Biochemical Functions as Weakly Emergent

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Abstract

This paper will consider how the account of weak emergence presented by Wilson in the book *Metaphysical emergence* (2021) can be used to explore the relation between biochemical functions and chemical structure in biochemical molecules, as vitamin B12. The structure of the paper is the following. Section 2 will introduce why biochemical functions are interesting from a philosophical perspective and why their relation to molecular structure can be seen as problematic. In doing so, it will consider the definition of biochemical functions as in Bellazzi (2022) for which they can be seen as sets of chemical dispositional properties that contribute to biological processes. Section 3 will explore how, given this definition of biochemical functions, we can interpret the relation between chemical structure and biochemical structure via weak emergence. Section 4 concludes.

Keywords: Metaphysical emergence, Biochemical functions, Biochemical kinds.

1. Introduction

This paper will consider how the account of weak emergence presented by Wilson in the book *Metaphysical Emergence* (2021) can be used to explore the relation between biochemical functions and chemical structure in biochemical molecules, as vitamin B12. The discussion of the relation between biochemical function and chemical structure is relevant to the debate concerning inter-level relations together with being a foundational topic for biochemistry (Santos et al. 2020).[1] Moreover, the results of this paper provide a novel application of Wilson's account of weak emergence, enriching the case studies that can fit with the framework and offering new insights into the understanding of weak emergence in non-yet-considered cases.

The structure of the paper is the following. Section 2 will introduce why biochemical functions are interesting from a philosophical perspective and why their relation to molecular structure can be seen as problematic. In doing so, it will

[1] This paper draws on some of the results in Bellazzi 2023.

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2. Structure and Function in Biochemical Kinds

Chemistry is often taken to be the domain of chemical structure and kinds characterized in micro-structural terms, such as constituent atomic properties.[2] Biology, instead, is the domain of evolutionary functions, etiological classifications and pluralism (Slater 2009; Bartol 2016). Biochemistry stands as an hybrid domain between the two. While it is not easy to provide a set of necessary and sufficient conditions for a kind to be biochemical, the literature on the topic agrees that biochemical kinds need to exhibit at least two kinds of properties: structural ones and functional ones (Slater 2009; Bartol 2016; Havstad 2016, 2018; Kistler 2018; Tahko 2020). Proteins, for example, are characterised in terms of structure, the amino-acid chain that composes them, and in terms of the functional roles that they play within biological systems.

Prima facie, this definition or the combination of these two sets of properties might not be particularly problematic, however the exact relation between structural and functional properties still posits questions (Bartol 2016; Tahko 2020). One of the reasons why this is so is based on the complexity of the relations between structure and function, as they often take the form of multiple realisability and multiple determinability. Multiple realisability (MR) refers to a phenomenon in which the same entity or property can be realised by different ones.[3] For example, the property of being an eye can be realised by different organs in different animals. Multiple determinability (MD) refers to the opposite phenomenon: when the same entity can determine different properties or other entities. For example, the same chemical compound can enter into different chemical reactions, realising different properties.

In the biochemical case, MR and MD are particularly relevant because the same biochemical function can be realised by multiple microstructures and the same microstructure can realise multiple biochemical functions (Tahko 2020). Two relevant examples in this regard are haemoglobin for MR and the crystalline proteins for MD. As discussed and presented by Tahko (2020, 2021), haemoglobin is a protein with the function of binding and releasing oxygen and can be constituted by at least two different polypeptide chains (or more). The biochemical function of haemoglobin can be considered an instance of MR, as the function of binding and releasing oxygen is realised by at least two distinct macromolecules (chains of polypeptides) that present some micro-structural differences. This can challenge the identification of an identity reductive relation between the chemical structural properties and the functional ones. Multifunctional proteins or "moonlighting" proteins, such as crystallines, represent instances of MD instead. Crystallines are structural proteins present in all vertebrates' eye lenses, having a function in allowing sight, but they can also have an enzymatic role in digestive

[2] Even if this has been challenged as in Tobin 2010, Havstad 2016, 2018.

