the chaoticity of particles' thermal motion"), being the type of energy which can only transform into heat: $G = TS$, where T is absolute temperature and S is entropy (Kulman, 1967, pp. 101, 103). In practice, it is not the values of internal energy and entropy that is determined, but of their change (Kulman, 1967, p. 102; Atkins & de Paula, 2009, p. 51). A calorimeter is the instrument used for measuring this change, or of the heat generated in a process, for instance, a chemical reaction. A simpler version of it contains a liquid (water) which is heated by the process measured, and the temperature of that liquid is measured with a thermometer before and after the said process runs (e.g., Atkins & de Paula, 2009, p. 50). In micro-level parlance, its particles are set into faster motion by

the process measured, or certain kind of work is done on it. This resembles Joule's experiments and conceptualisation of them, as he also measured the temperature rise in his apparatus as a result of work done (Joule, 1845), and is in concert with the statement "[e]nergy is the capacity to do work," and work is something done "to achieve motion against an opposing force" (Atkins & de Paula, 2009, p. 42). Thus, this notion may have a pragmatic origin similar to that of force, as noted in the discussion about Galileo (Mets, 2024). Regarding 'energy' itself, it may serve as an a priori concept, the mathematical pro-jection. The definition of thermal energy as heat flow thus forms the basis of this measurement. Measuring heat with a thermometer is a macro-level measurement, yielding results on a normal centigrade scale, an intensive scale. But energy itself, measured in calories or joules, is an extensive property: the more stuff in the system, the more energy; thus, accounting for the amount of measuring stuff heated, specific to each calorimeter. Then again, taking it in the shape more appropriate for the aspect of world it is about—that is, number, not bulk, of stuff, or moles—it becomes an intensive property.

3. Conclusions. Numericity and mathematicity

In my efforts to link the concept of φ-science to measurement, I have focused almost exclusively on its theoretical aspect: measurement scales and units. I found guidance in Vihalemm's early writings, in which he repeatedly uses the term 'measure' as a quantity that truthfully reflects the essence of a property or phaenomenon. I have analysed his own examples of measure and essence, aiming, to some extent, to detect features of φ-ness and identify measurements deemed appropriate for the exact sciences, as discussed in the previous paper.

Firstly, the Galilean idealisation that Vihalemm posits as foundational in his characterisations of φ-sciences is shown to be insufficient. Mere idealisation is not enough to uniquely define elements in the system; numbers, often from measurement, are needed. This is evident in many periodic properties of chemical elements, such as ionisation energies, for instance. Secondly, the systematisations themselves were results of extensive measuring work carried out throughout the 19th century, thus the empirical basis was indispensable. Finally, in accordance with Vihalemm's own contentions, the theoretical foundation of the phaenomenon—its essence, in Vihalemm's terms—must be obtained to correctly apply idealisation to the yet unknown reality in anticipation of new empirical content.

Can essence, as defined here, truly be determined prior to empirical research, as the pro-jection component of φ-ness, described in the first paper, requires? Vihalemm likely does not mean pure pro-jection devoid of any prior empirical ideas. The empirical ideas may rely on something possibly already forgotten in their concreteness, such as may have been the case of the conservation of matter and energy, or the practical-pragmatic forerunners of the concepts of force and energy, the universal orderliness of the world and its building blocks, or the analogy between the planetary system and electron shell structure, which was also not totally fruitless. This would agree with Vihalemm's practical realist philosophy of science. However, it a priori cannot function in isolation: we cannot know whether our hunches really apply to what we study otherwise than by means of empirical research, which necessarily includes material measurement. The theoretical hunch may rely on generalisations, analogies and metaphors may suggest a scale, or measure, in Vihalemm's parlance, that are inappropriate for the phaenomenon in focus, as he also admits. The measure must be, and was, verified for empirical, possibly even ontological, counterparts. The ontology, however, is not always straightforward, and may be rather contrived, the attribute denoting something quite pragmatic and technical. I am not completely certain whether Vihalemm noticed this when he bestowed them the title 'essence.' Such is the case with the attributes that cannot be assigned any number, such as internal energies. Calling them theoretical, quantitative essences or qualitative quantities may be farfetched.

