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Matter versus Form, and Beyond

Joachim Schummer
Department of Philosophy, University of Darmstadt; js@hyle.org

1. Introduction

There is the popular notion according to which the world is built up in a hierarchical order, such that combining entities from the lower level results in entities of the next higher level, and so on. It seems beyond doubt in this view that the entities at the lowest level are some subatomic particles, to be followed at the next levels by atoms, molecules, biological organs and organisms including humans, and eventually societies. Accordingly, a scientific discipline is assigned to each level, resulting in a disciplinary hierarchy that starts with physics and goes via chemistry, biology, and psychology to sociology. This popular notion has its merits as it assures us that both the world and our scientific knowledge are perfectly ordered in a harmonious but hierarchical manner. It provides philosophical food to discuss the interfaces between the ontological levels or disciplines in terms of reduction, emergence, supervenience, and so on. And it appeals to some philosophers who are interested in science but unable to read the about two million scientific publications per year, because it allows them to focus on the handful of publications in what is supposed to be the fundamental level of Everything.

The hierarchical picture became popular in the 19th century just when most of our scientific disciplines emerged in a process of *horizontal* diversification, when each discipline carved out and established its own specific subject matter, methodology, theories, and problems and rejected just the idea of the hierarchical dependencies between the disciplines (Stichweh 1984). Despite its anachronism at the time of its popularization, the hierarchical picture was appealing to all those who felt lost in the exploding fields of science and who were yearning for the good old days in which a simple metaphysical scheme could provide order to the entire world. It is more than likely that the hierarchical picture is appealing still nowadays for the same reasons.

It would not be worthwhile to discuss the anachronistic hierarchical picture, if it had not such a great appeal to many philosophers.[1] In this paper I discuss only one particular problem of the hierarchical picture, the lack of matter or stuffs[2] in the ontological hierarchy, which actually consists in a series of structures or forms. Correspondingly, the hierarchy of disciplines disregards all our knowledge about stuffs, including chemistry and most of our experimental sciences. Indeed, one could even argue that the ontological hierarchy leaves no particular place for sciences like chemistry. From particle physics to molecular physics, physics could easily cover all the lower ontological levels to be followed directly by biology at the next level. That chemistry, as well as many other disciplines, can so easily be skipped, might be reason enough to dismiss the popular picture. However, as I argue in this paper, the hierarchical picture expresses a more fundamental problem that runs through the history of philosophy: the notion of matter and form as two opposing and mutually excluding principles.

In Section 2 I argue that matter and form arise from two, among many other, epistemic perspectives on the world, which I call stuff and form perspectives. However, once these perspectives are transformed into ontological categories, they tend to exclude each other as opposing principles that form the basis of opposing philosophies. Section 3 provides a brief historical sketch of how the form perspective took over in mainstream philosophy. That had little

[1] For a modern philosophical articulation of this view, see for instance, Oppenheim & Putnam 1958.

[2] In the following I use the term ‘stuff’ equivalent to the German ‘Stoff’, which comprises (solid) materials as well as liquids and gases of any kind.

to no impact on sciences like chemistry, however, other than that these sciences have been neglected by philosophers. Thus, Section 4 gives a brief philosophical reconstruction of the neglected stuff perspective as it had been developed in chemistry in order to systematically investigate and classify the material world. Section 5 deals with form philosophical approaches in theoretical chemistry and points out both their usefulness and limits, whereas Section 6 complementary emphasizes the limits of stuff philosophy in chemistry. I conclude with some general lessons of what philosophy (of science) can learn from (philosophy of) chemistry and its more relaxed and productive way of combining stuff and form perspectives.[3]

2. Matter versus Form

Imagine you hold a coin you have never seen before in your hand and are asked to provide a detailed description of the object. You might want to point out that the coin has a circular shape with a diameter of about 2.3 centimeter and a thickness of 2.4 millimeter. Unfortunately, on both sides there are some strange contours that you cannot describe with words. So, you put the coin into a three-dimensional scanner that yields a perfect geometrical description of its size and shape including all its dents. Your neighbor, who is an old-fashioned chemist, is less respectful of the coin's shape. Indeed, he cuts the coin into little pieces on which he conducts all kinds of experiments with a battery of reagents and instruments. He treats some pieces with various acids and pours some reagents into the solutions, upon which some colorful precipitation occur. He cuts a little cube-like piece out of the coin and measures its weight, pretending that the weight of the piece tells us something meaningful about the whole coin. And he has some sophisticated instruments that treats the pieces with mechanical force, electric voltage, electromagnetic fields, and so on, and carefully observes the behavior of the pieces or their remainings. Eventually he tells us that the coin is an alloy of silver, copper, and gold of certain proportions. Another fellow, who had glimpsed the coin before our chemists took it apart and who happens to be a historian, tells us that the coin was once used as money in an old culture. He identifies on the contours of the coin the symbols as belonging to their political and religious symbol systems. He knows in detail how much it was worth with regard to other coins in that society, how much bread one could buy with that coin, how long people usually worked to earn the equivalent value, and the current price collectors would have paid for the coin if our chemist had not destroyed it.

