Chemical causal relations across different levels of description

A preliminary analysis¹

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Two forms of chemical reaction statements are standardly found in the chemical corpus. First, individual reactions statements describe reactions that occur between specific chemical substances, leading to the production of specific substances. Secondly, general reactions statements describe chemical transformations between groups of substances. Both forms of statements track regularities in nature and are thus warranted to be viewed as representing causal relations. However, a convincing analysis in terms of causation also requires spelling out the metaphysical relation between individual and general reactions. This is because their relation prompts concerns regarding causal priority and causal overdetermination. I present these concerns and address them by arguing that we should view individual and general reactions in the context of the determinate/determinable distinction.

1. Introduction

informative in ways that other sciences are not. It is a field of study that is not troubled (at least in total) with the weirdness of quantum physics; and at the same time, it does not have to deal with complex issues around life and consciousness (like biology does). Chemistry is also a very well formed science in the sense that there are no particularly unresolved theoretical aspects to it.² For example, there is no mystery around chemical reactions; how atoms and molecules are structured; or about the chemical properties of matter. There is a lot of settled and empirically well-established knowledge in chemistry that philosophers can study and invoke in order to address classical metaphysical questions, such as about causation.

There are of course aspects to chemistry that one may deem peculiar when comparing it with the most paradigmatic example of a natural science, namely physics. Chemistry is not as mathematically formalised as physics (whether we talk about quantum physics, classical physics or some other branch of it). In large part it employs its own language which is based on symbolising chemical elements with letters of the latin alphabet and ordering them in terms of increasing atomic number via the periodic table. In addition, when chemists speak of equations, they usually do not have in mind mathematical equations consisting of numbers and mathematical functions, but rather refer to statements that describe how matter transforms from one set of substances to another.

One of these uniques aspect of chemistry will be the focus of this paper, namely chemical reactions and their representation in chemistry. A chemical reaction is a "process that results

² There are of course open questions that chemists are still investigating (such as the limit of the periodic table or matters around quantum chemistry) but it is safe to say that chemistry is a mature science in the Kuhnian sense.

in the interconversion of chemical species" (IUPAC 2014: 262). It does not involve changes in the atomic number of the relevant atoms, but rather the rearrangement of atoms and possibly the breaking and forming of chemical bonds. Chemical reactions are represented by the so-called chemical reactions equations. A chemical reaction equation is a "(s)ymbolic representation of a chemical reaction where the reactant entities are given on the left hand side and the product entities on the right hand side. The coefficients next to the symbols and formulae of entities are the absolute values of the stoichiometric numbers" (IUPAC 2014: 262).

A chemical reaction can be represented by two different forms of reaction equations: what I call *individual* and *general reaction statements*. Individual reaction statements describe transformations between specific chemical substances which lead to the production of specific substances. For example, solutions of hydrochloric acid react with sodium hydroxide to produce sodium chloride and water: HCl + NaOH \rightarrow NaCl + H₂O. Such statements often specify the thermodynamic conditions under which the reaction takes place, the phase in which the reactants and products are found, and the catalyst which may participate in the reaction. On the other hand, general statements, the thermodynamic conditions, the presence of a catalyst and the phase of the reactants and products are not usually mentioned.³ For example, the above reaction can be understood as a special case of the so-called acid-based (neutralisation) reaction which occurs between an acid and a base to produce an ionic salt and water: HA + BOH \rightarrow BA + H₂O (more on this reaction below).

³ Usually, this is because the more specific instances covered by general reaction statements take place in ranging conditions, phases and/or with the presence of different (if any) catalysts.

Based on the above, it follows that general reaction statements describe reactions which can also be described by individual reaction statements. Therefore, the two forms of statements describe partially the same set of chemical transformations. The key difference between them lies in the level of detail and preciseness. Statements of individual reactions offer more fine-grained details of chemical reactions relative to statements of general reactions which are more coarse-grained descriptions.⁴ In light of this, I address the following question: what is the metaphysical relation between these two forms of reaction statements? Can they be considered statements of causal relations and if so, do they hold equal ontological weight? If not, are general reactions statements derivative descriptions of what is potentially genuine causal, namely individual reactions?

