5 Reductive Practices

5.1 Introduction: Reductive Practices and their Ontological Implications

The general topic of this and the following two chapters is the investigation of some of our reductive practices with respect to the question what ontological assumptions these practices commit us to. The reductive practices I will focus on are reductive *explanatory* practices as well as the construction of reductive relationships in intertheory relations. These reductive practices are sometimes taken to be constitutive for or at least to be evidence for fundamentalist claims. The theoretical physicist Max Dresden, for example, observes that "most physicists would agree that among the sciences physics is surely the most fundamental discipline." (Dresden 1974, 133). He then goes on to explicate what is meant by the claim that one area is more fundamental than another: "A field A is more fundamental than B, if A explains and describes everything that B does *and more*." Dresden notes, first, that

> "there are a variety of ways in which the 'more' could be interpreted, it could mean 'with greater accuracy' or 'more different phenomena' and, second – and more important in our context – that "the definition of 'fundamental' just given uses the idea of 'explanation' in an essential fashion" (Dresden 1974, 137).

Dresden then sketches what he means by 'explanation' as follows:

> "For the present purposes an explanation of the behavior of a system consists of 'the *reduction* of the properties of the system to those of the triple: *constituents*, *interactions*, *dynamics*" (Dresden 1974, 137).

The fact that we can explain the behaviour of compound systems in terms of that of the parts is taken to be essential for the fundamentality of physics.

More recently Carl Hoefer and Chris Smeenk have provided another attempt to spell out physical fundamentalism. They consider what they call the "received" or "ideal" view of the physical sciences. Among other claims this view is committed to fundamentalism:

> "Fundamentalism: there is a partial ordering of physical theories with respect to 'fundamentality'. The ontology and laws of more fundamental theories constrain those of less fundamental theories; more specifically: (1) the entities of the less fundamental theory T_i must be in an appropriate sense 'composed out of' the entities of a more fundamental theory T_f, and they behave in accord with the T_f-*laws*; (2) T_f constrains T_i, in the sense that the novel features of T_i with respect to T_f, either in terms of entities or laws, play no role in its empirical or explanatory success, and the novel features of T_i

> can be accounted for as approximations or errors from the vantage point of T_f."(Hoefer and Smeenk 2016, 117)

Hoefer and Smeenk's first condition requires that the behaviour of the less fundamental system can be part-whole explained in terms of that of the parts, i.e. the more fundamental level. In their explication of condition (2) and in particular of the claim that "the novel features of T_i can be accounted for" Hoefer and Smeenk write:

> "The empirical and explanatory success of T_i must be grounded in the fact that it captures important facts about the structures identified by T_f. Or, in other words, T_i's success should be recoverable, perhaps as a limiting case within a restricted domain, in terms of T_f's ontology and laws." (Hoefer and Smeenk 2016, 117).

So, what Hoefer and Smeenk require for fundamentalism is that the behaviour of compounds can be explained in terms of the behaviour of the parts and that theories that describe that behaviour of the compound can be reduced (recoverable as a limiting case) to the theories describing the behaviour of the parts.

The passages quoted leave it open whether physical fundamentalism as defined by Dresden or by Hoefer and Smeenk comes with ontological commitments. However, some ontological commitments suggest themselves: If physical fundamentalism is true then physical theories give us *the real story* of what is going on in the world. The claim that physics gives us *the real story* of what is going on in the world, can be spelled out in different ways. First, it might be read as an eliminativist claim: The only facts there are, are fundamental physical facts; macroscopic everyday facts are only apparent facts (*Physical Eliminativism*). Second, it might be construed as a claim about ontological priority or metaphysical dependence. According to this reading the existence of 'higher order' facts is not denied, there are different layers of facts. On the second reading, the view is spelled out as the claim that all other facts, i.e. the higher order facts, obtain *in virtue of* or are *metaphysically dependent on* fundamental physical facts. The latter facts are ontologically prior to all other facts (*Foundationalism*).

It may seem natural to suppose that either Physical Eliminativism or Foundationalism is implied by our reductive practices or may be indispensible to make sense of our reductive practices. By contrast, I will argue that this is not the case: neither the assumption of an ontological priority relation nor an eliminativist view is necessary to account for the reductive practices we have. A metaphysics of scientific practice that attempts to be minimal in the sense of not postulating anything beyond what is needed to account for scientific practice does not require the assumption that nature satisfies an ontological priority relation (Chapter 6). Nor will it end up, as I will argue, being committed to Eliminativism (Chapter 7).