The three epistemic approaches or perspectives to describe the coin apply different reference frames. The first one uses geometrical space and its metrics to describe the coin in terms of its size and shape, which I call "form perspective" in the following. The second one applies the chemical reference frame to determine from various material properties the chemical composition of the coin, which I will call the scientific "stuff perspective". The third one describes the coin by applying a historical reference frame as well as the symbolic reference frames of religion, politics, and economics. Each of these descriptions is meaningful in its own right; each provides useful information with regard to certain questions, which no other perspective is able to provide. If we want to have a full description of objects, we should combine the information of as many perspectives as possible.

Among the variety of epistemic perspectives, the form and stuff perspectives stand out because they became the backbones of rivaling metaphysical systems since antiquity. A metaphysical system sets the conceptual frame of an epistemic perspective absolute and claims that this epistemic perspective, if fully developed and transferred into ontological categories, provides a complete and sufficient description of the world. Simply speaking, form metaphysics claims that the world consists of nothing else than forms, while stuff metaphysics claims that the world consists of nothing else than stuffs. In order to do so, the epistemic de-

[3] The following sections draw on about two dozen papers and a monograph mostly published in the 1990s. Thus if readers feel that the text is too condensed, that my arguments are too superficial, or that they simply want to know more details, they are kindly referred to the references.

scriptions need to be transformed into ontological categories. Form metaphysics transfers morphological properties into forms as the essential kinds of the world, while stuff metaphysics transfers material properties into stuffs as the essential kinds of the world. Once the systematics of form types and stuff types are developed, form and stuff metaphysics identify all objects as forms and stuffs, respectively. In order to provide a more integrated picture of the world, each has developed its own notion of part-whole relationship, such that a form-whole consists of structural parts, whereas a stuff-whole consists of material parts, ultimately chemical elements. To provide a dynamical account of the world, form metaphysics has developed its laws of how forms move in geometrical space, while stuff metaphysics has its laws of how stuffs change and react with each other. In the end we have two mutually exclusive pictures of the world. Each picture is compelling in its own right. Yet, since each picture is meant to describe completely and sufficiently the one world we live in, one picture is assumed to be wrong.

Purist metaphysics requires us to make a decision whether the world consists of either form or matter. Such a decision naturally transcends common sense, since we all know very well to distinguish between the formal and material aspects of objects and we usually also know when one of these two aspects is important and when none of them matters at all. There were even times when people favored other perspectives than the form and stuff perspectives, and some even do so today. For instance, the symbolic reference frames are particular powerful to conceive everything from the perspectives of religion, politics, or economics. Moreover, if two people differ in their religious reference frames, they might even have an argument about the meaning of simple entities, like hills, animals, or wine bottles. Yet, the profession of natural philosophers, who have later been called scientists, wanted the world consist of either matter or form, and most have favored form.

3. The philosophical dematerialization of the world[4]

Most natural philosophers in ancient Greece were stuff philosophers. They assumed that the world consists of some material or quasi-material elemental substances, and that any form emerges out of the inner dynamics of these substances, by self-organization as we would call it nowadays. The two major exceptions were Democritus and Plato, who drew his ideas from the Pythagorean School. Democritus argued that the world consists of matter and empty space and that matter consists of invisibly small and indivisible parts, called atoms, that are fully characterized by their size and shape. Yet, critics argued soon that size and shape is characteristic not only of matter but also of empty space in this view. So what distinguishes matter from empty space? Democritus had nothing to respond other than that matter exists because it is not empty whereas empty space does not exist, which means that the world consists of something that does not exists and which therefore most philosophers rejected as contradictory nonsense. Plato, in his dialogue *Timaeus*, narrated a creation myth according to which a god had created the world by folding invisibly small three-dimensional geometrical figures out of triangles. He carefully avoided any reference to materials and suggested instead that the material of the geometrical figures is space itself. Critics soon argued that Plato confused mathematical ideas of the world with the world itself. Both Democritus and Plato conceived the world consisting of invisibly small entities that were pure forms, either irregular forms or regular geometrical forms, without any matter or material properties. They provided the form philosophical model of dematerializing the world.

Before that strategy became mainstream modern natural philosophy, Aristotle developed a synthesis that simply combined stuff and form philosophies to comply with our common sense: Unlike mere ideas, every real thing, be it invisibly small or as large as the entire universe, has a form and consists of matter, which are both important for understanding and

[4] This section draws on Schummer 1995a, 1996a (Sect. 3.2), 1996b.

explaining the world, but by no means the only important aspects.[5] While Aristotle's natural philosophy became the standard approach in the Christian and Islamic world, in natural philosophy as well as in technology, another type of form philosophy dwelt in various religious movements in the Middle East. In particular Gnosticism followed the Pythagorean model in dividing up the world into polarities, like good and evil, god and devil, bright and dark, mind and body, ideas and matter, and so on. As these polarities were related to each other, matter was associated with and became the visible embodiment of all negative poles. Plotinus, the founder of Neoplatonism, changed the polarities into a hierarchy by introducing "emanation" steps between the poles, which were his god-like principle of one-ness on top and matter, the equivalent of evil, ugliness, and falsity at the bottom.[6] Despite all their efforts to prevent Gnosticism from infiltrating their own religion, the early Christians remained not unaffected by these views. Indeed, these views shaped the Christian attitude towards the material world as the pool of sins, to their individual bodies as the source of evil lust, and their inclination to identify themselves with pure minds. As Giordano Bruno, a 16th-century critical observer who ended up burning at the stake, once remarked, it also shaped the social role of women, who since Aristotle have been associated with matter, which the Latin term *materia*, from *mater*, has conserved.[7] And despite all his other criticism of Gnosticism, the most influential Church Father Augustine could not help but conclude that matter is ultimately incomprehensible, and thus cannot be an object of knowledge or science.[8]