Several of the properties or attributes that Vihalemm identifies as measures are statistical or summative in nature. I mentioned that, according to Vihalemm, mere statistical description is not φ. Yet, is it not the measure of what is described and calculable, hence also mathematically numerical? For instance, when we count some objects, as voters and seats are counted in Taagepera's (2008) laws of politics, constituting an absolute scale (in measurement theoretic terms), then this counting yields the number of those well-defined objects, the number obtained really represents their quantity. (One could argue that not all voters really consider their choice, nor do all members of a legislative body perform their work well, or something along those lines; however, such finesses pertain to a different matter.) One can calculate with the counts, add more objects—for instance, natural numbers are additive, the absolute scale is extensive in this sense. One can find different statistical indices, etc. that reflect aspects of the statistical collection. If some of those statistical indices do not make sense for the studied reality, as Taagepera criticises, then this reality, or the empirical relational system, must be adjusted for accountability and comparison to restrict the model and

its application. If counting does not really qualify as φ, as Vihalemm might be speculated to contend, if it does not yield an exact-scientific scale, then is the atomic number also non-φ? Its measurement did not really proceed by counting individual protons. Does this then imply that the method and technology of measurement determine φ-ness? These issues will be discussed in a follow-up paper.

Now, as noted above, the thermodynamic and other aspects discussed here are not, strictly speaking, statistical (with the exception of contemporary atomic masses and, in certain respects, the mole). But then, their technical mode of definition or measurement may be more pragmatic than essential. If the numericity and mathematicity apply to this pragmatically defined entity, is this entity then still φ-scientific? And should we then consider the essence itself of the phaenomenon to be primarily technical? In some cases, it may indeed be (additionally) colligative, gathering certain empirical-technical phaenomena and their corollaries, bound together by means of theoretical assumptions (e.g., particle motion), into one practically useful notion. But is it then still essence in the sense that Vihalemm would want to conceive it?

Not all the quantities used in those examples that Vihalemm considers to be measures are extensive, as stipulated by measurement scholars to be inherent to physical or exact scientific quantities. So, temperature, pressure, or any property counted per mole as is appropriate in chemistry and chemical physics are intensive properties. That means, mathematical operations with these properties, as well as those of combined systems, are more complex than simple summation. Then, what if a property is indeed essentially represented by a certain type of scale which perhaps is not extensive but still displays meaningful numerical relations beyond mere ordering (without mentioning the other more obviously non-representative numerals of scales presented in the first part)? The Kelvin scale of temperature certainly holds significant meaning for both physics and chemistry and is used in precisely calculated laws. But is the assignment of '0' to an unattainable condition acceptable? In this case, as a tentative answer, I would liken this to Galilean idealisation, where the theoretical calculation on models considered of fundamental level convey the full scale. I admit that this answer merits further detailed analysis. Compared to the other assignment of '0' mentioned here—the Gibbs free energies for formation of simple substances—it seems more Galilean and hence more φ, as the latter relies on more pragmatic considerations (what I would here term colligative attributes/attributions).

When some models are assumed to convey the essence of a phaenomenon, we seem to assume that we can know the essence. What if the authors of the planetary model of atom also believed that they had conveyed its essence, or the phlogistonists believed to capture the essence of substances and their chemical change? This leads to the standard objection to naïve scientific realism. Vihalemm (2023, p. 130) sort of acknowledges that scientists can err in the import of their research results, when he argues that Thomsen and Berthelot "took the manifest—the automatic progress of a reaction towards greater emission of heat, observed in many cases—as the essential, the particular as general." On the one hand, this cautions for more epistemic humility and thus possibly suggests renouncing the notion of essence altogether. On the other hand, Vihalemm overlooks the possible confusion with generality and specificity: he deems general physical weight units too general for specific phaenomena such as chemical substances, yet exothermic reactions too narrow for the definition of affinity. He never asks or explains where to draw the line between too general and too specific or narrow. In some cases, such as electron-volts and joules for energy, their appropriateness may just depend on the quantity of matter in question. In other cases, more importantly, the conceptualisation of the unit depends on the specific manifestation of the property, its context and type of phaenomenon. Unification of phaenomena is an aim characteristic of physics, serving simplicity and economy of thought and theory that Vihalemm, as a relative monist, might welcome.