Chapter 5 will be devoted to the following two questions: 1) How are the above-mentioned reductive practices to be characterised? 2) Why are we interested in these practices, i.e. what is the rationale behind the practice? Do we have to make metaphysical assumptions to account for why we have these practices? In Chapters 6 and 7 I will look at the internal structure of part-whole-explanations and will investigate whether this internal structure by relying e.g. on the part-whole relation or on an explanatory backing relation thereby commits us to Foundationalism or Eliminativism.

In the first part of this chapter (Sections 5.2 to 5.4) I will be concerned with disentangling various notions of reduction that have been discussed in the philosophy of science literature and elsewhere. Starting with Section 5.5 I will argue that we are interested in these forms of reduction because we aim at understanding how different accounts of one and the same system can simultaneously lead to successful predictions, manipulations, etc. The rationale for reductive practices, I will argue, is an epistemic commitment that is constitutive of good scientific practice. There is thus no need to assume that the search for theory reduction or for reductive explanations makes sense only on the basis of ontological assumptions along the lines of Foundationalism or Eliminativism.

5.2 Concepts of Reduction[1]

The term "reduction" is typically used in the sciences and in philosophy both with respect to representations of the world and with respect to features of the world itself. Reduction is often conceived of as a relation between two items of the same kind, e.g., between two properties, states, theories, models or explanations. It is commonly thought of as asymmetric: if an item A reduces to an item B then B does not reduce to A in the same sense of reduction. My starting point is an analysis of reduction as an asymmetric relation between representational items.

One influential line of thought considers theories to be the relevant representational items. The debate about theory reduction has been shaped by the logical empiricists' views and by Ernest Nagel's in particular. For the Logical Empiricists the concept of reduction was closely associated with those of *Unity of Science* and of *Progress*:

[1] Sections 5.2. and 5.3. use materials from Hüttemann and Love 2016.

7 Reduction and Ontological Monism

In Chapter 5 I looked at some reductive explanatory practices and argued that we can explain why these reductive practices are the way they are by appeal to our interest in achieving an understanding of how different descriptions of either one system (part-whole explanations) or of classes of systems (theory reduction) are related. Still, the details of these practices might commit us either Foundationalism or Physical Eliminativism. In Chapter 6 I argued that Foundationalism is not implied by our scientific practice. In particular there was no need to assume ontological priority relations to obtain. In this chapter I will examine two different brands of ontological monism – views that do without the assumption that there are different layers of facts/entities/events. Physical Eliminativism and Ontologically Neutral Monism agree that ontologically speaking there is no hierarchy of facts/entities/events. I will argue that from the perspective of a minimal metaphysics of scientific practice in comparing these two views Ontologically Neutral Monism should be preferred to Physical Eliminativism because the former can explain all the features of scientific practice the latter explains while making less metaphysical assumptions.

7.1 Physical Eliminativism

In Chapter 5 we characterised Physical Eliminativism as the view that the only facts there are, are fundamental physical facts; macroscopic everyday facts are only apparent facts. All but the physical facts are eliminated.

On the one hand Physical Eliminativism differs from Foundationalism because where Foundationalism sees two kinds of facts/entities/events that are related by a relation of ontological priority, Physical Fundamentalism sees only one kind of fact/entity/event, namely physical facts/entities/events. On the other hand, Physical Eliminativism has to be distinguished from what I will call Ontologically Neutral Monism. Both agree in denying what Foundationalism presupposes, namely that there is a relation between different kinds of facts, entities or maybe events. Both agree that there is only one kind of fact/entity/event. While Physical Eliminativism holds that it is the physical facts/entities/events, which are the only facts/entities/events Ontologically Neutral Monism is not committed to this privileging of the physical (or the micro). Ontologically Neutral Monism is merely committed to the claim that there is one kind of fact/entity/event and allows there to be various theoretical accounts of such facts/entities/events. I will now examine two arguments for Physical Eliminativism that might initially be thought to be implied by scientific practice and argue that they do not show what they purport to show and will turn to Ontologically Neutral Monism in Section 7.2.

Before I start to examine causal overdetermination arguments it is helpful to distinguish various levels of descriptions of systems. In an ideal gas, for example, we have the molecules, their velocities etc. and their interactions – let's call this the description of the behaviour of the parts. Second, we have the system as a whole constituted out of these molecules and we may attribute a certain behaviour to this whole, e.g. a certain mean kinetic energy – call this the 'micro-based' description of the system. Furthermore, there is an additional description or characterisation in terms of thermodynamics, we might want to attribute a certain temperature to the gas – call this a macro-description of the gas. So, there are two different relations we should keep separate in our analysis.