When early modern mathematicians, like Descartes and Galileo, tried to overcome the Aristotelian natural philosophy during a renaissance of Platonism, all these views might have contributed to their eventually broad acceptance. More importantly, however, as mathematicians they were striving to become respected natural philosophers – a social ambition that has frequently been called the "Scientific Revolution". They naturally preferred the form perspective, because only that allowed applying their professional language of geometry. Thus, they proudly announced that God had written the world in mathematical language, "and the characters are triangles, circles, and other geometrical figures",[9] which became the crypto-theological motto of modern form philosophy. Not surprisingly they rediscovered Democritus and Plato and copied their model of dematerializing the world. The only essential property of matter is extension, said Descartes,[10] echoing Plato and puzzling the common sense.

According to our prevailing histories of philosophy, form philosophy has become the mainstream philosophical view since the 17th century in circles that are retrospectively considered to include the most important philosophers of their time. These narratives suggest that form philosophy flourished in many intellectual areas and that all the "big" philosophical issues were debates among form philosophers. For instance, in epistemology rationalist are said to have debated with empiricists the most reliable source and foundation of truth. While rationalists like Descartes sought the foundation of truth in and on the model of geometry, i.e. the science of pure form, so-called empiricists like Locke believed in the Democritean idea that all our ideas about the world are ultimately caused by objects imprinting their specific form on our sensory organs, which requires the "the operation of insensible particles on our senses" of sight, hearing, taste, and smell.[11] However none of these philosophers, except Bacon, said anything about how their contemporaneous scientists actually worked in their laboratories and performed experiments to gain and secure scientific knowledge. In aesthetics,

5 Aristotle, *Physics*, bk. I.; *Metaphysics*, bk. I.

6 Plotinus: *Enneads*, I.6.5; I.8.4.

7 G. Bruno, *De la causa, principio et uno* (1584), particularly the 4th dialogue.

8 Augustine, *Contra Faustum*, XX, 14.

9 G. Galilei, *Il Saggiatore* (1623), sect. 5: "Egli è scritto in lingua matematica, e i caratteri son triangoli, cerchi, ed altre figure geometriche, ...".

10 R. Descartes, *Principia philosophiae* (1644), pt. II.

11 J. Locke, *An Essay concerning Human Understanding* (1690), bk. II, chap. VIII.13.

particularly in 19th-century idealism, we find a vivid debate about how “form” should dominate “matter” in art because the true source of perceived beauty was considered pure form. To quote only one of the epigones:[12] “The master’s true secret of art is *destroying matter by form*.” Plotinus could not say it better.

After the so-called linguistic turn in the 20th century, metaphysical doctrines of the world were no longer philosophically correct. Thus, form philosophers developed various approaches to eliminate stuff concepts from our language. For instance, Quine, who still in the late 20th century believed that the world consists of elementary particles with definite time-space coordinates, argued that a term like “water” denotes not a stuff but a specific form that comprises all water “particles” in the world (Quine 1960, pp. 91ff.). The characteristic form of water, i.e. that what makes water being water, differs from the characteristic form of, say, a chair only in that it is not closed and stable but distributed all over the world and changing over time. Another mathematics-turned philosopher, Hilary Putnam became famous by suggesting that ordinary people are wrong in thinking that the term “water” denotes a stuff that one can drink or swim in. Instead, he argued that the proper meaning of the term “water” is H_2O, by which he meant not the empirical formula, i.e. the elemental composition, but the structure of a molecule.[13] Apart from the science that these philosophers carefully ignored, they both tried to purify our language through eliminating stuffs by definition. In so doing they repeated the form philosophical approach on the more rigorous linguistic level. Rather than arguing that stuffs do not exist or cannot be discerned, they suggested that one could not meaningfully speak about stuffs.

From the stuff perspective, all properties that describe the world have the logical structure of dispositions, i.e. they describe the behavior of an object under certain contextual conditions (see Section 4). For instance something is soluble in water if it dissolves in water. From the form perspective, however, all properties are intrinsic and manifest rather than dispositional properties, i.e. they describe an object as it is independent of contextual conditions. This logical difference has posed an insurmountable obstacle to the form philosophical redefinition of material properties. In a simplified version the logical problem is that as long as the object is not put into water it does not dissolve; whereas once it is put into water, it dissolves and thus no longer exists (Carnap 1936-7). Generations of logicians have worked on formal semantics that shall translate dispositions into manifest properties. However all their efforts, including the assumption of wondrously possible worlds and multi-dimensional truth value tables, have remained unsuccessful in translating stuff properties into form properties. It would seem as if Augustine was right that matter is incomprehensible – but it is so, of course, only from the form perspective.

