Chemistry and Physics: No Need for Metaphysical Glue

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Events and Discourses

Consider four discourses for speaking about water.

1. The human-centred (non-scientific) discourse concerning manifest features of the world, what Putnam (1975) called the stereotypical features of water. This discourse on the “stuff” water is not restricted to common sense. It may include sophisticated (Husserlian or Wittgensteinian) phenomenology.
2. Scientific discourse concerning macroscopic bodies of water, emerging from the manifest discourse; for example the event of boiling water. Here we encounter macroscopic (scientific) theories such as thermodynamics and hydrodynamics.
3. The scientific discourse surrounding the characteristic “molecule” found in water, H_2O . I will refer to it as the molecular or microscopic discourse.
4. Quantum mechanical discourse in which molecules such as H_2O are thought of as systems of nuclei and electrons. I will refer to this discourse as submicroscopic or microphysical.

There is nothing special about the number four. You may wish to distinguish an atomic discourse from the molecular discourse, in which case I will want to separate the atomic discourse into a chemical atom/element and a physical (free) atom discourse. Or I might suggest that we should distinguish a physico-chemical discourse from a chemical and physical discourse.¹ There is no reason or need to essentialise the demarcation of different discourses.

I will use the word 'event' (including states and situations) to cover both systems and events considered in scientific practice, as well as the pre-theoretical events talked about in the manifest discourse.² System or event identification in the "real world" is always to some extent approximate. An event is identified by a description; other descriptions may claim to say something about the same event, but this is strictly speaking a slightly different event correlated with the first (see further below).

I prefer not to speak of levels, because below I want to distinguish part/whole and interdiscourse relations, whereas “levels” may be associated with either or both. Often a level is associated with a “special science”. In my terminology there can be (and usually are) many different discourses in one special science (or physics for that matter). Also the micro/macro terminology can be ambiguous unless regimented. For example giving an explanation of the transparency of water in terms of a micro-based

property of water (using molecular discourse) may be thought of as a micro-macro relation and thought of as *interlevel*. But one might also say, the subject of discussion is an *intralevel* interdiscourse relation, because the focus is on the relation between two properties of the same thing, viz. water.³

Web of Belief

A central presupposition of this paper is that science, and knowledge in general, is a web of cooperative discourses addressing the “same” (expanding class of) pre-theoretical events and in doing this design new scientific as well as manifest events (the technological side of science and other practices). Different discourses are engaged in a cooperative effort, extending or improving the web of belief.⁴ There is one world of (pre-theoretical, manifest) events that holds together the different descriptions of these events. Let me give a preliminary example of how discourses about the same event are intertwined.⁵ Consider the experiment that was (allegedly) carried out by Benjamin Franklin to make a rough estimate of the size of molecules. It being an absolutely wind-free day, he went to a small lake nearby and dropped spoon-fuls of some pure oil on the surface of the lake, until the whole lake had that typical rainbow-coloured-oily appearance. Assuming there was now a monomolecular layer of oil on the water surface, he could estimate the size of the oil molecules. Now consider questions such as: how many surfaces are there and what are they like, e.g. is it a flat surface; is it permeable; is it a separate phase (in addition to liquid and gas phase)? One can give a variety of answers, depending on whether one approaches it from a hydrodynamic, molecular, quantum mechanical and so on perspective. These discourses are brought in when deemed relevant in a particular scientific endeavour. However, Franklin didn’t bother about distinguishing different discourses. He was thinking about one and the same event. According to legend his estimate of the size of the molecules was correct as to the order of magnitude.⁶

Although in practice discourses interact and are brought in when deemed (possibly) relevant (even if some of them are, strictly speaking, inconsistent or “independent”) and borders between discourses are at best pragmatic (as specified, say, in the type of articles a particular journal will consider for publication),⁷ we may still wonder whether something can be said about the relations between discourses. For a start this will introduce another (meta-)discourse.

Can Chemistry (or Physics) be Reduced to Physics? – Particle Physics

This question is meaningless. Why?⁸ First the nature of the reduction relation(s) has/have to be specified. More importantly, the two sides that are to be related have to be identified. Concrete questions such as “Can one give a statistical mechanical or quantum mechanical description of the three-phase line between a solid, a liquid, and a vapour phase?” or “Can we understand the notion of ‘chemical substance’ in a quantum mechanical discourse?”⁹ make some sense, but the general question concerning chemistry and physics does not, because the meaning of “chemistry” and “physics” is far too vague. One may as well ask “Can chemistry be reduced to chemistry” (think of boiling water and molecular theory) or “Can physics be reduced to physics?” (“it proves to be impossible to associate the description in terms of neutrons with any fixed number of quarks”)¹⁰.

