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Perspective

Consciousness: A Molecular Perspective

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Abstract: This perspective examines the role of chemistry and molecular biology for a science of consciousness. Opposed to the consensus view, we argue that the molecular organization of biological systems is key to arrive at a thorough understanding of the dynamics correlated to the phenomenology of consciousness in complex organisms. This is indicated by the fact that the molecular sciences either provide one or more mechanisms directly related to phenomenology or otherwise describe the dynamics of the underlying substrate. In addition, we discuss substrate-independence in information-processing theories of consciousness and the issue of combination in panpsychist theories of consciousness, both from the angle of the molecular sciences. In any case, molecular details matter.

Keywords: consciousness studies; molecular mechanism; substrate independence; supervenience; information-processing theories; panpsychism

1. A Molecular Basis for Consciousness?

When trying to answer the question how to fit consciousness into a naturalist image of the world, there are different explanatory strategies one could pursue [1][1]. Many exclusively believe in either (cognitive) neuroscience or fundamental physics to advance the science of consciousness. Unfortunately, this sometimes leads to a neglect of the molecular picture that underlies the former and emerges from the latter. Taking the molecular perspective as advocated here also sharpens one's appreciation of problematic issues in consciousness studies that might otherwise be overlooked all too easily.

Most popular among many working in the field is the idea that consciousness is a (structural or systemic) property of information-processing networks. This is exemplified by many neurobiological [2], functional [3], or information-processing [4] theories of consciousness. The role of chemistry, accordingly, lies in supporting the relevant neurobiological and computational substrate: Consciousness has a chemical basis; but the right level to look for a mechanism that "gives rise" or "correlates" to the contents of consciousness is not the molecular level itself but the level of, e.g., assemblies of neurons in the brain. Instead of providing molecular mechanisms, chemistry plays the role of materially grounding the corresponding theories of consciousness.

We shall argue that limiting chemistry and molecular biology to a supportive role is deficient. In particular, we wish to stress the importance of taking the concrete molecular picture into account when trying to explain the way in which the content of consciousness—its "phenomenology"—is shaped. To this aim, we shall look at three issues in consciousness studies and emphasize the role of the molecular dynamics involved: First, we shall consider possible mechanisms *at the molecular level*, which we put into the context of reduction and supervenience. Second, the role

[1] Different strategies are not exclusively linked to particular philosophical positions. We shall discuss the prospects of physicalism and panpsychism in this article, because these appear to be currently the two most prevalent lines of thought. However, this does not rule out other realist proposals to study consciousness and relate it to the physical world.

of substrate-independence for information-processing theories of consciousness shall be assessed and related to molecular organization; and third, we shall consider panpsychism, the idea that all forms of matter are intrinsically sentient. We shall argue that one of panpsychism's inherent challenges—the combination problem—is closely related to chemistry. In every case, we find that acknowledging the role of chemistry and molecular biology might imply subtle but important insights when trying to explain changes in phenomenology.

2. Molecular Mechanisms

There are at least three conceivable scenarios in which truly *molecular* mechanisms are causally related to the phenomenology of consciousness. According to the first, a bio-molecule (say a hormone or an enzyme) would be engaged in a reaction that interferes with the phenomenology of consciousness. In another possible scenario, a known molecular mechanism (such as proton tunneling or isomerization) would relate to the phenomenology of consciousness via a genetic pathway, for example via altering the sequence of genes, controlling their activation or transmission. According to yet another scenario, some chemical property or reaction would shape the synaptic transmission, which in turn would affect the phenomenology of consciousness.

One could thus distinguish between kinetic, genetic or neurochemical mechanisms. Of these three, it would be the first which *directly causes* a change in phenomenology, but also genetic or neurochemical mechanisms should be studied on the molecular level in order to understand and/or intervene with the structure of phenomenology. One view that is consistent with this is the "ruthless reductionism" proposed in [5]. There is, however, also another view which emphasizes the importance of molecular levels of organization without appealing to overly-strong versions of reductionism: Living cells, such as neurons, arise from complex arrangements and interactions between molecules, and, accordingly, all biology has a chemical basis. Molecular structure therefore constrains and *specifies the dynamics* of neurons, synapses, and any other biological tissue that might be relevant for understanding phenomenology[2].

This line of thought is rarely considered explicitly in philosophy; but neurobiologists themselves seem to be much more inclined towards the possibility of such a scenario [6]. Recently, there has also been a renewed interest in psycho-pharmacology [7]; and also, the role of molecular communication channels in communicating emotions outside of conscious access is currently being investigated [8]. These findings could all be interpreted as indicating molecular mechanisms that are closely related to the phenomenology of consciousness. So indeed, philosophers paying close attention to what is going on in the molecular sciences would have to acknowledge a "molecular core" of consciousness studies. Exactly what this means, however, is contested: Either a *reductive relation* between chemistry and phenomenology holds, given that there is a molecular mechanism causally related to the phenomenology (**R**), or, since biological (functional) explanations *supervene* on chemistry (**S**), molecular mechanisms specify the dynamics of the substrate of phenomenology (Table 1, top row).