From metaphysics to epistemology, philosophy of language, logic, and even aesthetics, modern mainstream philosophers have developed a clear and powerful form philosophical profile. They have suggested that stuffs do not exist, that we cannot discern, comprehend, meaningful speak, and aesthetically perceive them, which is about the entire battery of skeptical weapons developed since antiquity. That modern philosophers of “science” paid also little attention to chemistry as the science of material substances, or believed in its reductionism as a must that requires no justification, should hardly surprise against their background. Yet the price of the form philosophical rigor is high. On the one hand, it blends out the metaphysical, epistemological, linguistic, logical, and aesthetic aspects of our material world to which everyone has everyday access. It makes philosophy appear like a grim esoteric sect or a remainder of Gnosticism, at least to the common sense view that allows us so easily switching between form, stuff, and other perspectives.

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[12] F. Schiller, *Ueber die ästhetische Erziehung des Menschen, in einer Reihe von Briefen* (1795), 22nd letter: “Darin besteht also das eigentliche Kunstgeheimnis des Meisters, *daß er den Stoff durch die Form vertilgt*” (emphasis in the original). For discussion of idealistic aesthetics, see Schummer 2003a.

[13] Putnam 1975; for a philosophy of chemistry criticsm see van Brakel 1986.

On the other hand, form philosophy not only ignores most of our sciences and all of our experimental sciences, which are necessarily based on dispositions, but gives also unworldly and bad advice on all issues that involve stuffs.[14] Ask a form philosopher if a chemical substance is toxic or bears some environmental hazard, and he could only point to some form as the proper essence of the substance. However, forms consist only of intrinsic, manifest properties, like being spherical or two nanometers thick, whereas toxicity is, as any stuff property, a disposition that in this case refers to some dynamic interaction between a substance and a biological organism. For logical reasons, pure forms cannot contain information about dispositions like toxicity, unless the information is later symbolically attached to the form based on previous material experience. Thus, if you find no toxicological information in the form, that is not because the substance is not toxic but because the material property of toxicity has not been determined yet. If you trust form philosophy in real life matters, the error can be disastrous. Our regulations to prevent such disasters have fortunately been based on stuff rather than form philosophy. Yet, as I will point out in Section 6, these regulations are too rigorous in their stuff philosophical approach, which currently poses new challenges.

4. A glimpse on the stuff perspective

4.1 Everyday stuff perspective

Everybody has ample experience with stuff properties. You boil water and pour it over your tea leaves or tea bag to extract the tea aroma and then put a sugar cube in your cup of tea to dissolve it. You strike a match to light wood, charcoal, or spirit for your barbecue, and you know that if your drinks stay too long in the freezer, they will freeze and the bottles will burst. You would not use your barbecue knife for cutting stones or confuse it with food, neither would you use your hair-dryer in the full bath tub, unless you want to commit suicide. You have once learned that magnetic badges stick to your fridge door and other pieces of iron, but not to your wall or your wooden table. You recognize many stuffs by their specific color as long as it is not dark, but you might once have experienced that under red light everything appears monotonously red.

Our everyday stuff perspective focuses on useful stuff properties and builds corresponding ontological categories, so that we divide up the stuffs according to our ends.[15] Digestible stuffs are food, combustible stuffs are fuels, stuffs with nice and persistent colors are paints or dyes, sticky stuffs are glues, stuffs that cure diseases are pharmaceuticals, stuffs that are useful for construction are construction materials, and so on. These categories are so persistent that we are sometimes puzzled by learning that a certain paint can also be used as pharmaceutical or that there is a construction material that one can eat. However, from a systematic stuff perspective, every stuff can have infinitely many properties.

4.2 Scientific stuff properties[16]

The systematic or scientific stuff perspective has been developed over many centuries in chemistry as a collective effort rather than being created by some scientific genius. It differs from the everyday stuff perspective by systematically exploring stuff properties and by building different ontological criteria. A stuff property describes the reproducible behavior of an object under certain reproducible contextual conditions. Therefore the systematics consists in analyzing and systematically varying and combining the contextual factors, i.e. what scientists

[14] On the following and on an approach that refelects the epistemology of stuff knowledge in an ethical and environmental context, see Schummer 1996a (sect. 7.3), 1996b (part II), 1997c, 1999, 2001.

[15] This section draws on Schummer 1996b; for an historical account, see Farber 1931.

[16] This section draws on Schummer 1995b, 1997a, 1998a/b, 1999.

call experimenting. There are at least six different groups of contextual factors that each defines a group of stuff properties if the other factors are kept at standard conditions:[17]

1. mechanical forces: *mechanical properties*, e.g. elasticity, viscosity;
2. thermodynamic conditions (temperature, hydrostatic pressure): *thermodynamic properties*, e.g. specific heat capacity, melting point;
3. electromagnetic fields: *electromagnetic properties*, e.g. specific magnetic susceptibility, specific electric conductivity, optical absorption coefficient;
4. different chemical substances: *chemical properties*, e.g. the capacity for oxidation, the solubility in a certain liquid, or the velocities of each of these processes;
5. biological organisms or organs: *biological* and *biochemical properties*, e.g. LD_{50}, antibiotic or anaesthetic effect;
6. ecological systems: *ecological properties*, e.g. ozone depletion potential, green house effect factor.