1. The relation between the properties of the parts and the interactions of the parts on the one hand and, on the other hand, the micro-based description of the compound (e.g. the kinetic energy of the compound). The relevant question in this context is: How is the micro-based behaviour of the compound related to the behaviour of the part?
2. The relation between micro-based property of the compound (e.g. kinetic energy) and macroscopic properties (e.g. temperature). The relevant question in this context is: How are the two different characterisations of the compound (e.g. in terms of statistical mechanics and in terms of thermodynamics) related?

Physical Eliminativism may concern the first issue. According to this version of Physical Eliminativism the only facts/entities/behaviours there are those concerning the (physical) parts of compound systems. Both, the micro-based description of the compound as well as the macro-description do not pick out genuine facts/entities/behaviours. It is, to return to our example, an eliminativism with respect to temperature as well as mean kinetic energy. A second, weaker version of Physical Eliminativism merely claims that the macro-properties have to be eliminated and is silent about the relation of the micro-based properties/behaviours to the properties/behaviours of the parts. The first version of Physical Eliminativism implies the second and is thus stronger.

7.1.1 Causal Overdetermination

Causal overdetermination arguments can be used to argue for a variety of philosophical positions. I will start with the discussion of an argument that aims to establish that only the (ultimate, physical) parts exist, but not compound beings. I will thus be concerned with the strong version of Physical Eliminativism.

The argument allegedly relies on our practice of causal explanation: Given the way we causally explain in the sciences, it is argued, we have good reasons to suppose that it is only parts rather than compounds that are causally relevant for effects. This in turn may serve as the basis for the claim that the behaviour of the compound is ontologically derivative (see e.g. Trogdon 2018) or for the claim that we have no reasons to assume that compounds exist. This latter claim, i.e. strong Physical Eliminativism, has been defended by Trenton Merricks.

The causal overdetermination argument according to Merricks runs roughly as follows: Consider a compound system such as a billiard ball *A* bouncing into another billiard ball *B*, which then starts to move. Physics tells us that the parts of the billiard ball *A* cause billiard ball *B* to move. However, if *the parts* of *A in concert* cause the effect there is nothing for *the compound* system to do. We should conclude that what the compound system appears to cause is epiphenomenal and caused only in virtue of what the parts cause. Everything that happens, happens in virtue of what the fundamental physical parts cause. (If one furthermore accepts the claim that existence goes with genuine causal powers one might argue for what has been called "nihilism" (van Inwagen 1990) or "eliminativism" (Merricks 2001) about macrophysical objects: there are only suitably arranged fundamental physical parts and that's it.)[1]

I will now have a closer look at Merricks' overdetermination argument:

(1) Object O – if O exists – is causally irrelevant to whether its parts $P_1 \ldots P_n$, acting in concert, cause effect E.

(2) $P_1 \ldots P_n$ cause E

(3) E is not overdetermined

Therefore:

(4) If O exists, O does not cause E. (Merricks 2001, 79/80)

[1] Van Inwagen (1990) and Merricks (2001) both believe that organisms exist. For the purposes of this chapter I will not take this positive existence claim into account.

Let us consider the premises of the arguments. Premise (2) seems unproblematic. When one billiard ball bounces into another and causes it to move we are probably willing to assert that the parts of the billiard ball in concert cause the second ball to move. That's at least what I will assume. According to premise (1) the compound O is causally irrelevant to whether its parts $P_1 \dots P_n$, acting in concert, cause effect E. This premise has to be analysed carefully. Being causally irrelevant to whether its parts $P_1 \dots P_n$, acting in concert, cause effect E, according to Merricks' use of "causally irrelevant", implies all of the following and nothing more than the following: (a) O is not one of the parts that cause E, nor is it (b) a partial cause of E alongside the parts, it is (c) not an intermediate cause, i.e., it is not the case that the parts cause O to cause E, nor is (d) O a cause of the parts which then in turn cause E (Merricks 2001, 58). This is the sense in which O is causally irrelevant to whether its parts $P_1 \dots P_n$, acting in concert, cause effect E. Premise (1) thus neither claims that O is causally irrelevant *tout court* (that would be a *petitio*), nor is it claimed that it is irrelevant (without the qualification 'causally') to whether its parts $P_1 \dots P_n$, acting in concert, cause effect E. Read this way premise (1) is not objectionable, either. The problem is with premise (3). What it effectively says is that if the parts of O cause E then it cannot possibly be the case that O causes E, too. What is it about causation that could warrant premise (3) in the case of the parts and the compound?