Addressing this issue is important because it can influence one's views on two related issues in metaphysics: laws of nature and natural kinds. It is relevant to laws because if any of these two forms of statements can be thought of as statements of causal relations then this implies (at least by some accounts of causation) that they track laws of nature (namely laws concerning the chemical transformation of matter) (e.g. Ellis 2001; Seifert 2023; 2024). Secondly, it is relevant to natural kinds because elements, substances and classes of substances are considered paradigmatic examples of natural kinds (e.g. Hendry 2006; Hoefer and Martí 2019; Thyssen 2023). Therefore, if the regularity relations in which these classes figure are not (all) genuinely causal, this undermines viewing them as natural kinds. So, examining individual and general reaction statements from the perspective of causation is

⁴ Individual reaction statements are more detailed descriptions in the sense that they specify the specific substances that participate in the transformation but also may specify the use of catalysts, the thermodynamic conditions and/or the presence of a catalyst.

not just prompted by philosophical curiosity; it is an important and -so far- neglected aspect to ongoing discussions around pressing metaphysical topics concerning chemistry.

Section 2 sketches the main issues that need to be addressed for a robust theory of causation in chemistry. Subsection 3.1 presents the particular issue that is the focus of this paper and introduces the distinction between individual and general reaction statements. Subsections 3.2 and 3.3 examine individual and general reaction statements in the context of two alternative metaphysical frameworks: that of the type/token distinction, and that of determinables/determinates respectively. Section 4 discusses the philosophical implications of this analysis. Section 5 concludes.

2. Thinking of causation in chemistry

Causation is relatively under explored in the philosophy of chemistry. Rom Harré (2012) wrote about viewing chemical reactions as candidate causal relations, arguing in favour of an agent-based account of causation. Also, William Goodwin (2012) discussed reaction mechanisms in terms of a mechanistic account of explanation. Since then, not much has been said, though admittedly the discussion is starting to receive more attention in recent years. Notable is the work of Lauren Ross (2021) who argues for a Woodwardian difference-making account of causation and of Suárez and Gómez (2023) who spell out reactivity in terms of 'chancy propensities'.

In general, there are good grounds to think of chemical reactions as causal relations. As I have argued elsewhere (Seifert 2023; 2024), chemical reaction statements can be understood as statements of mind-independent regularities. Whenever a set of substances are put

together in close spatiotemporal vicinity, then one observes a distinct set of substances in relatively close spatiotemporal vicinity. Put differently, chemical reaction statements can take the form of 'whenever A and B, then C', thus suggesting that this could be indicative of a causal relation. In addition, when formulating statements about chemical reactions, we find in the scientific corpus use of terms that are strongly associated with the idea of causation.⁵ Take for instance: 'The reaction of methane with molecular oxygen *produces* carbon dioxide and water', or 'Cake-batter rising is *caused* by a gas-forming reaction between an acid and baking soda'. Lastly, and perhaps more convincingly, reaction mechanisms have been invoked as paradigmatic examples of mechanistic explanations in science, thus further motivating a causal understanding of reactions (Goodwin 2012).

Of course, this is far from sufficient to establish that chemical reactions correspond to causal relations. In fact, I believe that in order to understand chemical reactions as candidate causal relations one needs to address at least four questions:

- a. What are the relata of such a purported relation?
- b. What is the relation?
- c. At what scale are these causal relations found?
- d. Do all statements of chemical reactions track causal relations?

Addressing question a. requires identifying the cause and effect of these purported causal relations. If we are to view a reaction of- say- an acid with a base as causal, then something must act as the cause and something as the effect. However, as I point out elsewhere (Seifert

⁵ By no means do I suggest that scientists make any explicit causal claims when using such terms.

2024) identifying the cause and effect is far from obvious with chemical reactions as it is not evident how chemical causes should be distinguished from background conditions.⁶

Unpacking this challenge naturally leads to question b.; namely, if we view reactions as causal relations, then what sort of relations are they? This involves bringing forward different accounts on causation and investigating which- if any- convincingly captures what we know (through science) about reactions. In this context, elsewhere I explore how Ned Hall's (2004) concepts of causation in terms of dependence and production fare with respect to the empirical and theoretical knowledge chemists have developed about reactions, defending a productive view for chemical reactions (Seifert preprint).