The historical background to such questions is the influential idea of there being one (most) fundamental level to which “in principle” everything can be

reduced, a hierarchy of discourses (Oppenheim and Putnam 1958). But what would this fundamental level be like? Although it is sometimes said among experts that a description in terms of particles is untenable in the quantum world,¹¹ probably the dominant view which also sells well to the general public (including most philosophers)¹² is thorough going atomism: there are particles, containing smaller particles still, until we have reached the real “atoms”.¹³ Passing over the relevant question whether we consider the fundamental level to be something like fundamental physics today or IDEAL PHYSICS (which could be anything; the latter might tell us that the basic building blocks are Poltergeists), what *does* contemporary particle physics tell us?¹⁴ Hopefully it will at least give us a hint of what the most fundamental level might be like.

The so called standard model based on quantum field theory has ordered the particle zoo by means of 61 fundamental particles,¹⁵ including quarks, electrons, photons, but also gluons, the graviton and the Higgs particle; some particles have mass zero (gluons); some can only exist in bound forms (quarks). Fundamental laws are also (the exchange of) particles.¹⁶

More speculative theories predict the existence of more or deeper fundamental particles, the prospects of which depend on future experimental data. Perhaps we need a chronon, the proposed quantum of time, that is, a discrete and indivisible “unit” of time as part of a theory that proposes that time is not continuous.¹⁷ Or the notorious tachyons, which travel faster than the speed of light. There is no other support except faith that this particle hunt is going to stop ever. If we want to find out, for a start we need to make particle accelerators of the size of the solar system completely isolated from the rest of the universe.

Can Chemistry be Reduced to Physics? - Quantum Mechanics

The non-reduction of molecular chemistry has often been argued for by pointing out that quantum chemistry *borrow*s the notion of molecular structure from classical chemistry, following influential publications of Woolley (1978) and Primas (1983). In quantum theory an atom or molecule has no extension in space or time;¹⁸ neither electrons nor nuclei exist as individual objects; electrons in a molecule are indistinguishable, not identifiable entities.¹⁹ According to Primas the property “having a shape” emerges from interaction with the environment. When and where to suppress the correlations with the environment is not something that can be derived from quantum mechanics - more precisely: the only truly *ab initio* approach would not allow *any* correlation to be suppressed. But it is the decisions when to suppress them that, as it were, abstract objects out of the quantum mechanical formalism. Large molecules have structure (on a limited time-scale), not inherently or intrinsically, but because of interaction with the environment.²⁰

It has been suggested that molecular structure might be explained by the quantum mechanical phenomenon of decoherence (Joos 1996, 2006). This notion refers to (spontaneous) interactions between a system and its environment that leads to suppression of interference.²¹ The complete resultant Hamiltonian (the “true” one) contains interaction terms with the environment. This may well be the source of structure to be explained by decoherence. However, whether this approach can avoid putting in molecular structure “by hand” is a moot point.²²

A consistent description of a phenomenon in quantum terms must strictly speaking include the entire universe. This might offer empirical support for global

supervenience, but it leaves no room for local (or “weak”) supervenience,²³ where supervenience is understood as (somehow) combining ontological reduction (whatever this means) and conceptual (epistemological) autonomy.

Variety of Reduction and Emergence Relations²⁴

I will understand emergence as the denial of reduction and reduction as the denial of emergence.²⁵ Consider the most well-known example of reduction: temperature is average kinetic energy of the molecules (of an ideal gas at equilibrium).²⁶ Hüttemann has made the important observation that we can ask two questions:

1. Questions concerning the relation between components or parts of the system and the system as a whole; in this case the relation of average kinetic energy and properties of individual molecules – a (vertical) part-whole relation.
2. Questions concerning the relation between two properties of the system as a whole, in this case average kinetic energy of molecules (micro-based property) and temperature – a (horizontal) interdiscourse relation. This type of relation can be identified with bridge laws.²⁷

Hüttemann and Papineau (2005) argue that because of this distinction one should distinguish (at least) two types of physicalism: part-whole microphysicalism and interdiscourse identity-physicalism. They also give arguments to show that the interdiscourse and part/whole relations are independent.²⁸ For example, one might (as they do) “reject part-whole physicalism, while upholding levels [interdiscourse] physicalism.”