Here is one view that might make sense of premise (3): According to the 16th century Jesuit Francisco Suárez "a cause is a principle per se inflowing being to something else". (Suárez, DM XII.2, 4). Given Suárez' conception of causation as the transfer of being, it might seem plausible that there is a competition between the behaviour of the parts and that of the compound with respect to giving some sort of complete being to the second billiard ball's motion. Presumably, it can only be the case that *either* the parts are sufficient for giving complete being to the effect *or* the compound is sufficient for giving complete being to the effect but it cannot, on this conception, be the case that *both* the parts *and* the compound are sufficient for giving complete being to the effect. If both were sufficient causes, we would have too much being, twice the effect or two effects.

But how about contemporary accounts of causation? The view that causation needs to be spelled out in terms of the transfer of being has long been dismissed. So, the question is whether contemporary accounts exclude the option that both the parts and the compound are sufficient causes of the effect in question. Suppose causation is spelled out in terms of a regularity view. Given premise (2) there is a regularity such that whenever the parts act in concert in a certain way, the effect occurs (nothing depends on the particular version of the theory). Is there anything in regularity theories that would disallow a further regularity between the compound object O's behaviour and the effect? As far as I can see there isn't: the basic idea of a regularity account does not exclude the possibility that both the parts' and the compound's behaviour are sufficient causes of the effect in question.[2] On this account there is no causal competition between the behaviour of the parts and that of the compound and thus a prohibition of causal overdetermination in the case of the behaviour of parts and wholes cannot be made plausible.

Similarly, for counterfactual accounts of causation: Suppose there is a counterfactual dependence between the parts acting in concert and the effect E. This dependence does not per se exclude that there is furthermore a counterfactual dependence between the compound's behaviour and E. (A lot of course depends on the exact semantics for counterfactuals and I am not claiming that, if there is a counterfactual dependence between the parts' behaviour and E, then it is guaranteed that there is a counterfactual dependence between the compound' behaviour and E (see, for instance Block (2003) and Bennett (2008) for discussion).

Process theories of causation, which spell out causal processes and interaction in terms of conserved quantities, have often been taken to be more fitting for overdetermination arguments (see Kim (2002) and Loewer (2002)). However, in this case they are of no help either. Physics allows us to say that the parts in concert transfer a certain amount of energy and momentum to the second billiard ball. At the same time, we may say that the compound transfers a certain amount of energy and momentum to the second billiard ball. There is no competition here either.

Similarly, my own account of causation (see Chapters 3 and 4) in terms of quasi-inertial processes (in this case: the second billiard ball *B* being at rest) allows us to characterise both the movement of the compound and the movement of the parts in concert, as the cause of billiard ball B to start moving.

The essential point is that contemporary accounts of causation – in contrast to a traditional account of causation such as Suárez' – do not imply that there is a competition between

[2] One might of course simply add by *fiat* a clause that disallows cases of causal overdetermination. Mackie in an early presentation of his INUS-theory of causation had such a clause (1965, 247). He later dropped it (Mackie 1980).

causation due to the behaviour of the compound and due to the behaviour its parts (given that the behaviour of compound systems can be explained in terms of that of the parts).[3] What is happening can be characterised equally well at the level of the parts or at the level of the compounds. Both characterisations might be true at the same time. The only constraint is that the descriptions have to yield the same empirical predictions – they have to fit together.

To return to the main argument of this section: None of the currently held theories of causation warrants premise (3) as applied to compound systems and their parts. And in fact, Merricks does not appeal to any of these theories but rather to intuitions we have about overdetermination, which might very well be informed by older ways of conceptualizing causation. Additionally, he appeals to

> "the 'scientific attitude' and 'bottom-up metaphysics' according to which the final and complete causal stories will involve only the entities over which physics quantifies." (Merricks 2001, 60).

This motivation for his argument – despite appearances – cannot draw on scientific practice. As I have just argued there is no reason to assume that physics quantifies only over the parts of billiard balls, but not over billiard balls.

Furthermore, in the context of our search for an argument for Physical Eliminativism an appeal to 'bottom-up metaphysics' amounts to a *petitio principii*.[4] In fact it is precisely the

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[3] Kim, whose overdetermination arguments were hugely influential, moved from claiming "there can be no more than a single *complete* and *independent* explanation of any one event and we may not accept two (or more) explanations of a single event, unless we know, or have reason to believe, that they are appropriately related – that is related in such a way that one of the explanations is either not complete in itself or dependent on the other." (Kim 1984 [2010], 159), where he stresses that the explanations have to be *independent* for competing with one another, to a version of causal exclusion arguments where the requirement of independence is dropped, e.g. "Exclusion Principle: No event can have two or more sufficient causes, all occurring at the same time, unless it is a case of genuine overdetermination" (Kim 2006, 196). While the initial claim seems entirely plausible to me, it is hard to see why the exclusion principle without the independence clause should be convincing.