Assume for a moment that ionisation energies would be directly observable and measurable, and thus constitute a concrete ontology with absolute values, rather than being indirectly determined by counting particles in a technical contrivance. If the unit joule had originally been found on the basis of those energies, it would have been a variable (property), allowing for only a select discrete set of values. The unit alone may not clearly indicate its possible values, just as atomic weight did not inherently suggest the values. Also considering light years, kilometres, and picometres as units of the same property length is phaenomenologically not self-evidently natural. But then, as units and/or quantities become generalised over more different kinds of phaenomena, they become what Vihalemm found too general and not capturing the specific essence of the phaenomenon of interest. This implies that all non-specific (ratio) scales and measures, such as length, mass, time, velocity, are non-essential. Galileo's measurements were essentially of such kind, even if he contrived his own measurement apparatus, with its own units. Then again, should punto and tempo be considered as measures of the essence of free fall, his studied phaenomenon,

and its approximations? Perhaps due to their precision and technical applicability in those situations, they indeed were, but we cannot know this from Vihalemm's sources, and those phaenomena can certainly be expressed in other units as well. Also, various local units are convertible into each other, which is something that is also being done across laboratories today. Another option for those scales and units is to consider them just as general as the field of physics is, and thus to be measures of those general and idealised properties and their essences.

The mole is a kind of an absolute or essentially discrete counting scale for something that in some other context, or even in the same context but alternatively, is counted in continuous weight scale (grams), an archetypical ratio scale. Nonetheless, the mole also makes up a ratio scale, recognising the same mathematical operations, and is thus extensive. As suggested above, it may not be essential in Vihalemm's sense, despite its ubiquity in chemical theory and practice, for particles by themselves or naturally do not group into collectives of that size. The quantities expressed per mole, however—the theoretically relevant use—fail extensiveness. Perhaps, if we adhere to the essentialist view, we may, in many apparently φ cases, not get to mathematicity at all, if mathematicity is defined very narrowly like for extensive quantities.

Acknowledgements

I am grateful to the anonymous referees for their valuable feedback and suggestions for improvement.

References

Atkins, P. & de Paula, J. (2009), *Elements of Physical Chemistry*, 5th ed., New York: Oxford University Press.

Atkins, P. & Jones, L. (2008), *Chemical Principles: The Quest for Insight*, 4th ed., New York: W. H. Freeman and Company.

Chang, H. (2012), *Is Water H_2O? Evidence, Realism and Pluralism*, Dordrecht: Springer. https://doi.org/10.1007/978-94-007-3932-1

Giere, R. N. (1988), *Explaining Science. A Cognitive Approach*, Chicago & London: The University of Chicago Press. https://doi.org/10.7208/chicago/9780226292038.001.0001

Gordin, M. D. (2004), *A Well-Ordered Thing: Dmitrii Mendeleev and the Shadow of the Periodic Table*, New York: Basic Books.

IUPAC (2019), 'Affinity of Reaction,' in *IUPAC Compendium of Chemical Terminology*, 3rd ed., International Union of Pure and Applied Chemistry, Online version 3.0.1. https://doi.org/10.1351/goldbook.A00178

Joule, J. P. (1845), 'On the Existence of an Equivalent Relation between Heat and the ordinary Forms of Mechanical Power,' *The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science*, vol. 27, no. 179 (September), pp. 205–207. Retrieved from https://archive.org/details/londonedinburghp27lond/page/204/mode/2up?view=theater [accessed 5 Nov 2024]

Kedrov, B. M. (1959), *Filosofskii analiz pervykh trudov D. I. Mendeleieva o periodicheskom zakone* [Philosophical analysis of Mendeleev's first works on periodic law], Moscow: Izdatel'stvo Akademii Nauk SSSR.