Consider the notion of “emergence” being introduced by saying: “some sense in which the behaviour of a compound system is independent of the behaviour of the parts.” This is not very helpful. In a strict sense properties of wholes *always* transcend the properties of the parts. (Hüttemann 2005, 122)

Using words like “behaviour” or “phenomenon” in definitions of reduction or emergence may be ambiguous with respect to the distinction between part/whole and interdiscourse relations. For example Chalmers (1996, 1) defines one variety of emergence as: “the high-level phenomenon arises from the low-level domain, but truths concerning that phenomenon are not deducible even in principle from truths in the low level domain.” Would this include both part-whole and interdiscourse relations in the sense just defined? And there is a second ambiguity: what about the truths concerning a phenomenon. Do they include the truths concerning the state of the system, the dynamic laws governing the system, or both? Probably most authors who use “behaviour” or “property” or “phenomenon” in their favoured definition mean to include “everything” (in the case of physical systems: two types of constant, states, and laws). But it might well be that for the particular type of system considered states are emergent and dynamic laws are not or the horizontal interdiscourse relation is emergent and the part-whole mereological relation is not.

An example of a definition of interdiscourse reduction in the context of the philosophy of chemistry could be:

If a property (e.g. molecular structure) of a molecular system is identical with a microphysical property it is reducible.

Notice that this is a relation between two properties of the *same* system: a microproperty and a submicro-based property. It could be argued that in terms of this

definition the property “structure of a molecule” is reducible,²⁹ but other definitions are possible.

As to part-whole relations an obvious further subdivision (for physical systems) is to distinguish, as already mentioned, the relation between the state of a compound system and its parts on the one hand and the dynamical laws governing the system on the other.³⁰ Focusing on states instead of dynamical laws one might define:

The state of a compound system can be deduced from the states of its parts and laws of composition. [deduction]

The state of a compound system cannot be deduced from the states of its parts and laws of composition. [emergence]

And then argue that because quantum entanglement is a feature of all systems of two or more electrons, this would seem to be an uncontested case of part-whole emergence.³¹

Hütteman refers to this feature as “[failure of] synchronic microexplanation”: The compound is in a determinate state, but, in the case of entanglement, this cannot be explained in terms of the determinate states of its constituents (because there are no such states). But he stresses that this says nothing about “diachronic microexplanation” (concerning dynamical laws), which he models on Broad’s definition of reduction and emergence as follows:³²

The dynamical laws applying to a compound system can be deduced from the dynamical laws applying to the components *were they isolated*, general laws of composition or combination, and general laws of interaction.

Note that this definition refers to counterfactual situations. In fact everything about the system is counterfactual, because it is presupposed that the environment is absent (no external disturbing factors).

Hence a further subdivision can be made by distinguishing (in the specific definition of part-whole reduction or emergence) between “contemporaneous parts” and “the parts were they isolated” (sometimes referred to as “parts that can be characterised independently”). Focusing on “contemporaneous parts”, Kronz and Tiehen (2002: 345) define what they call “dynamic emergence” as follows:³³

Emergent wholes have contemporaneous parts, but these parts cannot be characterised independently from their respective wholes. Emergent wholes are produced by an essential, ongoing, interaction of its parts.

Hüttemann (2005, 126) undermines the significance of Kronz and Tiehen’s “dynamic emergence” by pointing out that both classical and quantum systems have this feature. The temporal evolution of the earth cannot be explained independently of the whole system.

More variety can be introduced by further specifying terms in definitions; for example: what are reasonable restrictions on (laws of) interactions? Or: is it sufficiently clear what is meant by the phrase “general laws” - are generality and specificity matters of degree? What about the use words such as “to deduce” – how do various types of limits fit in?³⁴

The reader will have noticed that I am not committing myself to particular definitions or conclusions as to whether we have a case of reduction or emergence (for temperature, molecular structure, or whatever). My point is that it makes no sense

to look for a general argument for reduction or emergence that applies across the board. Depending on one's definition one can have either reduction or emergence. So, which definition to choose? A definition of reduction or emergence should make a relevant and interesting contribution to understanding the *variety* of relations in the web of belief.³⁵

Bridge Laws

I will consider two types of interdiscourse relations: bridge laws (with many concrete examples in science) and supervenience relations (the concern of philosophers, in particular in analytic metaphysics and the philosophy of mind).