[4] Merricks briefly considers that the prohibition of causal overdetermination does not apply when the causes aren't wholly separate but offers only a very lame reply: He argues (correctly) that with the assumption that overdetermination is problematic only if the causes in question are wholly separate, Kim's overdetermination argument wouldn't work because supervenient properties aren't wholly separate from their subvenient basis. (Merricks 2001, 71).

prejudice that a ‘scientific attitude’ requires a bottom-up metaphysics that I intend to repudiate in Chapters 6 and 7.

To sum up: The overdetermination argument for eliminativism about macrophysical objects fails to convince. There is no argument from causal overdetermination to strong Physical Eliminativism. We cannot use the causal overdetermination argument for establishing strong Physical Eliminativism without already assuming ‘bottom-up metaphysics’, i.e. without begging the question.

Exactly the same kind of causal overdetermination argument that Merricks discusses with respect to molecules (and their behaviour) and the compound (and its behaviour) that is constituted by the molecules can be advocated with respect to the issue of how the micro-based behaviour of the compound is related to the macro-behaviour of the very same compound. That is of course the well-known overdetermination argument as presented most notably by Kim. If successful it would be an argument for the weaker version of Physical Eliminativism.

However, Kim’s argument can be rejected for exactly the same reasons as Merricks’. There is nothing in contemporary theories of causation (with one possible exception) that would preclude the ascription of causal relations to either the micro-based properties or the macro-properties. The exception is this case (as opposed to the one we discussed above) is a process theory that spells out the relevant processes in terms of conserved quantities or other features, which, arguably, only make sense within a micro-based description but not in a description that relies on macro-properties. However, I have already argued in Chapter 3 why we should reject this version of a process theory. On all other accounts of causation, such as regularity theories, counterfactual theories and my own version of a disposition-based process theory, it does make sense to attribute causal relations both as relating to micro-based behaviour and to macro-behaviour.[5]

[5] There is an extended debate about whether the overdetermination argument can be run within the interventionist picture. The main problem concerns the question whether if causes depend on each other via, e.g. supervenience, they can be integrated into one causal model; see e.g. Baumgartner 2010, Hoffmann-Kolss 2014 and Woodward 2015.

7.1.2 Supervenience (again)

In Section 6.4 we argued that we may have good reasons to assume that the behaviour of compound systems supervenes on that of the parts, their interactions etc. While this might not commit us to Foundationalism it may commit us to Physical Eliminativism – at least if we allow ourselves to add considerations of parsimony. Having both, a billiard ball and a multitude of molecules arranged ball-wise, does not do any work in explaining scientific practice that could not be done by the multitude of molecules arranged ball-wise alone.

While I agree that two sets of entities/behaviours do no more work than one in this case, there is no reason to believe that scientific practice or considerations of parsimony commit us to privileging one candidate over the other. Physical Eliminativism, however, assumes that it is only the physical entities/behaviours that exist, there are no other entities/behaviours. When we are dealing with a system such as a billiard ball this asymmetry cannot be established.

In analogy to a similar worry raised in Section 6.4 we might wonder that while it may be true that we are not *committed* to Physical Eliminativism, Physical Eliminativism might still provide the best (or simplest) explanation of why the behaviour of compound systems supervenes on that of the parts. And we should infer the simpler explanation. I will take up this issue in the next section.

7.2 Ontologically Neutral Monism

As we have seen in the previous sections scientific practice neither commits us to Physical Eliminativism nor to Foundationalism. However, there are positive commitments that we have examined in the previous sections. Let me briefly recapitulate these commitments.

First, in many cases of part-whole explanation it is presupposed that compounds exist and that they have parts (there may be exceptions to a realistic understanding of compositions, for example in the context of so-called dual theories (see e.g. Castellani & de Haro forthcoming). In these cases, a modal, asymmetric relation of generic existential dependence (not between compounds and their parts but) between compounds and kinds of parts has to be presupposed. A particular physical compound does not depend *for its existence* on the *existence* of a particular part. It does however depend for its existence on there being certain kinds of parts and this is what was called “generic existential dependence” (Section 6.2) Furthermore this dependence is asymmetric. While the existence of certain sorts of entities (parts) is necessary for the existence of a particular physical compound the converse is not true. However, this dependence relation does not suffice to establish ontological priority or Foundationalism, as we have seen in Chapter 6.