Question c. has to do with the scale in which chemical reactions are found. By scale I refer to the energy, length and time scale in which all objects (of any ontological category; i.e. entity, property, process, etc.) are found. It is fairly uncontroversial that everything is scale-relative. As Ladyman and Ross put it, 'at the quantum scale there are no cats; at scales appropriate for astrophysics there are no mountains; and there are no cross-elasticities of demand in a two-person economy.' (2007: 199).

Similarly, chemical reactions are found at a specific scale: they take place within a specific range of energy; they take time; and, they refer to transformations between stuff of particular sizes. That reactions take place within a specific range of energy is not particularly controversial. We know from chemistry that chemical reactions take place within a range of

⁶ For example, should catalysts be regarded as one of the causes of a reaction? In the representation of chemical reactions, they are not admitted (usually) as one of the reactants, yet they do chemically transform during the reaction (as reactants do).

thermodynamic conditions (i.e. usually specified in terms of temperature and pressure). In fact, chemical reactions do not happen under any and all thermodynamic conditions: they can only occur within a specific range of temperature and pressure, a fact that is often made explicit when writing down a chemical reaction equation.

What is more difficult is specifying the length scale in which reactions take place. In chemistry, reactions are described as if they take place at the length scale of chemical substances. This is a length scale that is quite permissive in the sense of including different numbers of entities of different sizes.⁷ But this is not the only thing that one should point out with respect to the length scale of reactions. If one is- say- a reductionist about these entities, that is, if she believes that atoms, molecules and substances reduce to their physical constituents, then it is not clear whether facts about how substances chemically transform do not reduce to facts about their constituents' interactions. That is, one needs to address the question of reduction in order to specify where chemical reactions- as causal relations- are found in terms of their length. This is important because an eliminative reductionist could

⁷ While a chemical reaction statement describes a reaction as if it concerns single molecular entities (i.e. single atoms, molecules or ions), this is not usually the case. As IUPAC states in its definition of chemical reactions, "(d)etectable chemical reactions normally involve sets of molecular entities as indicated by this definition, but it is often conceptually convenient to use the term also for changes involving single molecular entities (i.e. 'microscopic chemical events')" (2014: 262).

purport that the relevant causal relation is not found at the scale in which chemistry depicts it but is rather at the scale of quantum physics (if at all).⁸

Beyond the question of scale, another issue that requires addressing concerns the forms in which chemists describe reactions. As noted above, there are two main ways in which chemists state a chemical transformation. They either talk in terms of specific atoms, molecular entities or chemical substances transforming into some other set of atoms, molecular entities or substances (what I call *individual reaction statements*). Or, they describe a reaction in more coarse grained terms, where at least one reactant or product (if not all) are described in terms of a more general class in which they fall (what I call *general reaction statements*).

One can find many general reaction statements in chemistry. In fact, all reaction statements that concern classes of elements and substances count as general. There are several classes of elements postulated in chemistry and whose reactivity is examined, including of 18 groups, 7 periods, and 7 families. So for example, reaction statements concerning transformations of noble gases, metals, or alkalis are all general. Chemists also posit classes of compounds such as acids, bases and salts. So, the acid-base reaction statement is a characteristic example of a general statement, as are redox reaction statements and combustion reaction statements.

⁸ This in turn implies that if reject the existence of causation in physics (as some do), then there may not be any genuine causal relation here at all (e.g. Russell 1913; Farr and Reutlinger 2013; van't Hoff 2022).

Addressing these four questions has to be pursued in a piecemeal manner (or in a monograph!).⁹ This paper focuses only on the latter issue (i.e. question d.). What is the metaphysical relation of general and individual reaction statements and what does this relationship tells us about the nature of chemical reactions as causal relations? Is there a causal priority of one form of reaction over another, with general reactions being (for example) derivative from individual reactions? Or, do they both track causal relations? The next section addresses these issues.