Varying two or more factors under controlled conditions results in combined properties, like electrochemical or photochemical properties.

All these properties describe objects from the stuff perspective, i.e. they aim at characterizing objects independent of their particular size and shape. Although each experiment is necessarily performed on an object with a particular size and shape, the experimental results that matter from the stuff perspective strictly eliminate all size and shape dependencies. For instance, while every object has its particular heat capacity and electric conductivity, depending on its particular size and shape, the experimental characterization states its *specific* heat capacity and its *specific* electric conductivity by eliminating all the size and shape dependencies. These specific properties are characteristic of the stuff of the object, i.e. they are characteristic of any object of whatever size and shape as long as the object is supposed to consist of the same stuff. On the other hand, only the recurrent patterns of specific stuff properties allows building the ontological category of stuff kinds, which we use when we claim that two objects consist of the same stuff.

4.3 The logical structure of chemical properties and chemical knowledge[18]

Among the stuff property types, chemical properties stand out because the relevant contextual factor is of the same type as the object under investigation, i.e. both are portions of defined stuff but of different stuff kinds. While all stuff properties are dispositions, chemical properties are logically particular because they are dispositional relations with the relata being of the same kind. The logical structure is even more complex, because chemical properties usually describe a transformation of stuff kinds and thus might better be called transformative dispositional relations. If A, B, C, and D are stuff kinds, then a typical chemical property in standard formulation is "under certain conditions the combination of A and B results in C and D" (in short "A+B → C+D"). Compare that with the thermodynamic property "A melts at 60°C under standard pressure", or with a form property "X has a cubic form" or a part-whole relation "P is part of Q". Formal logicians can deal with the latter two but encounter serious difficulties already with the first one, so that they have never tried to deal with chemical properties.

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[17] Note that the context rather the than behavior of the object defines the type of property, which is sometimes confused. If one mixes two substances and no chemical reaction occurs, that is a chemical property of nonreactivity or innertness rather than a nonproperty. What counts as standard condition differs in detail from research field to research field, but usually includes room temperature and pressure, inert container materials and atmospheres, and the absence of "unusual" electromagnetic fields, mechanical forces, and biological organism. Hence standard conditions are, strictly speaking, controlled conditions that are kept constant, but they are frequently not mentioned but taken for granted in experimental reports.

[18] This section draws on Schummer 1996a (sect. 5.2), 1997a, 1998a.

In a less formalistic approach, however, we can investigate how the logical structure of properties shapes the logical structure of knowledge. Form properties and thermodynamic properties enrich our knowledge about kinds, which we may further classify by similarities but never relate to each other (Table 1a). Part-whole relations can be combined if they serially apply to kinds, which yields a hierarchical structure (Table 1b). If they refer to stuff kinds from a common set, chemical properties can be combined to form a network structure in which stuff kinds are the nodes and chemical reactions the links (Table 1c). In this network structure, each stuff kind is connected to any other in many direct or indirect ways. The specific links of each stuff kind, i.e. its location in the network, defines its chemical identity. By formal analogy to geometrical space, the network forms a chemical space in which each stuff kind has a definite location.

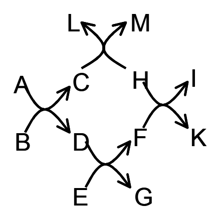
<table>
<tr><th>Property type</th><th>Example properties</th><th>Knowledge structure</th></tr>
<tr><td>(a) Form properties</td><td>X is round and 2mm
Y is square and 6 mm
Z is round and 4mm</td><td><table><tr><td></td><td>round</td><td>square</td></tr><tr><td>1-5 mm</td><td>X, Z</td><td></td></tr><tr><td>5-10 mm</td><td></td><td>Y</td></tr></table></td></tr>
<tr><td>(b) Part-whole relations</td><td>P is part of Q
Q is part of R
S is part of Q</td><td>R
↓
Q
↓
P, S</td></tr>
<tr><td>(c) Chemical properties</td><td>A+B → C+D
D+E → F+G
F+H → I+K
C+H → L+M</td><td>
</td></tr>
</table>

Table 1: Different knowledge structures result from different kinds of properties. (a) Form properties can be combined to form a multi-dimensional classification by similarities; (b) part-whole relations can be combined to form a hierarchy; (c) chemical properties yield a network structure.

Chemical properties tell us how stuff kinds are related to each other, but that is more than just a conceptual relation. Transforming the standard formulation yields two types of chemical information about stuff kinds: First, we learn about the reactivity of a stuff kind, as in "under certain conditions and in combination with B, A reacts to form C and D". Second, we learn how to make stuff kinds: "under certain conditions C and D can be formed from a combination of A and B." The information about reactivities (how something can change) and the information about synthetic possiblities (how one can make something) are but two sides of the same chemical properties. The first sounds more scientific and the second more technological, but both are equivalent, which explains the intermediary state of chemistry between science and technology in popular views (Schummer 1997b). Moreover, since each stuff kind is chemically defined by its unique location in chemical space, chemical properties tell us how to find samples of each stuff kind by actually making them in the laboratory. Rather than walking through geometrical space and searching for natural resources, we can start with some suitable stuff portions and move through chemical space by stepwise chemical syntheses.