Kulman, A. G. (1967), *Füüsikaline keemia ja kolloidkeemia* [Physical chemistry and colloid chemistry], Tallinn: Valgus.

Landau, L. D.; Akhiezer, A. I. & Lifshitz, E. M. (1967), *General Physics: Mechanics and Molecular Physics*, transl. by J. B. Sykes, A. D. Petford, & C. L. Petford, Oxford& London: Pergamon Press.

Lang, J.; Marran, H.; Mitt, A.; Mürk, H. & Pae, A. (1959), *Füüsika üldkursus* [General course of physics], Tallinn: Eesti Riiklik Kirjastus.

Lewis, G. N. (1913), 'The Free Energy of Chemical Substances,' *Journal of the American Chemical Society*, vol. XXXV, no. 1, pp. 1–30. https://doi.org/10.1021/ja02190a001

Mendeleev, D. I. (1871), 'Estestvennaia sistema elementov i primenenie eia k ukazaniiu svoistv neotkrytykh elementov' [The natural system of elements and its application to indicating properties of yet uncovered elements], *Zhurnal Russkago Khimicheskago Obshchestva*, vol. III, pp. 25–56.

Mendeleev, D. I. (1905), *Popytka khimicheskago ponimaniia mirovogo ethira* [An attempt towards a chemical conception of the world aether], St. Petersburg: Tipo-litografiia M. P. Frolovoi.

Mets, A. (2009), 'Sotsiaalteaduste teaduslikkusest. Rein Taagepera *Making Social Sciences More Scientific. The Need for Predictive Models*' [On scientificity of social sciences], *Studia Philosophica Estonica*, vol. 2, no. 1, pp. 112–134. (Available also in English as part of the dissertation *Normativity of Scientific Laws*, University of Tartu, 2013, at https://dspace.ut.ee/server/api/core/bitstreams/ac217aeb-9048-40a4-a083-e2f8879f0e9a/content).

Mets, A. (2020), 'A Measurement-Theoretic View on the Early Evolution of the Ordering of Chemical Elements,' *Acta Baltica Historiae et Philosophiae Scientiarum*, vol. 8, no. 1, pp. 5–32. https://doi.org/10.11590/abhps.2020.1.01

Mets, A. (2024), 'What Does 'φ-Scientificity' Mean? I. Models and Measurement: Galileo,' *Acta Baltica Historiae et Philosophiae Scientiarum*, vol. 12, no. 1, pp. 6–36. https://doi.org/10.11590/abhps.2024.1.01

Nikitin, Ie. P. (1963), 'Tipy nauchnogo ob'iasneniia' [Types of scientific explanation], *Voprosy filosofii*, no. 10, pp. 30–39.

Sagatovskii, V. N. (1965), 'Strukturnyi i geneticheskii printsipy raschleneniia ob'ekta v sisteme filosofskikh kategorii' [Structural and genetic principles of division of an object in a system of philosophical categories], *Problemy issledovaniia sistem i struktur. Materialy k konferentsii*, Moscow: Akademiia nauk SSSR.

Scerri, E. R. & McIntyre, L. (1997), 'The Case for the Philosophy of Chemistry,' *Synthese*, vol. 111, pp. 213–232.

Schummer, J. (1998), 'The Chemical Core of Chemistry I: A Conceptual Approach,' *Hyle*, vol. 4, no. 2, pp. 129–162.

Taagepera, R. (2008), *Making Social Sciences More Scientific. The Need for Predictive Models*, New York: Oxford University Press. https://doi.org/10.1093/acprof:oso/9780199534661.001.0001

Vihalemm, R., comp. (1979), *Teaduse metodoloogia* [Methodology of science], Tallinn: Eesti Raamat.