3. Individual and General reactions

3.1 Introducing the distinction

The example that will be used to unpack the distinction between individual and general reaction statements is that of the acid/base reactions. Consider the following reaction statement A:

HCl (aq) + NaOH (aq)
$$\rightarrow$$
 NaCl (aq) + H₂O (l)

According to statement A, hydrochloric acid (HCl) reacts with sodium hydroxide resulting to the production of sodium chloride and water. The mechanism by which the reaction happens is fairly understood by chemists. The hydrogen ion (H+) from the hydrochloric acid combines with the hydroxide ion (OH-) to form water (H₂O). The sodium ion (Na+) combines with the chloride ion (Cl-) to form sodium chloride. Moreover, hydrochloric acid and sodium hydroxide react in an aqueous solution and in a one-to-one molar ratio (i.e. one

⁹ This does not mean that the four issues are not interconnected. See also footnote 11.

mole of HCl for one mole of NaOH). All in all, this is an example of an individual reaction statement because it describes the transformation of specific chemical substances.

Nevertheless, this particular example is also considered a case of the so-called neutralisation reaction. Neutralisation reactions involve "direct proton transfer from the acid to the base" (Bell 2025) and are represented by the following reaction statement B:

 $HA + BOH \rightarrow BA + H_2O$

HA corresponds to the acid, BOH corresponds to the base and BA corresponds to the salt.¹⁰ Note that while these are classes that represent more than one chemical substances, this is not the case with H₂O which refers to a specific substance (i.e. water). So this reaction equation cross-cuts descriptive levels. Nevertheless, compared to the previous example, it is a more coarse grained description and counts as a general statement. In fact, it subsumes the previous example which is an instance of a neutralisation reaction. Specifically, hydrochloric acid is the acid (HA), sodium hydroxide is the base (BOH) and sodium chloride is the salt (BA).

3.2 Types, tokens, and the issue of causal priority

¹⁰ An acid is a "molecular entity or chemical species capable of donating a hydron (proton) or capable of forming a covalent bond with an electron pair" (IUPAC 2014: 21). A base is a "chemical species or molecular entity having an available pair of electrons capable of forming a covalent bond with a hydron (proton) or with the vacant orbital of some other species" (IUPAC 2014: 148). A salt is a "chemical compound consisting of an assembly of cations and anions" (IUPAC 2014: 1329).

How should we think of this pair of reaction statements? One way is to consider them in the context of the type/token distinction.¹¹ Both statements correspond to two different type statements. Reaction statement A is not talking about a particular instance of hydrochloric acid reacting with sodium hydroxide in a specific laboratory at a specific time. Rather, it talks about this reaction in general. Similarly with reaction statement B: it is not about a particular instance of an acid reacting with a base but rather describes how in general these types of substances react.

In this context, token instances are all the relevant instances of chemical reactions that take place at specific spatiotemporal locations. They include all reactions of hydrochloric acid with sodium hydroxide that are performed at the chemistry department of the University of Athens today; all such reactions performed -say- by Lavoisier in Paris three centuries ago; and so on. Note that instances covered by statements A and B supervene in part on the same set of tokens. To be more precise, the set of tokens on which type-A happenings supervene is a proper subset of the token instances on which type-B happenings supervene. The set of token instances on which type-B happenings supervene is greater because it also includes the tokens of all other acid-base reactions (i.e. not just between sodium hydroxide and hydrochloric acid but also all between other pairs of acids and bases).

While this is a coherent way of understanding these two forms of reaction statements, it can raise problems with respect to our causal understanding of chemical reactions. This is because a question of causal priority arises. If we admit that both statements track causal

¹¹ One could equivalently spell this out in terms of universals. For reasons of simplicity, I only focus on the type/token distinction.

relations then it follows that we have two causal relations doing the explanatory work for the same token instances.¹² That is, unless one admits that there is a priority of one causal relation over another then we are lead to the problem of causal overdetermination. To make this clear, consider the following hypothetical question: what caused the production of H₂O in Lavoisier's laboratory on the 5th of December 1785 in Paris? According to statement A, the cause lies in the chemical interaction of hydrochloric acid with sodium hydroxide.¹³ According to statement B, the cause lies in the interaction of a base with an acid. If we grant equal ontological weight to the two statements, that is, if we admit that both of them track a distinct causal relation, then we have to admit that there are multiple causes to the production of water.