At this point it seems necessary to add that intertheoretic relations—reduction and supervenience—could exclusively be conceived of as relations between types of descriptions. For example, supervenience implies that there is no observable change in the phenomenology of consciousness without an according change in molecular structure. From a purely logical standpoint this corresponds to specifying a sufficiency relation:

$$y \text{ supervenes on } x \Leftrightarrow \Delta x \leftarrow \Delta y$$

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[2] People holding a purely information-processing view or who think that consciousness might be implemented in a machine will object that there can be a non-biological basis of consciousness. Still, they have to rely on some chemical substrate that implements information-processing, even if it is silicon.

To speak of reduction in this context, one would need to additionally specify necessary conditions for the phenomenon Δy to occur [9]. Since our approach is primarily interested in the types of explanations given in consciousness studies and not in the metaphysical underpinnings of consciousness, such a descriptive analysis is sufficient. Note, however, that relating descriptions does not address *ontological* questions, for example whether consciousness "is nothing but ...". Traditionally, reduction and supervenience have been closely associated with ("reductive" and "non-reductive" forms of) physicalism. We shall stick with this classification and also discuss another metaphysical position in the section on panpsychism. There, it too becomes apparent that chemistry must not be neglected in the study of consciousness on a methodical level.

Table 1. Is chemistry relevant for consciousness studies? There are 3 possible answers (mechanistic reduction, supervenience, or emergence) that correspond to the relation of chemistry and consciousness in different ontological settings (physicalism and panpsychism). In some exotic models, one finds that there is even a loss of (proto-)consciousness at the level of molecules. For details see text.

	Causal Mechanism	**Other**
Physicalism	**R**	**S**
Panpsychism	**E**	**L**

3. Information-Processing Theories of Consciousness

In information-processing theories, consciousness is correlated to the properties of information processing networks realized by, e.g., neuronal assemblies. The study of molecular mechanisms is not necessarily in competition with such theories. However, one assumption often made in this context is the assumption of "substrate-independence" (compare this also to the "robustness assumption" in [10]) which is incompatible with the assumption that changes in molecular organization are relevant to changes in phenomenology. After all, assuming substrate-independence guarantees that we could neglect any influence that "lower lying" levels might have on the phenomenon under study.

The view according to which system properties could standardly be taken to be independent from their realization is, however, overly simplified. We think that it is important to acknowledge that functional properties are independent from the properties of the underlying substrate only relatively—and not categorically. This could be appreciated, for example, if we compared the seemingly digital nature of neuronal firing to. the analog nature of (electro-)chemical transmission. Substrate-independence is an important feature of digital computing. But computers were explicitly designed in a way such that digital signal processing is not corrupted by effects stemming from the analog nature of the substrate. This is different from the computations afforded by the brain, as already discussed by von Neumann in 1958 [11]. Information-processing in the brain must therefore not carelessly be regarded as purely digital. There are many physical layers that might jointly shape the phenomenology of consciousness. In many information-processing theories of consciousness, however, the elementary unit that constitutes the network of interest is binary (neurons are turned on or off). But what is it about *consciousness* in particular that affords this "digitalism"? And why is the information-processing that is going on *within* a neuron or within one of its molecular components not taken into account? At the present moment, it is nothing but speculation to assume that the complexity and dynamics which are relevant in this case are independent from the substrate's molecular make-up. An emerging new discipline known as "thermodynamics of information" [12] relates physico-chemical details (about, e.g., measurement, entropy production or free energy costs) to the abstract properties of information processing (e.g., memory, information retrieval or mutual information). This area promises to shed new light on general questions pertaining to the physics of information and is thus highly relevant for information-processing theories of consciousness.

4. Panpsychism

Some proponents of information-processing theories have recently appealed to the philosophy of panpsychism [13]. In its most common form, as advocated for example in [14,15], panpsychism is primarily justified by philosophical reasoning, namely that it is unintelligible to get consciousness from unconscious matter. With physicalists, panpsychists share the standard intuition that macroscopic properties inevitably are the result of the dynamics of elementary, microscopic entities. However, they differ from standard physicalists in that they assume that matter, even in its most basic form, is conscious. Panpsychism could thus be distinguished from physicalism by its ontological commitment to some form of mentality inherent in all forms of matter.

There are problematic issues though. It seems implausible to just "merge" psychological with physical properties; the structures of physical and psychological theories are very different from each other. For example, on the (sub-)atomic scale individuality is a misnomer (something like "an individual electron" does not exist). On the level of psychology just the opposite is true: Individuals abound. Accordingly, the introduction of "proto-consciousness", a precursor of consciousness in elementary physical systems, seems necessary.