4.4 Chemical substances and the operational hierarchy of stuffs[19]

Chemical properties require that stuff kinds are defined as precisely as possible to enable reproducible experimental settings. The stuff kinds that best meet these conditions are chemical or pure substances, but once we have defined them we can also use mixtures of chemical substances with exactly defined proportions. Chemical substances are not naturally given; they need to be made in the laboratory by purification of some raw materials. It follows that all chemical knowledge, both empirical and theoretical, refers to these artificially made stuff kinds and can only gradually be extended to other stuffs. In some sense, chemical substances are the experimental counterparts of theoretical idealizations in mathematical physics: in order to cope with the messy world, the objects need to be adjusted to our conceptual and logical necessities.

Chemical substances are the result of purification techniques, originally employing thermodynamic phase transitions, like distillation and recrystallization, and more recently chromatographic separation. All these techniques take stuffs apart and thereby define part-whole relations between two types of stuff kinds. A stuff that can be taken apart by any of these techniques is a mixture; a stuff that cannot is, by definition, a chemical substance. There are two other sets of separation techniques that each defines a part-whole relation between stuffs, and which altogether allow building an operationally defined four-level stuff hierarchy (Figure 1). A mixture that can be taken apart into different stuffs by mechanical means, like sorting or cutting, is a heterogeneous mixture, otherwise it is a homogenous mixture. A chemical substance that can be taken apart by chemical means, including electrochemical processes, is a compound, otherwise it is an element[20]

As with the chemical network, the concepts that define part-whole relations and thus the stuff hierarchy are all based on experimental procedures rather than built from a priori ideas about a hierarchical structure of the world. They refer to a sequence of experimental stuff analyses and a correspondingly reverse sequence of experimental stuff syntheses. If one chooses chemical substances as the basic stuff kinds of the chemical network, the hierarchical element-compound relations become an important feature of the network because they define for each compound the special chemical property of its elemental composition.

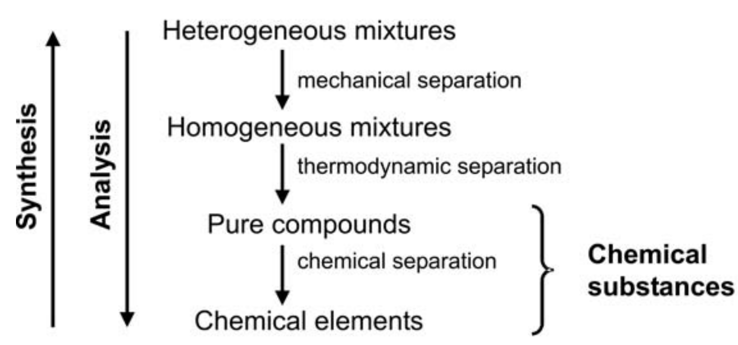


Figure 1: The experimental stuff hierarchy.

[19] This section draws on Schummer 1996a, sect. 5.1.

[20] There are several anomalies, however, discussed in the references.

The scientific stuff perspective should not be confused with the form philosophical notion of empiricism. It is an experimental approach that interacts with the world rather than passively waiting for some forms to make impression on our sensory organs. On the one hand, these interactions define all the central concepts of chemistry in an operational manner. On the other, these interactions create the objects of scientific investigations in a way that they best suit the stuff concepts. In a sense, the experimental approach adjusts concepts and objects to each other (Schummer 1994, 1996, chap 5).

5. The limits of form philosophy in chemistry

The scientific stuff perspective has largely escaped the attention of philosophers of science, although it has formed the experimental approach of all of chemistry and much of mineralogy, medicine, pharmacy, materials science, experimental physics, and so on for the past two centuries. Instead philosophers have, if at all, one-sidedly focused on form philosophical approaches that since the mid-19th century played an increasingly important role in theoretical explanations of chemistry. While chemists have worked hard to relate the stuff perspective in their laboratory work to the form perspective in their theoretical approaches, form philosophers have naturally noticed only forms without understanding their proper functions in chemistry.

A mere form, it may be recalled, has by definition no dispositional or dynamic properties, to say nothing about the transformative dispositional relations of chemical properties. Therefore it is impossible to reformulate or "explain" stuff properties merely by form properties for logical reasons. And yet, chemists routinely use structural representations of chemical substances like those in Figure 2a to explain stuff properties. So how does it work?[21]

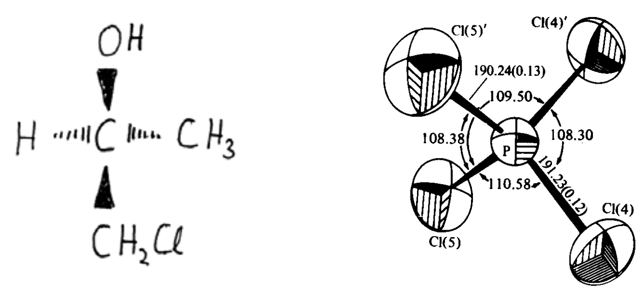


Figure 2: Two structural representations of chemical substances: (a) structural formula, and (b) geometrical features.