[3] Realization can be defined as a "synchronic ontological dependence relation, distinct from identity, and that transmits physical legitimacy from physical realizers to what is realized" (Polger and Shapiro 2016: II, 4).

processes. In these cases, we notice a form of MD, as the same chemical structure can lead to very different functions in sight and digestion mechanisms (Tobin 2010; Bartol 2016; Tahko 2020). This again challenges a direct identification of the relation between structure and function, as a strict identity relation between the some underlying structural properties and functional properties does not hold. Moreover, both MR and MD generate issues of taxonomy or classification. If we follow a micro-structuralist approach, then we should favour structure over function and have either many kinds that have the same function (in the case of MR) or one unique kind that has different functions (in the case of MD). If we follow a functional approach, then we have two or three—or as many as the functions—different kinds (in the case of MD) or one kind (in the case of MR).

As a reaction to these tensions, Bartol argues that we should bite the bullet and simply embrace the duality of the two sets of properties: there are chemical structural ones and the biological functional ones (2016). However this approach does not really do justice to the features of biochemical macromolecules that display *both* chemical structure and biological function. These two features are strongly entangled, as supported by some more complex relations between the functions and the chemical structure (see also Goodwin 2011). For instance, Tahko suggests that some cases of MD can be explained or derived from the amphoteric nature[4] of some microstructures (2020). In the cases of some moonlighting proteins for instance, their dual-functions nature can be seen as rooted in some chemical properties of the molecule (Goodwin 2011; Tahko 2020), or at least this can be an option to be analysed in detail.[5] The scientific successes of biochemistry in predicting, manipulating and explaining phenomena encourages instead the exploration of the relation between structure and function, despite its complexity. This is so because this discipline combines chemical and physical model systems to explain and predict biological phenomena.[6]

3. The Double Problem of Biochemical Functions

In order to explore the relation between the chemical structure and biochemical functions one should clarify what are the terms under discussion. Chemical structure comprises both the characterisation of the electronic structure and the molecular geometry of the molecule. What about functional properties? Functional properties in the biochemical context generate what we can call the double problem of biochemical function: the "relation problem" and the "function problem". The "relation problem" asks about the relationship between the chemical structure and the function of a biochemical molecule: how a chemical structure can realise a given biochemical function. As briefly introduced in the previous section, the relation problem is generated by the fact that functional properties in the

[4] An amphoteric chemical substance is one that can react both as a base or as an acid.

[5] The reducibility of the dual nature of moonlighting proteins has been challenged by Santos et al. (2020). This article stresses the importance of analysing the "dynamical interplay between the micro-level of the parts and the macro-level of the relational structures of their systems" in order to understand these proteins (2020: 1). Here I am not supporting the reducibility of biochemical functions to chemical structural properties but rather the relation between functional and structural properties.

[6] The Biochemical Society defines biochemistry as "the branch of science that explores the chemical processes within and related to living organisms" (https://biochemistry.org/education/careers/becoming-a-bioscientist/what-is-biochemistry/).

biochemical domain are often multiply realised, and because biochemical molecules manifest multiple determinability (see Slater 2009; Bartol 2016; Tahko 2020). Furthermore, it is difficult to understand which of the two components, the functional or the structural, has ontological priority in the taxonomy and identification of the biochemical kinds (Slater 2009; Bartol 2016; Tahko 2020). The "function problem" instead asks what biochemical functions are and how they relate to biological functions and the biological component of the kind (Tahko 2020, Bellazzi 2022). Let us consider these problems in more detail with the main case study of this paper, vitamin B12 (as in Bellazzi 2022).

3.1 Vitamin B12

Vitamins B12 are cobalamin chemical compounds that can act as coen-zymes in specific biological processes—specifically, propionate metabolism and methionine biosynthesis. This vitamin comes in four forms—or vitamers—that display similar but different chemical structures: cyanocobalamin, methylcobalamin, hydroxocobalamin, adenosylcobalamin (Combs 2012: 377; Fang et al. 2017).[7] They share a cobalt-corrin complex and the coenzyme function in humans for various biochemical processes such as hematopoiesis, DNA and RNA production, neural metabolism, and carbohydrate, fat, and protein metabolism.[8] Accordingly, these chemical compounds are classified under the same category, 'B12 vitamin', because they display a combination of stable microstructure, a cobalt-corrin complex, and physiological functions.