Second, we turned from the question of how the *existence* of a compound depends on the *existence* of kinds of its parts to the question of how the *behaviour* of an existing compound depends on the *behaviour* of its parts. In discussing the explanatory mechanism of part-whole explanations we have accepted explanatory realism and its commitment to so-called backing relations. Part-whole explanations presuppose that the behaviour of a particular whole (what is mentioned in the explanandum) depends on the behaviour and the interactions of its particular parts (i.e. on those features the explanans refers to). It is *laws of composition* that completely describe these dependence relations. As a consequence, it is not necessary to introduce further metaphysical inventory over and above what we introduced in Chapter 2 in the context of laws of nature, in order to give an account of the backing relation in part-whole explanations.

So, the overall argument is that reductive explanations show that science requires a backing relation, and the backing relation is not required to be asymmetric, it need not be nonmodal. We are thus not committed to Foundationalism. Nor are the arguments for Physical Eliminativism convincing, as we have seen in previous section. However, while we are not *committed* to one of these views, we might still have good reasons to embrace one of them because it provides the best and simplest explanation of some aspect of scientific practice or some other feature. For instance, both Foundationalism and Physical Eliminativism metaphysically account for why the macro-behaviour (e.g. temperature) of some systems supervenes on its' micro-based behaviour – the first in terms of grounding the second in terms of identity. Supervenience does not *commit* us to one of them because more than one account is available. However, one of these accounts may provide a better or simpler explanation than the others. Via inference to the best explanation we might then hold true one of these accounts.

It is here that I want to bring into play a third option: Ontologically Neutral Monism. In contrast to Foundationalism, Ontologically Neutral Monism agrees with Physical Eliminativism that when we are confronted with cases of supervenience as for example in thermodynamics and statistical dynamics, we should not assume there to be two sets of different kinds of properties. However, in contrast to Physical Eliminativism, Ontologically Neutral Monism is not committed to privileging the physical (or the micro). Ontologically Neutral Monism is merely committed to the claim that there is one kind of fact/entity/event and allows there to be various theoretical accounts of such facts/entities/events. Thus, Ontologically Neutral Monism provides a simpler explanation of supervenience than Foundationalism because it does not postulate different kinds of facts/entities/events that are related by a relation of ontological priority. It is also simpler and less committal than Physical Eliminativism because it does not insist on claiming that it is exactly one description of the behaviour of the system (namely the (micro-)physical) that gives us the only true account of what is going on. There can be more than one true story of the behaviour of a system *provided these different accounts can be related appropriately, e.g. by reduction*.

In the remainder of this section I will illustrate what Ontological Neutral Monism amounts to by discussing a number of cases.

(i) Billiard ball: In the previous section we have discussed two causal accounts of a billiard ball that is bumping into, say, another billiard ball. This is a simple case that serves ideally to illustrate what Ontological Monism amounts to. We can attribute the momentum and energy in terms of which we can explain that the second billiard ball starts to move either to the billiard ball considered as a compound (macro-description) or to the parts of the billiard ball which are suitably arranged and interact in certain ways (micro-based description). There is no need to postulate two different objects and to wonder about their relation. There is just one object (the billiard ball = the parts of the billiard ball which are suitably arranged and interact in certain ways) whose behaviour can be characterised in terms of the macro-description or in terms of the micro-description. The fact that we have a part-whole explanation shows that both descriptions are equivalent. Both accounts can be taken to be true.

(ii) Eddington's table: In a well-known passage the physicist Arthur Eddington ponders over what he is sitting at.

> "I have settled down to the task of writing these lectures and have drawn up my chairs to my two tables. Two tables! Yes; there are duplicates of every object about me—two tables, two chairs, two pens. […] One of them has been familiar to me from earliest years. It is a commonplace object of that environment which I call the world. How shall I describe it? It has extension; it is comparatively permanent; it is coloured; above all it is substantial. […] Table No. 2 is my scientific table. It is a more recent acquaintance and I do not feel so familiar with it. [...] My scientific table is mostly

emptiness. Sparsely scattered in that emptiness are numerous electric charges rushing about with great speed; but their combined bulk amounts to less than a billionth of the bulk of the table itself." (Eddington 1964, 5/6)

Eddington then goes on to argue that only of these tables is real:

> "I need not tell you that modern physics has by delicate test and remorseless logic assured me that my second scientific table is the only one which is really there—wherever "there" may be." (Eddington 1964, 8)

According to Eddington (in the context of the passages quoted here)[6] fundamental physics gives us the one real story of what is going on in the world. It is modern physics itself, he suggests, which tells us that physics gives us the one true story and that Physical Eliminativism is true.