¹² As noted in the previous section, establishing that any of the two statements represent causal relations requires independent justification as well as addressing the other issues mentioned above. In fact, these issues are interconnected as, for example, how we understand the metaphysical nature of this putative causal relation affects how we view the relation between individual and general reaction statements. Given that this is a preliminary analysis, spelling out such interconnections is left for another occasion. For the purposes of the present paper, it is assumed that there are good reasons to consider individual and general reaction statements of some kind.

¹³ For the moment, I disregard the causal significance of token relations. This is discussed in the next section.

This is an instance of what is called the overdetermination problem. This problem is mostly discussed with respect to special science causation and the relation between the special sciences and physics.¹⁴ But, as I will show below, it can apply here as well.

Very briefly, Kim (2005) points out that the acceptance of the causal autonomy of the special sciences is problematic if one accepts the Causal Closure of the Physical (CCP). The CCP states that "every lower-level physically acceptable effect has a purely lower-level physically acceptable cause" (Wilson 2015: 352). Or, as Hendry puts it, following Papineau (2002), "physical effects are brought about solely by physical causes via physical laws" (Hendry 2010: 185). The causal autonomy of the special sciences (together with the acceptance of supervenience) lead to the conclusion that there are effects that are caused by higher-level causal powers.¹⁵ However, if one accepts the CCP then this leads to the overdetermination problem: physical effects have more than one causes (Kim 2005: 39-51).

A similar problem arises here. If we admit form-A and form-B statements as tracking *distinct* causal relations then we would have to admit that chemical transformations have multiple causes. In this particular example, the production of water would be caused, in

¹⁵ Supervenience denotes a weak metaphysical relation between entities, properties etc. found at different scales or levels of ontology. A higher level entity A is said to supervene on some set of lower level entities in the sense that whenever there is change in the higher level entity, then there is some change in the lower level ones as well (e.g. Hendry 1999: 120 who explicates supervenience from the perspective of chemistry).

¹⁴ In the literature, the causal overdetermination problem is discussed independently of any particular metaphysical understanding of causation (as per, say, the counterfactual, productive or some other account of causation). The same strategy is followed here.

accordance to statement A, by the causal powers of the particular chemical substances and, in accordance to statement B, by the causal powers of acids and bases.

There are several responses to this situation. First, one could admit that one of the two statements holds causal priority over the other. That is, one would have to deny that one of the two statements tracks a genuine causal relation and view it instead as derivative from the other causal statement. There are two main ways this can be done. Either be a sort of reductionist and claim that facts about acids and bases reduce to facts about specific members of the class of acids and bases. This would render B-form statements derivative from the more fine-grained A-form statements. Conversely, one could be a sort of emergentist and claim that the explanatory power lies in being an acid and a base and that the causal powers of acids and bases somehow emerge from the causal powers of their members. In this case, the cause of water's production would not lie in the powers the reactants have as specific substances (i.e. in the powers specific to hydrochloric acid and sodium hydroxide) but rather in the powers that are characteristic to being an acid and a base.

These options have drawbacks. By claiming causal priority for any of the two purported relations, one would have to admit that the other relation does not hold ontological weight. That is, she would have to accept that at most one of the two statements tracks a genuine causal relation and that the other acts as a mere heuristic tool. Put differently, at most either being a specific chemical substance, or being an acid/base/salt is causally efficacious; it cannot be both.

This is a drawback for several reasons. First, it leaves inexplicable the immense explanatory power that both forms of statements (and consequently the classes they invoke) hold in chemical practice. It is on the basis of reaction statements A that chemists standardly spell out the precise mechanism that is followed during the realisation of a chemical reaction.¹⁶ On the other hand, reaction statements B also hold explanatory power as invoking the classes of acids and bases often illuminates the precise feature of chemical substances that is responsible for these kinds of reactions. Put differently, reaction statements B achieve explanation via unification. This cannot be achieved with reaction statements A.