Structural representations in chemistry are like words in a foreign language. You need to know the language to understand their meaning, otherwise you perceive only the form of the letters, which might satisfy the form philosophical need rather than the scientific need for explanations. The language here is a theory that allows you to interpret the structural features that encode dispositional and dynamic properties. In order to interpret the structural formula of Figure 2a, one needs to know chemical structure theory which has been developed since the mid-19th century so as to encode all chemical properties and perfectly match the logical structure of the chemical network. The elements of the formulas, like the OH-group on top of the graph in Figure 2a represent so-called functional groups, in this case the chemical properties of alcohols. A sophisticated set of thousands of reaction mechanism of how such functional groups can interact with each other to form new structural formulas correspond to the

[21] The following draws on Schummer 1996a (chap. 6), 1996d, 1998a.

transformative dispositional relations of chemical stuff properties. Only if you know these reactions mechanisms, you can read the formulas to predict and explain chemical properties.

By contrast Figure 2b allows hardly any such interpretation. Its focus is on geometrical details, like angles and distances, and so-called vibrational ellipsoids that represent atomic nuclei. Such a graph can be the result of a quantum chemical calculation and similarly also of an x-ray diffraction experiment. It includes the basic information about the elemental composition of the represented compound (here PCl_4), but, in lack of established functional groups and reaction mechanism, its information about chemical stuff properties is rather poor. Moreover, it is difficult to interpret the graph so that it provides information about or explains any other systematic stuff property of the compound, other than the result of x-ray diffraction experiments. There is only one interpretation of the graph that makes systematic use of the geometrical form details: we can feed a semi-classical quantum chemical model with the geometrical data and calculate the *dynamical* features of the system of nuclei and electrons. In so doing, the quantum chemical theory transforms the form properties of the graph into dispositional properties of the system. This interpretation, and only this one, provides useful and systematic explanations and predictions of the mechanical, thermodynamic, and electromagnetic properties of the compound. But it is extremely poor with regard to any other type of stuff properties.

Each type of structural representations of stuffs, and there are many more than the two ones in Figure 2, is developed for a specific kind of theoretical interpretation that provides explanations and predictions for a limited range of stuff properties. There is no such thing as a universal structural representation that serves all explanatory needs, as there is no universal theory to interpret all structural representation. Moreover, most structural representations apply only to a limited range of chemical substances. For instance, the concept of molecular structures includes assumptions and approximations that are meaningful only for most organic and some inorganic substances and only for certain explanatory purposes, but entirely useless for others like metals, salts, and even water for most purposes. If you have worked for your entire professional carrier on organic substances, or if you have never reached a level beyond introductory chemistry, you might erroneously believe that 'molecule' is a universal concept.

Form philosophers could argue that the proper objects of chemistry are structures rather than stuffs, and that the proper goal of chemistry is the precise description of structures in a universal representational language. Indeed many people seem to be doing that, including crystallographers, analytical chemists, theoretical chemists, many physicists, inorganic chemists, and molecular biologists, and more recently also some organic chemists (Schummer 2002). That could simply be a result of division of labor, such that some people are focusing on structures, some on stuffs, and some on building explanatory relations between stuffs and structures – naturally those who work on structures would argue their work is most important, that structures are the proper objects of chemistry, and so on. However, if that indicates a general reorientation of chemistry rather than a conflict about social prestige of subdisciplines, the effects would be tremendous. For, switching from structures as explanatory entities to structures as the proper object of science means giving up the task of explaining and predicting stuff properties. One can do so, of course. But that means the end of everything chemistry has been identified with ever since. If chemistry gave up the goals of explaining our material world, making useful predictions about stuff behavior, and producing new useful stuffs and, instead, turned to the form philosophical contemplation of structures that are disconnected from our empirical world, there would be little need and public support for such a chemistry. To be sure, other scientists would immediately fill the gap, might they be called materials scientists or whatever.

6. The limits of stuff philosophy in chemistry

It is more likely, however, that the majority of chemists will keep to the stuff perspective as determining the proper objects of chemistry as well as its explanatory, predictive, and productive tasks. However, as with any epistemic perspective, the stuff perspective has its limits. If taken to be absolute or turned into stuff metaphysics, it makes you blind and can sometimes even threaten our health.

It happens that the stuff properties of solids, like metals and semiconductors, do not depend only on their chemical composition. Indeed, if we decrease the size of particles of the same chemical substance down to the nanometer scale, their stuff properties begin to vary at a certain size. Moreover, in that size range the properties also vary with the shape of the particles. It appears that, at the nanometer scale, form philosophy takes over.

The phenomenon is long known for a few chemical substances and can, at least in principle, be understood by quantum mechanics. Simply speaking, the smaller the size of a particle, the more atoms are on its surface compared to the number of bulk atoms; and surface atoms behave differently from bulk atoms and differ in their behavior depending on the surface curvature. A related phenomenon has long been industrially exploited in petrol refining and other processes: the size and shapes of pores in solid catalysts essentially determine the catalytic activity.