Vitamin B12 represents an interesting case study relevant to discussing the relation between structure and function because it displays both MR and MD. First, it presents a form of MR in that the biochemical functions of vitamin B12 can be realised by each of the four vitamers recognised in scientific practice.[9] Second, vitamin B12 plays various roles in human physiology, acting in different biological processes, from DNA and RNA production to hematopoiesis, displaying a form of MD too. The combination of MR and MD challenges the identification of simple relations between structure and function. For instance, it makes forms of identity-based reduction, in which the functions of vitamin B12 would be identical to some of the properties of the microstructure, difficult to hold (Tahko 2020). For the sake of the example, let me focus on the function "being a coenzyme in hematopoiesis (the production of blood cells)" (**Coenz-Blood**). B12 vitamers have a biochemical function in the proliferation of erythroblasts (red blood cells) during their differentiation (Koury and Ponka 2004). This happens because vitamin B12 acts as a coenzyme in the reaction involved in regenerating methionine, which is required in normal erythropoiesis. This function is a definitionally important part of the four vitamers of B12: it distinguishes generic cobalt-corrin

[7] A more detailed description is the following: vitamin B12 is "the generic descriptor for all corrinoids (compounds containing the cobalt-centered corrin nucleus) exhibiting qualitatively the biological activity of cyanocobalamin".

[8] Reference for chemical structure and function of vitamin B12 (https://pubchem.ncbi.nlm.nih.gov/compound/Cobalamin). Also, Chapter 12 "B12 Vitamin" in Combs' *The Vitamins: Fundamental Aspects in Nutrition and Health* (2012).

[9] This might represent an instance of multiple constitution of the kind B12, where this kind can be constituted by different chemical compounds that share some functional properties (Kistler 2018). In Kistler, a kind is multiply constituted when it can be constituted by two or more microscopic structures (2018: 18). See also Gillet 2013.

complexes from B12 vitamers, and this shows that, even if it might not be necessary and sufficient on its own to define B12, the functional component is nevertheless important.

Let us go back to the double problem of biochemical functions and elucidate them with the example. First, the "relation problem": **Coenz-Blood** is realised in four different ways via the four vitamers of vitamin B12 and, as such, the relation between the chemical properties of the vitamin B12 and one of its functions should be further explored. The MR of **Coenz-Blood** means that it is at least challenging or not straightforward to map a 1:1 correspondence between it and the possible underlying physicochemical properties. The realisation of this function should be further explored. Second, the "problem of function": what does it mean that vitamin B12 has **Coenz-Blood**} as a *biochemical function*?

The combination of these two problems of biochemical functions might support the suggestion that structure and function could be considered independently. The realisation problem challenges the unification or reduction between the biochemical functions of B12 and its chemical structure. The function problem supports a separation between the chemical and the biological component of biochemical kinds because the nature of biochemical functions could be subsumed under some biological characteristics, which do not relate straightforwardly to the chemical. However, the successes of biochemistry itself seem to provide reasons for the opposite: if we can explain, predict and manipulate biochemical kinds in terms of their function and composition, the two aspects need to be related and, to some extent, ontologically unified.

In order to do so, we should, first, offer a definition of biochemical functions that considers the relation between chemical powers and properties and being dependent on biological context. In this regard, the analysis will start from the following characterisation of biochemical functions (as in Bellazzi 2022):

> **BC-function**: Biochemical functions are associated with a set of chemical powers to bring out a specific effect within biological processes. These biological processes are a product of evolution and, as such, the relevant chemical powers are indirectly evolutionary selected [Fig. 1].

This account of biochemical functions is in line with the general characterisation of biochemistry as the science that considers the behaviour and effects of chemical processes in biological systems (Santos et al. 2020). Moreover, this approach to biochemical functions allows us to answer the function problem, telling us what these properties are, while maintaining the autonomy of the two properties. This provides a starting point to explore the relation between structure and function.

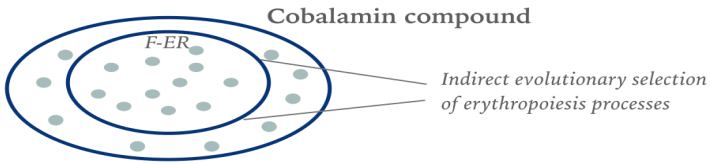

Fig. 1 – The evolutionary selection of the relevant dispositional properties or chemical powers for biochemical functions. In the example, F-ER is **Coenz-Blood** as the function to contribute to erythropoiesis for vitamin B12 as the relevant cobalamin compound.