Another consequence that may be considered a drawback is that it undermines our views on chemical kinds. As noted in the previous section, chemical substances, acids and bases are all considered paradigmatic examples of chemical kinds (e.g. Ellis 2001; Hendry 2006; Scerri 2022; Thyssen 2023). If the relations in which these classes participate no longer hold metaphysical weight then this affects our idea of them as natural kinds. Admittedly, this is something that some philosophers would likely accept. Chang (2012) for example has argued (based on independent reasons) that acids and bases do not correspond to natural kinds. If he is correct then a derivative view of the relations in which these classes participate, complements- if not reinforces- his position.

There is another option: deny that any of the two statements holds metaphysical weight as they effectively reduce to facts about the token instances on which they supervene. That is,

¹⁶ What is called a reaction mechanism, namely a "detailed description of the process leading from the reactants to the products of a reaction, including a characterization as complete as possible of the composition, structure, energy and other properties of reaction intermediates, products and transition states" (IUPAC 2014: 902).

one could argue that only the token instances track causal relations, dismissing all together any statements that concern types (whether these are types of elements, substances or groups of them). This option suffers from the same drawbacks outlined above. I discuss it in more detail in the next section.

So where does this leave us? In the next section I explore a different perspective through which we can understand individual and general reaction statements. This perspective is not based on the type/token distinction but on the distinction between determinates and determinables. I show that while this perspective helps overcome the overdetermination problem, it does not (on its own) circumvent the question of causal priority.

3.3 A relation of determinates and determinables?

Jessica Wilson explicates the distinction between determinates and determinables as follows:

Determinables and determinates are in the first instance type-level properties that stand in a distinctive specification relation: the 'determinable-determinate' relation (for short, 'determination'). For example, *color* is a determinable having *red*, *blue*, and other specific shades of color as determinates; *shape* is a determinable having *rectangular*, *oval*, and other specific (including many irregular) shapes as determinates (...). (2023: Introduction)¹⁷

¹⁷ Italics in original.

The determinate/determinable distinction has its routes in logic and was systematically studied by W.E. Johnson (1921).¹⁸ According to Armstrong (1978b: 111- 112), Johnson identifies three features to it. First, if a particular has a determinate property, then it follows that it has a determinable one too. For example, if a ball has the property of being red, then it follows that it has the property of colour. Secondly, if a particular has a determinable property, then it is follows that is has some corresponding determinate property. That is, if a ball has the property of being coloured, then it must have some specific colour (i.e. green, red, yellow, etc). Thirdly, a particular cannot instantiate more than one determinate properties.¹⁹ A ball cannot be red and yellow at the same time.

In a similar manner, one can construe acid as a determinable which has hydrochloric acid, carbonic acid, nitric acid and other types of acids as its determinates. If a substance is an acid, it follows that it must be some sort of acid. Secondly, if it is a specific sort of acid (say, hydrochloric acid) then it belongs to the class of acids. Thirdly, an acid cannot be more than one acids: it is either hydrochloric acid, nitric acid, etc. The same applies to bases and salts. In the example of statement B above, base is a determinable which has sodium hydroxide as one of its determinates; salt is another determinable with sodium chloride as one of its determinates.

Does viewing the relation between form-A and form-B statements in terms of determination resolve the concerns raised in the previous section? The determination relation has already

¹⁸ Aristotle is also said to have discussed aspects of this distinction (e.g. Granger 1984) Discussion of this distinction is often accompanied with discussion of the genus/species distinction. The latter is not applicable to the case here so it is disregarded.

¹⁹ This feature has been contested (e.g. Armstrong 1978b: 112)

been invoked as a solution to the overdetermination problem. When it comes to special science causation, some philosophers argue that the determination relation allows us to retain the causal efficacy of higher level properties, without running into Kim's problem of overdetermination (e.g. Wilson 2015: 357). This is because a defining feature of determinates and determinables is that they are causally compatible. Put crudely, it is not inconsistent to maintain that both red and scarlet are causally efficacious when it comes to a pigeon's pecking of a red patch (Wilson 2023). As Yablo states:

(W)e know that [determinables and determinates] are not causal rivals. [...]. Determinables and their determinates, like objects and their parts, are guaranteed to be on the same team. (1992: 259)

While this seems to suffice to overcome the overdetermination problem, the matter of causal priority and causal efficacy persists. This is because there is wide disagreement about whether determinables are irreducible to their determinates.