Often bridge laws in the tradition of Nagel are considered theoretical identifications or correlatory biconditionals (nomic or logic necessity linking two different vocabularies).³⁶ In the metaphysical model I am developing they are given a more empirical status, something like covariance subject to context, where this context dependence introduces *ceteris paribus* conditions. Bridge laws are not a priori principles or definitions (not like the causality principle or conservation laws), although a strict separation of the empirical-synthetic aspect of knowledge and the defining-analytic aspect is not possible, and not only because of Quine's arguments. There are numerous "laws" for which it has been a matter of contention whether they are defining-analytic or empirical-synthetic.³⁷

Even if bridge laws are understood as stipulative definitions that justify elimination or replacement of the reduced theory, there would remain the question of initial and boundary conditions. One thing is clear: the context and environment is not part of the reducing theory and restrict the range of a particular bridge law. Applying so called universal laws to concrete cases requires an appeal to initial and boundary conditions. Because fixing these requires measurement, prediction (or retrodiction) is never strict, even before we enter the realm of quantum mechanics or quantum field theory. More generally one might argue that any application of theory requires that the location is specified in pre-theoretical terms (van Fraassen 1992). This background understanding of what one is doing involves many discourses including ordinary language (the universal meta-language).

Bridge laws are *ceteris paribus* because of a range of interrelated features of (scientific) knowledge: indeterminacy or underdetermination of event identification, environmental constraints, initial conditions, approximations. Approximations are made when measuring initial and boundary conditions of the event or system, in specifying the boundary of the event or system, in specifying the parts, in specifying interaction with the environment, specifying laws of interaction, choosing a state space, and so on.³⁸ All calculations and predictions are approximate in that they only match experimental data approximately. For example current theory says that a neutrino has mass zero. But experimental confirmation of this "fact of nature" is never definitive.

I am sympathetic to Cartwright's (1999) arguments to the effect that there are no strict laws whatsoever, no strict laws in the special sciences, no strict laws in physics.³⁹ Physics provides models in which strict laws apply to closed (model) systems, but in the real world there are no closed systems. The general picture is something like this. What we have is (*ceteris paribus*) phenomenological laws that normatively model phenomena vaguely described in common sense terms. These phenomenological laws are more or less empirically adequate in the sense that they

are more or less useful in guiding future actions that interest us. Such laws employ models of phenomena that are already severely regimented. Then more models at the theoretical level are added; the confirming experimental measurements are carried out in more and more artificial environments; and applications are more and more carefully tailored patches of order in a messy world. We build devices to approximate our well-understood models. Industrial equipment and processes as well as scientific instruments are ever-better streamlined so that they can become the right environment for ever-more powerful nomological machines.

Consider as an “ordinary” example of the *ceteris paribus* character of bridge laws the notorious example of “water is H_2O ”. Passing over the issue of different phases of water and related thermodynamic considerations,⁴⁰ and focusing on the meaning of (ensembles of) H_2O (molecules), one may wonder:

Does water consist of H_2O molecules? No! Water molecules interact and form larger clusters in liquid water. In ice there aren’t really individual molecules. In solid neon one might come across water hexamers. Ions in liquid water truly belong to water.

Can the relevant molecules be clearly identified as being “like this”? No! Water contains isotopic variants such as HDO and D_2O . The physico-chemical properties of deuterium oxide are different from those of ordinary water, and therefore its role in biochemical processes. I don’t think we would survive if all D_2O is replaced by H_2O .⁴¹

Restricting the discussion to one set of isotopes, are all H-atoms in water identical? No! There is ortho- and para-hydrogen, which have different physico-chemical properties.⁴²

Does a water molecule always behave as a H_2O molecule? No! Apparently in some circumstances, water molecules are not “seen” as H_2O by entities which with it interacts, but more something like $\text{H}_{1.5}\text{O}$.⁴³

Forgetting about molecules, ions, isotopes, can we rest assured that water always consists of closely interacting H and O atoms? No! There is some probability (however small) that a water molecule will suddenly transform into a Neon atom (Balyev et al. 2001).

At best the parts of water in the molecular discourse have a fleeting appearance, the specifics depending on the context of a sample of water (temperature, pressure, hysteresis).

The example of the macroscopic-molecular interdiscourse relation for water illustrates that the content of the interdiscourse relation depends on the context, which is another way of saying that it is *ceteris paribus*. Therefore interdiscourse relations are empirical *ceteris paribus* laws unless they have been raised to the status of analytic definition (“postulate”) for the time being, that is, as long as developments in the web of belief give no reason to give up this particular *stipulation*.

Indeterminacy of Event Identification

Different discourses use different descriptions of “the same” event, system, object, etc. For example protein crystals may be studied by physicists, chemists and biologists and would include various loosely related macroscopic, molecular, and submicroscopic discourses. There is “automatically” some sort of interdiscourse relation if different discourses claim to have something to say about the same

situation. However, interdiscourse relations are not strict laws or definitions because the criteria of event identification are discourse dependent and never absolutely exact. For a start note that it is often difficult to know what entities, states or processes to identify with which when considering interdiscourse relations. As Ramsey (1997, 237) remarked in the context of the philosophy of chemistry: “The requirement that events at one level be naturally isolable at another is enormously implausible as intertheoretic compatibility condition.”