4. Biochemical Functions as Weakly Emergent

As mentioned in the previous sections, a straightforward form of identity reduction is challenged by the widespread cases of MD and MR in the biochemical domain. Moreover, the set of dispositions relevant to biochemical functions are not any arbitrary chemical powers of the considered molecule or compound but some very specific ones. The relevant powers are those contributing to biological processes and have undergone at least an indirect selection process. The consideration of the biological process they contribute to and—indirectly—evolution that has selected such specific chemical powers is necessary to understand the relevant set of powers (Santos et al. 2020; Bellazzi 2022). Moreover, the causal efficacy of biochemical molecules is distinctive in that it should bring about specific effects within biological processes. Accordingly, an answer to the relation problem should take into account the specificity of biochemical functions together with the relation with structure. In order to provide such an answer, I will consider weak emergence via the proper subset strategy, as in Wilson (2011, 2015, 2021) and as suggested by Tahko (2020). This account, I will suggest, provides an answer to the relation problem and allows for the specificity of biochemical functions.

4.1. Weak Emergence and the "Proper Subset of Powers Strategy"

Weak emergence is a form of emergence compatible with non-reductive physicalism: there is only one broader kind of properties, physical properties. According to non-reductive physicalism, higher-level entities are real and constitute a novel level of reality, being distinctively causally efficacious; at the same time, their causal actions operate in a way respecting physical causal closure and hence in line with physicalism.[10] This combination of distinctiveness and causal efficacy, together with a sense of dependence, can be maintained by defending a form of weak emergence based on the "Proper Subset of Powers strategy" (Wilson 2011, 2021; Tahko 2020).[11] This strategy comprises two steps: i) accepting the *Token Identity of Powers Condition*; ii) accepting the *Proper Subset of Powers Condition*. The first states that every token power of a given token feature H on an occasion *t* is identical with a token power of the token feature L on which H co-temporally materially depends at *t*.[12] The second states that the token feature H has at *t* a non-empty proper subset of the token powers of the token feature L on which H co-temporally materially depends on at *t* (as formulated in Wilson 2021, 57-58). The combination of these two conditions constitutes the basis for a weak emergence relation between the higher and the lower-level entities or features:

[10] The principle of causal closure is often taken as a condition for forms of physicalism and claims that "all physical effects have sufficient physical causes", avoiding cases of problematic overdetermination.

[11] This strategy presupposes a very simple ontology of objects, properties, and powers. Properties are instantiated by objects and are identified by a range of causal powers (Shapiro 2020). In this case, a biochemical molecule instantiates the property "having a given biochemical function", individuated by a specific set of causal powers.

[12] Material dependence implies a form of substance monism, in line with physicalism, and a form of minimal nomological supervenience of the emergent features *type* H on the base features *type* L (Wilson 2021: 73). This means that supervenience should happen with at least nomological necessity.

> **WE**: "What is it for token feature H to be **Weakly Metaphysically Emergent** from token feature L on a given occasion is for it to be the case, on that occasion, i) that H co-temporally materially depends on L, and ii) that H has a non-empty proper subset of the token powers had by L" (Wilson 2021: 75; variables modified, emphasis added).

The first condition i) allows for a form of dependence as there is a token identity of the powers associated with the two features; the second condition ii) allows for a form of distinctiveness. In particular, this account allows for a form of relation between the features because the token powers of the realised feature H are nothing more than a subset of the token powers of a realising feature L, and the two features can be unified as the two sets of powers are both physically acceptable and the token powers of both sets are identical (as also in Shapiro 2020). At the same time, H is ontologically autonomous from L because H has a *proper subset* of the token powers of L and by Leibniz's laws and via set-theory principle, a proper subset of token powers is different from its set of token powers. This permits to maintain the type difference between H and L. The proper subset strategy also allows for a form of causal autonomy, as discussed by Wilson (2011, 2021). Specifically, H has a distinctive causal profile compared to L because it possesses a distinctive set of causal powers or distinctive causal profile compared to L. H's causal autonomy is based on the fact that H has a distinctive set of powers compared to the feature from which it emerges. One of the advantages of this account is that it allows for the relation between the higher and the lower level features, but the higher level ones can still be maintained as ontologically autonomous (Wilson 2011).