Prima facie, determinables such as acids and bases could be regarded as causally distinct from their determinates because they are multiply realisable by their determinates. There are more than one determinate that can realise a determinable. Multiple realisability is not a particularly controversial feature of determinables. Colour can be realised by red, blue, yellow and so on. Similarly, acids can be realised by hydrochloric acid, nitric acid, etc. However, multiple realisability does not suffice to retain the causal efficacy of determinables as it does not necessitate that determinables are irreducible to determinates.²⁰ In light of this, different positions can be defended which range from admitting that determinables are reducible to their determinates, to the view that they are metaphysically secondary (or less fundamental), or that they are causally distinct and efficacious (just as determinates).

Armstrong has characteristically developed one such view in the context of his theory of universals. Specifically, he argues that there are no determinable universals but only determinate ones, because the former are related to the latter in terms of partial identities (Armstrong 1978b: 130). As he puts it:

The problem arises, what unifies classes of universals such as the determinate lengths or the determinate shades of colour. It is suggested that the unifying factor is a series of partial identities holding between different members of the class in question. (Armstrong 1978a: 135)

All in all, it seems that the question comes down to how we construe the relation between determinates and determinables. In Armstrong's case, that relation is one of partial identity, thus admitting causal priority to determinates (and dismissing determinables). However, there are other options too. I cannot do justice to all existing proposals here. Instead, I focus on one particular position which may sensibly accommodate our understanding of chemical

²⁰ While there is a lot of discussion around how to accommodate multiple realisability in the context of some form of reductionism, it is generally accepted that multiple realisability does not necessitate antireductionism (see for example recent approaches by Franklin 2021 or Tahko 2020).

causal relations across different levels of description. In particular, I consider the proper subset view as applied in the context of a power-based understanding of causation.²¹

Power-based accounts of causation track the causal efficacy of entities in the causal powers they possess. Very crudely, a knife has the causal power to cut meat; a table has the power to retain objects; water has the power to hydrate humans; and so on. Whether the nomological structure of nature is reduced or derived solely by such powers, or laws, or powers and laws is left open (see Ioannidis et al. 2021 for this discussion). Whatever the case, it is assumed that the causal efficacy of the entities involved in chemical transformations can be spelled out in terms of the causal powers they possess. In this context, I take that form-A and form-B statements can be understood as statements about the causal powers of the relevant relata (i.e. of atoms, molecules, substances and their more general classes). Hydrochloric acid has the power to react with sodium hydroxide; acids have the power to react with bases, and so forth. Viewed from this perspective, the question raised in this paper can be reformulated as follows: is there a way to maintain that determinables possess causal powers which are distinct (i.e. non reducible) to the powers of their determinates?

Wilson proposes a proper subset view of causal powers so as to retain the causal efficacy of determinables. She states:

the reason why "determinables and their determinates are not causal rivals" is because it is plausible, in the case of determinables and determinates, that each causal power of the determinable is identical to a causal power of its determinate.

²¹ My analysis should be viewed as an exercise in thought and not as a definitive defence of this position as this would require a detailed analysis of alternative accounts as well.

[Moreover, and for example,] the property of being scarlet, which is a determinate of the property of being red, evidently has more causal powers than the property of being red. (Wilson 1999: 47)

The proper subset view has been discussed in connection to non-reductive physicalism (e.g. Tahko 2020; Wilson 2011). In the context of special science causation, it allows the non reductive physicalist to regard the higher level as causally efficacious with respect to the lower level because the former's causal powers correspond to a non-empty proper subset of the powers of the latter. This retains the distinctness of the two levels, while avoiding overdetermination in virtue of their relation being one of determination (i.e. of determinable/determinate).

In the context of the acid/base example, this can be spelled out as follows. When both statements A and B are taken to apply, the causal powers of the determinables (i.e. acid, base, salt) are a proper subset of the causal powers of the respective determinates described by statement B (i.e. of hydrochloric acid, sodium hydroxide, sodium chloride). This ensures the causal distinctness between these pairs of classes, while at the same time avoiding (in virtue of the determination relation) the overdetermination problem.