As Aristotle already said: there is no *thisness* without *suchness*. Sortals play an essential role in individuation. But, event, thing, individual, entity are not genuine sortals. Only proper sortals are capable of delimiting what falls in their extension in a definite way (and even then doubts can be raised about the definiteness). Therefore how events are individuated is relative to the language used to describe them. Of course rough hints are possible, but they don't give exact descriptions.

My notion of event derives from the notion of event Davidson invokes in his anomalous monism, but I am sympathetic to the concern that no clear individuation conditions of events have been provided.⁴⁴ However this criticism is irrelevant in the following sense: The request for individuation must stop somewhere. We start with what scientists call a working hypothesis and philosophers might call a transcendental or metaphysical assumption: “the world consists of events.” At this level it doesn't make sense to ask for criteria of identity, because such criteria require *descriptions* of the events. We can only ask about criteria of identification if something is in place. There is no God's-Eye-point-of-view-meta-description that gives the only true identification of events.

Parcelling out of events only makes sense given a particular discourse in place. Event identification is only approximate and there is no strict token-token identity, no strict one-to-one (causal role) correlation between events or systems under different descriptions. Hence the token-token level supervenience relation is also subject to the indeterminacy of event identification. When there is no multiple realisation a simple *ceteris paribus* bridge law may apply, diffusing the distinction between token-token and type-type relations.⁴⁵

Because identification of events, objects, properties is subject to a discourse, I follow Davidson in defining supervenience in terms of a relation between discourses, or in Davidsonian discourse: “languages”. His (preferred) definition of supervenience is:⁴⁶ “a predicate *p* is supervenient on a set of predicates *S* if and only if *p* does not distinguish any entities that cannot be distinguished by *S*.”

Quine said, when formulating his understanding of supervenience: “Nothing happens in the world, not the flutter of an eyelid, not the flicker of a thought, without some redistribution of microphysical states. ... physics can settle for no less.” This could be accepted if properly qualified. There is “approximate” supervenience of all special science discourses on physical discourses (because “physics can settle for no less”), but strictly speaking there is at best only global supervenience.⁴⁷ Because of the indeterminacy of event identification and the holism of the web of belief there is no use for local supervenience relations, except as hypothetical basis of *ceteris paribus* non-strict bridge laws.

Because physics claims to have something to say about every change of every event, there will be approximate supervenience of all other discourses on physical discourses. That is to say the physical embedding of “everything” can stay. Even if

there are no strict laws, physics can still claim that it has something to say about everything, although it doesn't exclude there to be part-whole emergence and context-dependence to be all over the place in physics.

No Need for Metaphysical Glue

The remarks made in this paper are preliminaries for a metaphysical model characterised in the following statements.⁴⁸

There isn't any clear conception of fundamental ontology. Already in physics there is emergence and context-generated ontology all over the place. Physics cannot be reduced to physics. There is only (approximate) global supervenience of the special sciences on the physical (and of parts of physics on other parts of physics).

There are many possible definitions of interdiscourse and part-whole relations. Proposed definitions of interdiscourse and part-whole relations are interesting if they split up the web of science in different ways.

Event identification conditions are discourse-dependent. The request for individuation must stop somewhere. Scientifically regimented events supervene on manifest events.

Different discourses are held together in the web of belief, because here and there and everywhere different discourses claim (can be made) to speak about the same event, which is the basis of "pragmatic" supervenience relations, which, proper empirically support being provided, can be upgraded to *ceteris paribus* bridge laws. Because of the *ceteris paribus* feature there is no neat distinction between bridge laws and supervenience relations.

Unless empirically shown otherwise, intertheoretical relations are assumed to be *ceteris paribus* *symmetrical* covariances (van Brakel 1996).

A strict separation between different discourses is not needed (and not possible) and primarily serves as a model imposed on a messy world. We should neither speak of unified nor of disunified science, but of a variegated interconnected patchwork, perhaps a confederacy, but not a unified whole. If there is something unified, it is at the manifest level.