Vihalemm, R. (2003a), 'Are Laws of Nature and Scientific Theories Peculiar in Chemistry? Scrutinizing Mendeleev's Discovery,' *Foundations of Chemistry*, vol. 5, pp. 7–22. https://doi.org/10.1023/A:1021980526951

Vihalemm, R. (2003b), 'Natural Kinds, Explanation, and Essentialism in Chemistry,' *Annals of the New York Academy of Sciences*, no. 988, pp. 59–70. h ttps://doi.org/10.1111/j.1749-6632.2003.tb06085.x

Vihalemm, R. (2007), 'Philosophy of Chemistry and the Image of Science,' *Foundations of Science*, vol. 12, pp. 223–234. https://doi.org/10.1007/s10699-006-9105-0

Vihalemm, R. (2011), 'The Autonomy of Chemistry: Old and New Problems,' *Foundations of Chemistry*, vol. 13, pp. 97–107. https://doi.org/10.1007/s10698-010-9094-5

Vihalemm, R. (2015), 'Philosophy of Chemistry against Standard Scientific Realism and Anti-Realism,' *Philosophia Scientiæ*, vol. 19, no. 1, pp. 1–15. https://doi.org/10.4000/philosophiascientiae.1055

Vihalemm, R. (2016), 'Chemistry and the Problem of Pluralism in Science: An Analysis Concerning Philosophical and Scientific Disagreements,' *Foundations of Chemistry*, vol. 18, no. 2, pp. 91–102. https://doi.org/10.1007/s10698-015-9241-0

Vihalemm, R. (2019), *A Story of a Science: On the Evolution of Chemistry*, Special Issue of *Acta Baltica Historiae et Philosophiae Scientiarum*, vol. 7, no. 2, pp. 8–179. https://doi.org/10.11590/abhps.2019.2.01

Vihalemm, R. (2020), 'On the Transition to Quantitative Inquiry in Chemistry,' transl. by A. Mets, *Acta Baltica Historiae et Philosophiae Scientiarum*, vol. 8, no. 1, pp. 126–132. https://doi.org/10.11590/abhps.2020.1.07

Vihalemm, R. (2021), 'On the "Two-Layeredness" of Structure and the Relation of Quantum Mechanics and Chemistry,' transl. by A. Mets, *Acta Baltica Historiae et*

Philosophiae Scientiarum, vol. 9, no. 1, pp. 110–129. https://doi.org/10.11590/abhps.2021.1.08

Vihalemm, R. (2022), 'On Stages of Cognition,' transl. by A. Lazutkina, *Acta Baltica Historiae et Philosophiae Scientiarum*, vol. 10, no. 1, pp. 138–155. https://doi.org/10.11590/abhps.2022.1.08

Vihalemm, R. (2023), 'The Cognitive Move from Being (Immediate Phaenomena) to Essence in the History of the Study of Chemical Affinity,' transl. by A. Mets, *Acta Baltica Historiae et Philosophiae Scientiarum*, vol. 11, no. 1, pp. 118–137. https://doi.org/10.11590/abhps.2023.1.05

Vihalemm, R. (2024), 'On the Transition to the Theoretical Stage of Cognition (on the Example of the History of the Study of Chemical Affinity),' transl. by A. Mets, *Acta Baltica Historiae et Philosophiae Scientiarum*, vol. 12, no. 1, pp. 128–138. https://doi.org/10.11590/abhps.2024.1.06

Ave Mets, PhD from the University of Tartu, 2013, is a research fellow of philosophy of science at the University of Tartu and a cadet at the Estonian Nautical School. She has worked as a junior research fellow at RWTH Aachen (2009–2013), did her post-doctoral studies at Belarus State University (2015–2016), and was a Fulbright visiting fellow at Washington State University (2022–2023). Her research interests include philosophy and history of science and technology, especially of chemistry, scientific world picture and alternative, especially indigenous, world pictures, and the measurement theory.