Nanoparticles also challenge the operational stuff hierarchy. Are silver nanoparticles of different size and shape all pieces of the same chemical substance of silver? Or should they be treated as a heterogeneous mixture of different silver stuff kinds? The operational criterion would require some mechanical technique to sort the particles according to their size and shape. However, there are practical limits at the nanometer scale. Nanoparticles that consist of several hundred atoms can almost continuously vary in size and shape. Any feasible process to sort the particles would have to work with coarse distinctions.

Because nanoparticles do not really fit the stuff perspective, their potential for developing new materials has largely been overlooked by chemists until recently. Instead, materials scientists first began to explore nanoparticles and nanostructured materials, and the field is arguably one of the most promising areas of stuff research for industrial applications.

However, chemists were not alone in sticking to the stuff perspective. Indeed, the idea that stuff properties are independent from the size and shape of stuff portions is so deeply entrenched in our common sense that it is also incorporated in our regulations. Up to today, all the national laws that regulate chemicals for worker, consumer, and environmental safety disregard the size and shape dependence of stuff properties in the nanometer range. Hence, a chemical substance is considered safe if it passes a safety tests performed on bulk stuff. Unfortunately such tests tell us nothing about the safety of the same chemical substance in nanoparticle form.[22] The tests would suggest safety even if some nanoparticles are extremely toxic. And if the tests are performed on certain nanoparticles, that would allow no definite conclusion about nanoparticles of different size and shape. Since size and shape can almost continuously vary, the number of necessary tests grows tremendously.

As long as the stuff perspective was guiding the research, development, and manufacturing of stuffs for industrial and consumer purposes, the regulatory gap was not very important. Now that materials scientists and engineers put enormous efforts on researching and developing nanoparticles and nanostructured materials (with nanoparticle abrasion) for industrial and consumer purposes, the regulatory gap has become a big ethical issue (Schummer 2007). In the regulation of chemicals and consumer and industrial products, the stuff perspective needs to be urgently complemented by the form perspective to prevent hazards that are looming on the horizon.

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[22] For instance, while gold as bulk substance is non-toxic, gold nanoparticles are cytotoxic depending on the particles size.

7. Conclusion

In mainstream philosophy of science, some of the tensions between stuff and form philosophies discussed in this paper have been transformed into epistemological and metaphysical issues. For instance, the stuff perspective is frequently equated with empiricism and the form perspective with theoretical science; sometimes the issues are even discussed in terms of the reduction of chemistry to physics. In yet another transformation, stuff philosophy and form philosophy appear as anti-atomism versus atomism, and so on.

The distinction between stuff and form philosophies is both much more fundamental and much simpler than these epistemological and metaphysical issues. It is more fundamental because stuff and form philosophies are mutually excluding basic conceptual frameworks for understanding the world. They can be, and have historically been, applied to virtually anything, including aesthetics and philosophy of language, to create opposing philosophical views. Moreover, our common sense understanding of ordinary objects as consisting of matter and form is, at least since Aristotle, such a powerful metaphor that we also use it to distinguish between different aspects of abstracta and ideas, like between the formal and material aspects of a sentence, a novel, a law, and so on.

On the other hand, the tensions between stuff and form philosophies are much simpler, once we understand that these philosophies arise from making absolute a certain epistemic perspective on the world. For instance, the stuff perspective is not "anti-atomistic" in the sense of claiming that matter has no atomistic structure; rather the stuff perspective only disregards the size, form, and structure of objects, just as the form perspective disregards all stuff properties. The stuff perspective is unable to make any claim about structure or form, just as the form perspective is unable to describe stuffs. Any attempt to do so abuses the categories or plays with metaphors, as Plato already did in his creation myth where a god builds the world by geometrically forming empty space, the metaphorical analogon to matter. The tensions between stuff and form philosophies only arise if we forget that they are epistemic perspectives, if we confuse our conceptual frameworks for understanding the world with the world itself.

Chemistry has been the general science of stuffs ever since. It is not surprising therefore that virtually all monographs by philosophers on philosophy of chemistry highlight the stuff perspective.[23] If the stuff perspective is characteristic of chemistry, any purist form philosophical approach to chemistry is misleading, even though it pleases mainstream philosophy of science that follows the paradigm of physics. If, as I have argued elsewhere (Schummer 2006), philosophy of chemistry becomes mature only when it focuses on philosophical issues that are characteristic of chemistry, it cannot do without the stuff perspective.

That does not require making the stuff perspective absolute or building a stuff metaphysics. By contrast, as I have argued in Sections 5 and 6, the form perspective is important in chemistry both at the theoretical and experimental level. That chemistry can combine different perspectives in a coherent scientific approach, as it combines a multitude of different models, is perhaps the most interesting philosophical aspect of chemistry. Like our common sense, chemistry does so without the idealistic fallacy of confusing its conceptual frameworks with the world itself. That is an important epistemological lesson that philosophers can learn from chemistry.

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[23] For instance, Schummer 1996a, Bensaude-Vincent 1998, Psarros 1999, van Brakel 2000; for review articles on the philosophy of chemistry see Schummer 2003b & 2006.

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