A thoroughgoing physicalism leads to a world picture in which we have to wait for the great unification in order to be able to understand what happened during the first femtosecond (or less) of the universe.⁴⁹ Knowledge of a Theory of Everything (unifying all physics) will be of little relevance for mundane matters.⁵⁰ It won't even help us to understand such ordinary phenomena as turbulence (in fluid flow). An alternative is to think of the world as a complicated and diverse place described by different discourses working together side by side, related by a variety of *ceteris paribus* interdiscourse relations, without any universal metaphysical glue to bind it all together. Perhaps the strength of scientific activities lies, not in formal monolithicity, but in it forming a complex unity of diverse interacting discourses and practices.

As philosophers of an empirical bend are well aware *the world itself* is a posit, which lacks extension except when a particular intensional context is provided. As van Fraassen (2002, 24) puts it: "[The word 'world'] is a context-dependent term which indicates the domain of discourse of the sentence in which it occurs, on the occasion of utterance." There is no need to commit oneself to a priori assumptions concerning one pre-given physical world. There is no need for the assumption that the chemical world coincides in an ontologically strict sense with the physical world. The

physical and chemical world, themselves patchworks of the many worlds they are making (Goodman 1978), are connected by numerous interdiscourse relations. But the latter should be taken as empirical *ceteris paribus* regularities, not metaphysical necessities - the only circumstances in which they may be thought of applying strictly, are conceptual models and thought experiments. Such interdiscourse relations are symmetrical, leaving the autonomy of both sides intact, without preventing forms of explanatory interaction or extension *in both directions*, by borrowing, synthesis, criteria of overall coherence, and so on.

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Endnotes

¹ Cf. Harris' (2008) arguments to the effect that "the chemical bond is best described as a theoretical synthesis or physico-chemical entity." Duhem argued that a rigid distinction between physical and chemical properties cannot be made (Needham 2008a).

² By definition a physical state gives a complete description of the system's condition at a given time (given a discourse, e.g. microdiscourse, macrodiscourse). A physical system has a state, properties associated with that state (varying quantities and constants) and dynamic laws describing its evolution. Note already that talking this way requires that the boundary with respect to the environment can be defined.

³ The distinction in physics between classical and quantum systems doesn't easily correlate with micro/macro either. A sugar molecule is classical. On the other hand there are macroscopic quantum states in superconductors.

⁴ A (Quinean) web of belief in which distinctions such as analytic/synthetic or theoretical/empirical are contingent and ontology is always a matter of hypothetical "posits".

⁵ A more sophisticated example (the polywater episode) and more on (Quine's) notion of 'web of belief' is given in van Brakel (2008, 149-51). See also the section on "realism" in this paper (pp. 153-4), which serves as a background for the present paper. Among many other possible examples of complete "disciplines", chemical engineering is an excellent example to illustrate how complex events are described and explained using many different discourses together.

⁶ As a practical man Franklin wasn't interested in molecules. He was doing the experiments to explore the use of oil to calm rough waters (Harte 1998, 5).

⁷ It has been suggested in a number of publications that theoretical understanding at the level of solid state physics (e.g. concerning superconductivity) is independent of particles physics, although methods and models are shared and borrowed between these fields - though there is no consensus on this matter (of "epistemological reduction"). For a recent discussion see Howard (2007).

⁸ For more detailed discussion see van Brakel (2004).

⁹ See for statistical mechanics and the "thermodynamic limit" and ensuing discussions on reduction and emergence Batterman (2005); for "substance" and quantum mechanics Loferer and Amann (2001).

¹⁰ Citation from Dieks and de Regt (1998).

¹¹ Because there are always interactions in the real world, Quantum Field Theory would not provide "grounds for regarding particlelike entities as constituents of reality" (Fraser 2008).

¹² See Ladyman et al. (2007) for a rare example of a "naturalistic metaphysics" committed to the view that "the attempt to domesticate twenty-first-century science by reference to homely images of little particles ... is forlorn." (4)

¹³ For example, Kim (1998: 15) writes: “The bottom level is usually thought to consist of elementary particles, or whatever our best physics is going to tell us are the basic bits of matter out of which all material things are composed. As we go up the ladder, we successively encounter atoms, molecules, cells, larger living organisms, and so on.”

¹⁴ Of course atomism is taken for granted in particle physics. Noble laureate Martinus Veltman (2003: 8, cf. 35) writes: “All matter is made up from molecules, and molecules are bound states of atoms. For example, water consists of water molecules which are bound states of one oxygen and two hydrogen atoms. This state of affairs is reflected in the chemical formula H_2O .”

¹⁵ Depending on how one counts; an alternative number is 48. As the theory still contains 18 (or 17) “arbitrary” constants (which have to be measured) one may expect that future developments will have to introduce more or different entities (or drop the notion of particle completely).