In the previous sections I have rejected this claim. Scientific practices neither commits us to Foundationalism nor does it commit us to Physical Eliminativism. But what shall we say positively about the problem of the two tables?[7] Here is what Steven French has to say about the solidity of the familiar table:

> "As already noted this holds in virtue of the relevant physics as expressed by the Exclusion Principle and, more fundamentally, the anti-symmetrization of the relevant aggregate wave-function. In this case one might then insist that the latter feature of quantum mechanics entirely explicates the solidity of everyday objects and in doing so eliminates the predicate from the scope of our fundamental ontology." (French 2014, 170)

French thus endorses Physical Eliminativism. But Ontologically Neutral Monism rather than Physical Eliminativism provides a better explanation of what is going on. We should not expect there to be two tables, that can be granted. But there is no "remorseless logic" that forces us to conclude that fundamental physics gives us *the only* true story of the world. It is precisely because we have a reductive account of solidity in terms of quantum mechanics that we can conclude that we have two adequate and true accounts of a property of the chair. What is characterised as the solidity of the chair can at the same time be characterised in terms of quantum mechanics. We might privilege one or the other account in certain contexts but a minimal metaphysics of scientific practice does not commit us to an ontological privileging.

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[6] I make no attempt to do justice to Eddington's more elaborated views. See French 2014, 79ff. for discussion.

[7] There is a vast literature discussion this issue; see e.g. French 2014, Chapter 7.

It might of course be the case that in developing reductive accounts we need to revise some of the assumptions we had. For instance, it might have been thought that the solidity of an everyday object requires that its volume is filled completely with material stuff all the way down. This assumption had to be revised, but that only means that we have learned something about solidity and does not make solidity go away. An account of the table in terms of macroscopic properties such as solidity and an account in terms of quantum mechanics can both be true. There is no reason to believe that alethic overdetermination is forbidden. An ontological monist will argue that we have two true accounts of chairs and tables, reductive explanations make explicit why this possible. In different contexts there will be different pragmatic considerations that make us prefer the one or the other account.

(iii) Phase transition: In Section 5.6 we briefly discussed phase transitions and critical phenomena. Suppose we are dealing with some substance, say water, that undergoes a phase-transition. We can distinguish three levels of description (as before): First, a description of the parts (molecules) on their own, in terms of mechanics. Second, a micro-based description of the substance as a whole in terms of statistical mechanics and, third, a description of the substance as a whole in terms of thermodynamics. According to the Ontological Monism two descriptions of the substance as a whole are descriptions of just one object. Neither are there two objects nor is there a statistical-mechanical behaviour *plus* a thermodynamical behaviour. Both, the thermodynamical and the account in terms of statistical mechanics are characterisations of the behaviour of the substance in question.
As already indicated in Section 5.6 the behaviour of the compound if described in terms of thermodynamical quantities involves discontinuous changes in a derivative of a thermodynamic function, while the account in terms of statistical mechanics of finite systems involves no such discontinuities when it comes to the description of phase-transitions. But no measurements with finite precision can establish that what we have measured needs to be described as truly discontinuous rather than as something smoother in the vicinity. In other words: As long as our measurements have only finite precision, we can account for the observed macro-behaviour both in terms of statistical mechanics and in terms of thermodynamics.
Both accounts give equally good accounts of the observed behaviour. Our reductive practices – in this case both part-whole explanations, which take us from the behaviour of individual molecules to the characterisation of the compound in terms of statistical mechanics, as well as

inter-theory reduction, which allows us to see how and under what circumstances both theories converge on the same empirical predictions – let us understand why both theories give an empirically adequate account of what has been measured.

The ontological monist will hold that there are two theories that describe the behaviour of one and the same system. These theories may very well make different predictions so that at most one of them can be true. This is a case of empirical underdetermination – at least at present. But what do we make of the fact that statistical mechanics is the more *general* theory? Let us assume that statistical mechanics is the more general theory in the sense that the thermodynamic description is empirically adequate in a domain that is a strict subset of the statistical mechanics' domain of empirical adequacy.

Suppose T_1 gives us an empirically adequate account of systems x_1 and x_2, while T_2 gives us an empirically adequate account of x_2 only. What would be the argument for establishing that if the more general theory T_1 is true of x_2, therefore T_2 cannot be true of x_2 as well? If T_2 is false with respect to x_1, while T_1 is true with respect to x_1 this somewhat undermines our belief in T_2, I suppose. However, if we have a reductive account of why T_2 works for x_2 given certain conditions are met, there is no reason why the less general theory T_2 should not be true of x_2 too.