The belief in proto-consciousness, however, brings with it a problem of emergence: How do higher forms of consciousness result from a complex combination of proto-consciousness? This has been called the "combination problem" for panpsychism [16], which becomes even more pressing once one has taken a molecular perspective. If quarks and electrons are (proto-)conscious, what about atoms and molecules? Atoms and molecules form cells which in turn form tissue that makes up the whole organism. This question thus naturally leads to the puzzle of identifying the point of emergence of higher forms of consciousness starting with proto-consciousness. Judging purely from empirical knowledge, it is implausible that it takes place at a lower level than other life-processes (i.e., lower than at the level of biochemistry); and it is also implausible that it exclusively takes place at much higher levels either, because much of what is biologically relevant already takes place (or is initiated) at the level of cellular and molecular interactions (e.g., transcription, self-replication, formation of a boundary, synaptic transport etc.). So why not also the emergence of organism-level consciousness from proto-consciousness? Chemistry, after all, is the paradigmatic science of emergence [17]. It is quite appropriate then to suspect that chemistry or molecular biology is the place where to look for a mechanism underlying the emergence of consciousness.

But if this were the case, and if we shared the panpsychist belief that some form of (proto-)consciousness is realized in all physical systems, then the intuition that inorganic chemicals (like the ones that make up rocks and chairs) are devoid of any consciousness would almost certainly be false—at least potentially there would still be some form of (proto-)consciousness left in those systems. This is due to the fact that there is no sharp distinction between organic and inorganic chemicals, similar as there is no sharp distinction (according to panpsychism) between conscious and unconscious matter. Any organic molecule is composed of (and is in principle synthesizable from) parts of inorganic compounds (pure carbon is inorganic, but most organic material is carbon-based etc.). It should be possible then to experimentally probe panpsychism and perhaps arrive at artificially produced conscious systems—analogous to research currently done in synthetic biology.

Rejecting this possibility leaves us with a strange variant of panpsychism, according to which proto-consciousness is had by elementary particles, gets lost in the process of forming atoms and molecules, and emerges again at the higher neuronal level. This leads to a complementary problem of *dissolution*, that is, to explain how and why proto-consciousness dissolves or degrades. To date, there are no philosophical arguments that would render this plausible. Such thinking even seems incoherent, given the panpsychist's intent to state the ubiquity of consciousness in nature and to avoid any bifurcation into "conscious" and "non-conscious" domains, which were reminiscent of introducing a conceptual mind/matter split. From an explanatory standpoint, the situation is even worse than before because we would not only have to account for the emergence of organism-level consciousness *but also for* the loss of proto-consciousness in any theory based on this variant of panpsychism.

So, given a panpsychist ontology (second row of Table 1), one could either acknowledge chemistry's explanatory role for the emergence of higher forms of consciousness from proto-consciousness (**E**), which would possibly result in an experimental research program, or one could live with a "gapped-panpsychism" that assumes that proto-consciousness were lost at one point and regained later on (**L**).

5. The Middle Ground

We have argued that the molecular sciences are important for consciousness studies—regardless of one's ontological commitments. The relation between consciousness and chemistry could be one of reduction (molecular mechanisms causally related to the phenomenology of consciousness), supervenience (chemistry specifies the dynamics of the relevant substrate that supports consciousness), or intra-attributive emergence (higher forms of consciousness emerge from proto-consciousness, initiated by certain chemical reactions). It is improbable that exclusively one of these relations holds: First, it is plausible that some properties related to the phenomenology of consciousness could reductively be explained in terms of molecular mechanisms, whereas other properties might require explanation in terms of higher (e.g., systemic) levels of organization; and second, neatly distinguishing between reduction, supervenience and emergence with respect to phenomenology might be difficult in the concrete case; just as chemistry, the middle ground between (atomic) physics and (cellular) biology, resists any attempt to unambiguously classify its phenomena into the categories of reduction, supervenience or emergence [18].

To summarize, let us repeat the arguments given above. We were interested in the question to what extend molecular research is relevant to consciousness studies. Traditionally, it has been assumed that either neuroscience or fundamental physics is the relevant discipline which ought to make a contribution to a science-based understanding of consciousness. We have challenged this mainstream view by noting that there is an intermediate level—the level of the molecular sciences—that might be equally important. There is no principled reason not to engage in a molecular research program, no matter whether one believes that consciousness could reductively be related to a molecular mechanism or whether one thinks consciousness should primarily be studied in terms of information-processing. This is also true if one endorses panpsychism, the idea that consciousness is irreducible and ubiquitous in the universe, because there are open puzzles (the combination problem) that might require us to take molecular transformations into account.

Once one has taken a molecular perspective, some important issues in consciousness studies are readily appreciated; these pertain to molecular mechanisms related to the phenomenology of consciousness, the relativity of substrate-independence in biology and the difficulties concerning emergence and the apparent loss of proto-consciousness in a panpsychist model.

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