¹⁶ According to Veltman (2003), strictly speaking, “the concept of a force makes no sense” (71). “Particles appear and disappear and all properties of matter derive from the properties of the constituent particles.” (38) It is said that “electron-phonon” interaction explains electron-electron interaction; so what does explain electron-phonon interaction?

¹⁷ A chronon is a proposed quantum of time, that is, a discrete and indivisible “unit” of time. The minimum measurable period of time would be 1.078×10^{-43} seconds. This time scale is too small to be noticeable on the space-time scale of humans, so the universe appears very continuous even though it is happening in discrete segments of time. But it may play a role on scales much smaller than the nucleus of an atom, and on much larger scales when a lot of mass is concentrated in a small space, like in a gravastar or a black hole. The chronon might assist in combining quantum mechanics with general relativity to produce a theory of quantum gravity. (Actually nobody has the slightest idea how to fit in gravity.)

¹⁸ That molecules do not occur with a definite shape according to quantum mechanics, quite in contrast to what is believed in chemistry, was already noted by Hund (1927): “The fact that the right-handed or left-handed configuration of a molecule is not a quantum state might appear to contradict the existence of optical isomers.” Isomeric molecules are described by the *same* Hamiltonian.

¹⁹ Some will say that electrons (or nuclei) have individual existence in a molecule, but not individual states. If lower level particles are indistinguishable how are we going to make sense of ascribing causal powers to individual particles?

²⁰ Another way of putting this is saying that contexts are at least as important as first principles; the latter being necessary conditions, not sufficient conditions (Atmanspacher and Bishop 2006). In this context “contexts” are contingent conditions referring to the degree of abstraction at which a theoretical framework is formulated. Each description requires “abstracting from,” meaning disregarding those details of a given system (and its environment) which are to be considered irrelevant. In applying quantum mechanics or in general any universal law under particular initial and boundary conditions, one needs global constraints in order to obtain well-formed problems and to avoid degeneracies (multiplicity of possible solutions).

²¹ The environment would have an effect similar to the collapse of the wave function on measurement. Perhaps one could say: the environment is monitoring the system as if continuous measurement is taking place.

²² Of course opinions on the (philosophical) significance of decoherence differ.

²³ Definitions (Kim 1984): *S weakly supervenes* on B iff necessarily any two things that have the same properties in domain B have the same properties in domain S (that is, B-indiscernibility entails S-indiscernibility). *S globally supervenes* on B iff any two worlds that are B-indiscernible are also S-indiscernible. Supervenience as defined by Kim is not a part-whole relation, even though in earlier publications he has referred to it as “mereological supervenience.” More on global supervenience below.

²⁴ The classification(s) introduced in this section are following, in large measure, Hüttemann (2004, ch. 3). See also Hüttemann and Terzidis (2000), Hüttemann (2005), Hüttemann and Papineau (2005).

²⁵ Of course one can give definitions of emergence such that irreducibility does not entail emergence; for an example see Rueger (2006). Nowadays the use of words like “emergence” may be more common in the philosophy of physics, or even physics itself, than in the philosophy of chemistry. Physicists are used to saying things like “renormalizability is an emergent property of ordinary matter” (Laughlin and Pines 2000, 29).

²⁶ In general, there is no neat correlation between temperature and energy, not even for individual substances (Needham 2008b).

²⁷ Including bridge laws without “level” distinction; for example the relation between gravitational and inertial mass.

²⁸ The issue of causal completeness of the physical is relevant in the discussion on interdiscourse relations, but has no bearing on the question of part-whole emergence or reduction in physics (Hüttemann and Papineau 2005).

²⁹ For example: The structure of a molecule is given by the average positions of the nuclei, which is determined by the potential minima, fixed in turn by the probability position distribution for the system’s electrons, which is given by the non-resultant (configurational) Hamiltonian.

³⁰ Of course the same distinction can be made for interdiscourse relations. Hüttemann associates the micro-explanation of *states* with explaining determinate properties and the micro-explanation of *laws* with determinable properties.

³¹ Entanglement is sometimes used as a general argument for saying that it is impossible to derive molecular structure from quantum mechanical first principles (Atmanspacher and Bishop 2006). Even supervenience as normally understood fails: Because there are no states of the parts, there is nothing for the state of the compound to supervene upon (Humphreys 1997).

³² Alternative formulation: The behaviour of macrophysical wholes is *asymmetrically* determined by the behaviour of their microphysical parts plus *general* laws that do not apply only to wholes of that kind (Hüttemann and Papineau 2005).