But what about the following thought: theories typically postulate mechanism in virtue of which they get things right or wrong. The more general theory postulates a widely successful mechanism while T_2 only got it right by accident – reduction tells us why T_2 *appears* to be right.

An interesting case is the second law of thermodynamics, which is part of a less general theory. This is clearly a case where attempts to reduce it to statistical mechanics have led to a reconceptualization of what the law says (it is now considered to be a statistical law). Another interesting feature is that the pressure to come up with a good account of what is going on is on statistical mechanics rather than on thermodynamics. Even though the laws that go into statistical mechanics and in virtue of which statistical mechanics is a general theory, are established beyond doubt (and provide a "mechanism" to develop empirically adequate accounts of phenomena), these laws alone do not provide us with a reductive account of how the second law is connected to statistical mechanics. Much depends on assumptions about initial conditions etc. These are non-general assumptions.

Thus, the mere fact that statistical mechanics is the more general theory in the sense that the thermodynamic description is empirically adequate in a domain that is a strict subset of the statistical mechanics' domain of empirical adequacy does not make the statistical mechanical account more truth-likely than the thermodynamic account. In fact, with respect to the case at hand many have argued that the second law of thermodynamics is more likely to be true. Eddington, for example, noted:

> The law that entropy always increases holds, I think, the supreme position among the laws of Nature. If someone points out to you that your pet theory of the universe is in disagreement with Maxwell's equations — then so much the worse for Maxwell's equations. If it is found to be contradicted by observation — well, these experimentalists do bungle things sometimes. But if your theory is found to be against the second law of thermodynamics I can give you no hope; there is nothing for it but to collapse in deepest humiliation. (*The Nature of the Physical World* (1915), Chapter 4)[8]

(iv) Decoherence – classical properties. In the case of chairs and tables, I have just argued, we learn something about their solidity when we turn to quantum mechanics. But sometimes when we turn to a new theory, we learn quite a lot, and the acceptance of the new theory leads to a replacement of the old ontology.

Whether or not the acceptance of a new theory leads to learning more about the old objects and their properties (including some revisions), or rather to a replacement depends on how these objects are individuated, i.e., on what is taken to be *essential* for the objects in question. Learning that light is an electro-magnetic wave or a bunch of photons does not commit us to give up our belief that light exists because light was never individuated or defined in terms what it is composed of but (presumably) rather in terms of laws, e.g. those of geometrical optics.

An interesting question is what we ought to say about classical objects and their determinate properties (such as being at a particular place or having this or that velocity) in the light of the

[8] Einstein similarly remarked: "A theory is the more impressive the greater the simplicity of its premises, the more different kinds of things it relates, and the more extended its area of applicability. Therefore the deep impression that classical thermodynamics made upon me. It is the only physical theory of universal content which I am convinced will never be overthrown, within the framework of applicability of its basic concepts." Albert Einstein in: Paul Arthur, Schilpp (editor). Autobiographical Notes. A Centennial Edition. Open Court Publishing Company. 1979. p. 31 [As quoted by Don Howard, John Stachel. Einstein: The Formative Years, 1879-1909 (Einstein Studies, vol. 8). Birkhäuser Boston. 2000. p. 1]

decoherence approach that I briefly mentioned in Section 5.6. One possible conclusion is to argue that classical objects and their determinate properties are just illusions. It is essential to our conception of chairs and tables that they are localised and that there defining features are (maybe with the exception of their colour) non-relational, intrinsic properties. Quantum mechanics tells us that there are no such things. Furthermore, decoherence theory, our account of how the classical and the quantum description are linked, explains *the appearance* of a classical property in terms of the interaction of the system in question with the environment (Joos et al. 2003; Schlossbauer 2004). What is explained is not why the compound has classical properties given the environment, but rather, why they *appear to be classical to an observer*. However, the conclusion that there are no chairs and tables need not be drawn provided they are individuated as functionally defined objects. If chairs are simply those things that we can sit on, the argument that quantum mechanics tells us these kinds of things don't exist, doesn't go through. Rather, thanks to quantum mechanics, we have simply learned a lot about their constitution and how and why they appear to us the way they do.

To conclude, the positive picture that emerges is one that can be characterised in terms of 'ontological monism' and 'descriptive pluralism': It allows for a plurality of descriptions of a system (or of reality), none of which is ontologically privileged as the exclusively true account of reality, provided they are empirically adequate. However, these different descriptions – by virtue of being descriptions of one and the same system (or reality) – are constrained by an epistemic requirement: We need to be able to give reductive accounts of how and under what circumstance the different descriptions can be accounts of the behaviour of one and the same system.