One may note that the determination relation does not really solve the problems addressed in the context of the type/token distinction (see previous section). That is, it does not resolve on its own the problem of causal priority. Indeed, the determination relation is insufficient for a complete account of how general and individual reaction statements relate. We also need to say something extra, especially if we want to retain the causal efficacy of both determinables and determinates. On the other hand, I do not believe it is a particular stretch to accept that- in virtue of being in a determination relation- the determinable-acid has causal powers which are a proper subset of its determinates. If anything, it is easier to accept this claim with respect to determinables and determinates than it is when we think of relations between types or between parts and wholes (as is usually done with respect to the proper subset view).²²

4. This is far from over

So, with respect to general and individual reaction statements, there are two advantages to the determinate/determinable distinction over the type/token one. First, it allows a more natural understanding of how different classes or categories in chemistry relate to each other. As already noted, the type/token distinction does not help elucidate the relation between acids and -say- hydrochloric acids, as both of them are types. All we can say is that they are different types postulated in chemistry, each specifying their tokens by invoking a different degree of detail. This is not particularly illuminating. Instead, the determinate/ determinable distinction manages to illuminate the relation between type-acid and typehydrochloric acid. By understanding the former as a determinable of the latter, important features of their relation are clarified.

²² One could say that the proper subset view can also be coherently applied in the context of the type/token distinction. I do not disagree with that. However, I take the determination relation to add something to our metaphysical understanding of these two forms of chemical description, that is not tracked if we talk of these statements exclusively in terms of types.

The second advantage of the determinate/determinable distinction is that it resolves the overdetermination problem. Viewed as statements of causal relations, form-A and form-B statements seem to suggest that there are more than one causes to the production of the products of a chemical reaction. This is an instance of the overdetermination problem which is naturally circumvented if the putative relata of the two statements are viewed as being in a determinate/determinable relation.

However, invoking this distinction is not sufficient to establish whether determinables or determinates holds causal priority over the other. Armstrong believed that only determinates are causally efficacious (thus dismissing determinables). On the other hand, Wilson claims that a proper subset view allows to maintain determinables as causally efficacious. These are strikingly different options. While I do not offer an argument against Armstrong's view, I take Wilson's account to match naturally with one's intuitions about how determinates relate to determinables in chemistry.

There is one last issue that has not been addressed and which is essential in order to maintain the causal efficacy of either determinates and/or determinables. This is because the causal efficacy (of any of the two) hinges on an important assumption that has not been addressed. This concerns the determinables' and determinates' relation to their tokens. Recall, in the discussion of the type/token distinction above, it was mentioned that the types that are posited in form-A and form-B statements supervene on tokens and that the set of tokens on which form-A statements supervene is a proper subset of those on which form-B statements supervene.

The question that arises in this context is whether the causal efficacy of any of the two type categories are eliminated by the causal efficacy of their tokens. Lewis (1973) for example takes type causal statements as generalisations of token causal claims. On this view, there are no genuinely causal relations at the type-level; only token causal relations. If one accepts this then the entire discussion of the causal efficacy of either general or individual reaction statements becomes moot. On the other hand, this is not a problem peculiar to the metaphysics of chemistry: it affects science in its entirety to the extent that we take it to be in the business of making claims about types. So I leave this open to be explored in depth on another occasion.

5. Conclusion

I claim that there are two forms of regularity statements concerning chemical transformations: individual and general reaction statements. To the extent that we seriously entertain these as being statements of causal reactions, a number of important questions arise, including how these two forms of statements relate. I considered two ways in which their relation can be considered. The first is in the context of the type/token distinction and the second is in the context of the determinable/determinate relation. I argue that form-B statements of chemical reactions should be viewed as being statements about determinables, whose determinates are tracked by form-A statements.

Apart from this being a more natural way of understanding how different categories of stuff relate in chemistry, the determination relation also circumvents the overdetermination problem. There is one problem however which concerns how to maintain the causal efficacy of the determinables. I claim that this can be done by adopting a proper-subset view of causation.

Evidently, this discussion is far from over. If anything, more questions are now prompted that require to be addressed. Nevertheless, I believe that some progress is made, given how little has been said about causation in chemistry.

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