³³ Alternative formulation: “Only resultant wholes have contemporaneous parts, emergent wholes do not.” (346)

³⁴ For a recent discussion on modifying Nagelian reduction to include the idea that in physics typically the “finer” theory reduces to the “coarser” theory in an *approximate limit*, see Batterman (2005).

³⁵ Of course this epistemic virtue is already tacitly invoked in discussions about definitions of reduction and emergence. For example, Hüttemann and Terzidis (2000, 279) argue that neither Broad’s concept of emergence nor Kim’s concept of emergence “is able to divide the class of physical systems into interesting subclasses.”

³⁶ Nagel (1961:372) has used the word “postulate” for bridge laws

³⁷ Such as: “density is mass divided by volume”, “force is mass times acceleration”, “extensive quantities are additive.”

³⁸ Following Ostrovsky (2005) who has stressed: No physical theory can be blamed for using approximations, because every theory does this. We shouldn’t think of approximations as something to be overcome. They come with the models, and the models give understanding, which calculation does not.

³⁹ Not all physicists like Cartwright’s account of physics; see e.g. Anderson (2001, 492, 500) and Cartwright (2001, 496).

⁴⁰ Is there a bridge law connecting the boiling of water and the phase transition of ensembles of H₂O-molecules? How does the latter whole relate to its parts?

⁴¹ Although the major difference is in the ability to absorb or emit high-energy radiation (hence its application in nuclear reactors), having a pH of 7.41 (instead of 7.00) may be considered as a significant chemically relevant difference. The operational criterion of “same substance” clearly suggests that if we set the standards of purity high enough, ordinary water and heavy water are different substances.

⁴² The two isomers were first described in some detail (together with heavy water) in a book of Farcas (1935). The para modification’s complete insensitivity to the magnetic field could be of use in magnetic resonance imaging (Tikhonov and Volkov 2002).

⁴³ Schewe, Stein and Riordon (2003): A water molecule’s chemical formula is really not H₂O, at least from the perspective of neutrons and electrons interacting with the molecule for only attoseconds (less than 10⁻¹⁵ seconds).

⁴⁴ See in particular Hornsby (1997).

⁴⁵ Both micro- and macro-properties might be multiply realised. In most supervenience discussions asymmetric dependence is presupposed. Because the nature of the dependence needs to be explained to make a difference (between different metaphysical models), the distinction between supervenience *and ceteris paribus* bridge laws collapses.

⁴⁶ Davidson (1993:4). Elsewhere I have argued that the common understanding of Davidson’s (or Hare’s) notion of supervenience as a specimen of what Kim called “weak supervenience” is incorrect and completely misses the point of Davidson’s (externalist) anomalous monism cum supervenience (van Brakel 1999). The present paper provides some ingredients of what I have called “anomalous anomalous monism”. This metaphysical model differs from Davidson’s anomalous monism in dropping the assumption of physics ideally being concerned with strict laws

(providing causal closure). According to Davidson, any S(pecial science)-event-token is co-extensive with *some* P(hysics)-event-token, though there are no limitations on the holistic nature of the S-domain, to which I add: “nor the holistic nature of the P-domain”.

⁴⁷ The phenomenon of entanglement mentioned earlier might be invoked to argue that even global supervenience fails.

⁴⁸ A metaphysical model is underdetermined by the practice of science. It has to meet the meta-epistemic virtue of “fitting in” (Goodman 1978, 132), scoring well on the criteria “empirical adequacy” and “coherence.”

⁴⁹ In a detailed study of three case studies of (generally accepted cases of) unification, Morrison (2000) has found a bewildering variety of uses of the words ‘unity’ and ‘unification’. Different degrees of reduction, synthesis and integration yield distinct ways in which phenomena can be united under a common theoretical framework. Not all forms of theory unification depend on isomorphism or reduction. Often unification is at odds with explanation. Unification is not sufficient for theory acceptance. It is just one of the many vague epistemic virtues that can play a role in theory acceptance, but it is not a determining factor. Even within the framework of the localised settings of specific theories different kinds of unity emerge. Of course the unity of knowledge also has its defenders; e.g. Wilson (1998), Anderson (2004).

⁵⁰ See Lauglin and Pines (2000). As Redhead (1991) says: "It is generally agreed that the present state of the universe is the outcome of a series of randomly occurring symmetry breakings, which means that the TOE [Theory Of Everything] cannot itself predict many of the universe's essential features as we currently observe it - a very important limitation on what TOEs can be expected to deliver, even in principle." Even if we are prepared to accept the *idea* of a Theory of Everything, the possibility that *absolute* chance is a factor in the universe cannot be excluded (van Brakel 1991).