Moreover, as will be further detailed in 4.3, the proper subset strategy and weak emergence are able to deal with MR and MD. In the case of MR, it can be possible to identify more than one district token power subset of the lower-level L that can be associated with the higher-level feature H. While in the case of MD, the token set of powers of a given lower-level feature L could present different proper subsets of token powers associated with different higher-level emergent feature H. This allows the account to tackle with some of the issues concerning the relation between structure and function.

4.2 Biochemical Functions Are Weakly Emergent

Let us now consider the interface between biochemical functions and chemical properties and the answer to the relation problem in the light of weak emergence. As in the provided definition, a biochemical function is associated with a set of chemical token powers to bring in a given effect within biological processes (Bellazzi 2022). More precisely, the relation between the token powers associated with the biochemical functions and the correspondent chemical powers can be interpreted with the proper subset view. A biochemical function (BF) has in a given *t* a proper subset of token powers of the set of chemical token powers of the chemical molecule. This proper token subset is individuated via the evolutionary history of the biological process to which BF contributes. Accordingly, following the aforementioned account, we can state the weak emergence of the BF:

> **WE$_{BF}$**: A biochemical function BF weakly emerges from the chemical compound (C) under consideration at a given *t* because: i) BF co-temporally

materially depends on C at *t*; ii) BF has an identifiable and non-empty proper subset of token powers of C at *t*.

At a given *t*, it is possible to identify the biochemical functions as being associated with a proper subset of the chemical powers, with the powers associated with BF being token identical at *t* to powers in C. This makes the biochemical function BF *type* different from C, while it also allows us to maintain that the biochemical functions are co-temporally materially dependent on the chemical ones. Biochemical functions can then be considered weakly emergent from the chemical powers of the molecule and this provides an answer to the relation problem: the relation between the chemical properties of a biochemical kind and the functions is weak emergence. This also allows the identification of a relation between structural and functional properties, given by the token identity of the instances of the biochemical functions and the chemical properties, while at the same time maintaining a type difference and the related causal efficacy. Moreover, as will be elucidated in the next subsection, this view is also compatible with MR and MD.

In the case of vitamin B12, **Coenz-Blood** has a specific proper subset of the chemical powers of cobalamin, the ones relevant to the regeneration of erythroblasts in hematopoiesis. Those powers are those involved in the relevant co-enzymatic action that the vitamin plays: the token of the powers of **Coenz-Blood** are the same token powers of the cobalamin compound involved in the process, however the causal contribution is distinctive. The function **Coenz-Blood** emerges from the chemical compound in that it has a proper specific subset of causal powers. Specifically, in this specific case, it amounts to those chemical properties that allow for the regeneration of methionine via "the transfer of a methyl group from 5-methyl-THF to homocysteine via methylcobalamin" (Koury and Ponka 2004: 109). This set is not arbitrarily chosen, but it is identifiable thanks to the evolutionary history of the different biological processes in which B12 acts as a co-enzyme [see Figure 1]. The causal contributions are those relevant to the given environment and the given process. The biochemical functions of B12 vitamins can be considered weakly emergent from the chemical dispositional properties of cobalamin compounds at a given time *t*. This makes the causal profile of vitamin B12 distinctive, as recognised in scientific practice and in the functional characterisation of B12. At the same time, this emergence is only weak as it does not presupposes any stronger forms of ontological novelty, as the one of a strong form of emergence of a physically unacceptable variety. The identity of the token powers associated with both the emergent feature and the lower basis allows us to maintain a relation between structural and functional properties. The proper subset view and weak emergence allow us then to answer to the relation problem.

4.3 Multiple Realisability and Multiple Determination

As previously presented, biochemical functions are multiply realisable, and in some biochemical cases, such as in the crystallin protein, the same chemical features can be determined into many biochemical functions. This is often taken as a challenge to the identification of a relation between structure and function. Here, we have presented the proper subset view and weak emergence as an answer to the relation problem. However, more must be said on how this view can be compatible with MD and MR.

MR and MD are "type issues": it is the realised *type* that can be multiple realisable or be one of the determinations of a given lower-level feature. How are they compatible with weak emergence as defined above? Starting with MR, it is the type function **Coenz-Blood** that is multiply realisable by the four vitamers of B12. However, in a given moment, such as during a specific instance of hematopoiesis, a token instance of **Coenz-Blood** will be realised by a specific token instance of the four vitamers of B12. At the time *t*, *only* the token powers of a proper subset of the lower-level entity are identical to the token powers of the emergent feature **Coenz-Blood**. This implies that despite MR at the type level, at *t* the token entity is realised by one lower-level set of features. In the case of MD instead, there is only one token subset of powers that in a given time *t* realises the biochemical functions under discussion. A token biochemical function is emergent in that it has a proper subset of the token powers of chemical features. This makes the proper subset view straightforwardly compatible with multiple realisation and multiple determination, as discussed by Tahko (2020, 2021). Let us consider these them in more detail.

For MR, there may be several distinct token proper subsets of powers of the chemical features that can be associated with the biochemical function. In the case of **Coenz-Blood**, there are several distinct token proper subsets of the B12 vitamers that can be associated with the function and, as such, can realise the biochemical function under consideration. This is possible because, while the type is multiply realised, the token is always realised by a specific subset of token powers. For MD, two aspects should be considered. From the perspective of the token realised feature, one identifiable proper subset of chemical powers is associated with the higher-level feature, and, as such, MD is not problematic. From the multiply determinable feature perspective, instead, the token set of powers of a given chemical feature could present different proper subsets of token powers associated with different biochemical functions. Or, as suggested by Tahko 2020, there could be one proper subset of powers associated with two distinct type features, bringing in different effects in the relevant biological context. Accordingly, the token powers of the functional properties are a subset of those of a single chemical kind [Fig. 2].

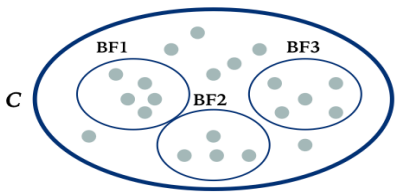

Fig. 2 – Multiple determinability of the cobalamin molecule, for which only one subset of powers is realised at a given *t*.

Moreover, the proper subset view is also able to deal with the reductionist view of MR for which it can be explicated in terms of a closed disjunction. This would make the biochemical functions reducible, and not emergent, to a closed disjunction of chemical structural powers. In this respect, Wilson discusses how the proper subset view ensures a form of ontological autonomy *contra* the disjunctive

strategy (2021). In the case of MR, when the entity H is weakly emergent, the token powers of H are a proper subset of the token powers of either L1 or L2. This makes H type different from the disjunction of Ls because of Leibniz's law: there are some powers of L that are not of H. Moreover, the nature of biochemical functions as defined here also allows to see how the defended view is compatible with MR and MD. The BF is associated with a set of powers whose selection is at least indirectly a result of evolution, and their causal efficacy is embedded in biological systems that are currently evolving. This has an impact on the fact that the types of realisers of the biochemical functions can change or increase in time. In addition to this, there could be a biologically possible world in which the biochemical function is realised by another chemical molecule yet unknown, or that does not play the function in current systems, but could have the function. This would make the disjunction an open disjunction, and, as such, challenges a straightforward reductionist approach.

In conclusion, the proper subset view and an account of weak emergence seem to be compatible with accounting for forms of MR and MD.

5. Conclusion

In this paper, I have considered how biochemical functions can be linked to chemical structure by using Wilson's account of weak emergence (2011, 2015, 2021). Section 2 introduced why the relation between structure and functions in biochemistry is interesting from a philosophical perspective and why can be seen as problematic. Section 3 focused on the double problem of biochemical function, the "function problem" and the "relation problem" offering further context to this debate. Section 4 then explored how, given a definition of biochemical functions, we can interpret the relation between chemical structure and biochemical structure via weak emergence. In doing so, I have considered how this framework offers us a way to think about the relation between structure and function that is compatible with multiple realisability and multiple determinability.

This paper has a series of interesting results. First, it enriches the case studies compatible with Wilson's account of weak emergence. This can bring in new insights relating to the emergence between entities that we would associate to the same level (Bellazzi, 2023). Second, it relates to one of the main research topics of biochemistry, the relation between biochemical functions and chemical structure. The account presented allows us to maintain a form of autonomy for biochemical functions while being compatible with the identification of the relation between structure and function. Third, the results of this paper contributes to the debates on unity of science and reductionism. In particular, they could be further explored to develop the our understanding of the interface between chemistry and biology, if we can establish a relation between the functional and chemical aspects of biochemical kinds.

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