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STRUCTURALISM AND SCIENTIFIC REALISM*

0. INTRODUCTION

(0.0) Professor Stegmüller's part in developing the so-called "structuralist view" of empirical theories is well known. It has been my privilege and pleasure to be associated with him in this enterprise. My contribution to this volume honoring Professor Stegmüller is an attempt to illuminate some rather general philosophical issues that have been raised about the structuralist view. The breadth of Professor Stegmüller's contributions to philosophy assures that this volume will reach a wider audience than most philosophical journals, thus it seems an appropriate place to air issues of this generality.

(0.1) The issues I want to discuss concern the relations between the structuralist view of empirical theories and the view of empirical science called 'scientific realism'. Roughly, I want to discuss the extent to which structuralism is compatible with some plausible form of scientific realism. By 'plausible' here I mean a form that most proponents of scientific realism might find acceptable. This caveat is necessary because "scientific realism" does not appear to me to be a completely well determined body of doctrine. Thus my first task shall be to come up with some claims that seem to be central to scientific realism in the sense that most proponents of this view would accept them. In a sense it will be a "minimum" form of scientific realism. Some, perhaps all, scientific realists may hold additional claims that they think are a part of scientific realism. Next I will identify those claims of structuralism that appear to be "prima facie" incompatible with this minimal scientific realism. Then, I will discuss the extent to which this incompatibility is only apparent. In the course of this discussion I will examine the way, according to the structuralist view, the meaning of "theoretical predicates" may change with the historical development of the theories of which they are a part. I will also suggest a structuralist account of "theoretical individuals" based on the reduction relation between theory elements and examine meaning change for terms referring to kinds of theoretical individuals. Finally, I will consider the question of the identity of

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theoretical entities in different theories. My discussion of these matters will assume some prior knowledge of the structuralist view, but little in the way of its mathematical details.

1. SCIENTIFIC REALISM

(1.0) Scientific realism (called hereafter 'realism') is, very roughly, the view that empirical scientists speaking about the subject matter of their profession "mean exactly what they say". If what they say is true then, it is a description of what some part of the world is really like. The individuals and properties that empirical scientists talk about, when they speak the truth, are "really there" in the same way that trees, mountains and people are really there. Further, there is good reason to believe that some propositions about these individuals and properties are true. Other truths about them await discovery. On this view, empirical scientists are steadily adding to the stock of things that we know about. Molecules, electrons, genes, force fields, spins, charm are being added to the more mundane individuals and properties like trees and greenness that we know about. Of course, empirical scientists aren't infallible. Sometimes they believe with good reason that some new "thing" has been discovered and later find out they were mistaken.

(1.1) Something like this rough formulation of realism seems to be the common sense view of empirical science – the view of the informed laity in scientific matters. Very likely, it is also the view held by most practicing empirical scientists. Some things about this formulation do, however, seem to cry out for clarification. To begin, what is meant by saying that scientists "mean what they say". Presumably, this means that text books and journal literature where empirical theories are expounded are to be taken literally as putative descriptions of some parts of or features of "the world". At least for those who understand the vocabulary, there is no need of any interpretation, reconstrual or "logical reconstruction" of these texts to understand what they are saying about the world. While this may be true of some theories, a casual glance through the text book and journal literature germane to even an old and well established theory like classical thermodynamics suggests that it is not true of all theories. Whatever the function of this literature is for the scientific community, it is pretty clearly not to tell this community or the informed laity what thermodynamics claims about the world. Anyone who wants an answer to THIS question is going to have to impose some kind of interpretation on this literature.

(1.2) I think most realists would agree with me on this point. Further, and perhaps more significantly, I think most realists would agree that the question itself is not just beside the point. On some "instrumentalist" views it would be pointless to look for "claims about the world" in the literature associated with a scientific theory. Making claims about the world is just not among the things that empirical scientists do professionally. Though realists would agree that it makes sense to ask what empirical science says about the world and that some "philosophical" interpretation of most scientific literature is required to answer this question, most realists appear to believe that this interpretation is relatively easy or trivial to provide. Once the literal minded philosopher poses the question: "What is the empirical claim of Newtonian particle mechanics?", it is relatively easy to consult the literature of this theory and "fill it out" to provide an answer. It is merely a matter of making explicit what is "taken as obvious" or "implicitly assumed". A bit more precisely, I think most realists believe that the "logical form" of the empirical claims of specific theories is readily apparent in the literature of the theory. A "logical reconstruction" of a theory will include just the same predicates and singular terms as the "unreconstructed" literature and these will be put together into sentences in pretty much the same way as in that literature.

(1.3) We might summarize these tenets of realism in this way.

(R1) The literature associated with empirical theories contains, at least implicitly, descriptive claims about their subject matter whose logical form is apparent.

The term 'descriptive' here is intended to rule out claims about "how to do things" which would be a part of an instrumentalist interpretation. The force of 'apparent' is that the "true" logical form does not depart radically from the logical form of some sentences actually found in the literature. The force is not that it is "apparent" what the "true" logical form ought to be, even though it is radically different from any sentence actually found in the literature.

(1.4) Assuming that we have carried out this minimal "logical reconstruction" of an empirical theory, the realist view appears to be that we read off the theory's "ontological commitment" from the logical form of the reconstructed claims. The theory is at least committed to the existence of the referents of its singular terms. Depending on the realist's general views about the ontological status the referents of predicates, he may also claim the theory is committed to the existence of the referents of the predicates. Whatever his general views, the realist thinks that all referents of singular terms – individuals – and all referents of predicates – properties – have the same ontological status. If the reconstructed claim of the theory refers both to containers of gas and to molecules with singular terms, then the theory is committed to the existence of both kinds of individuals. If it contains predicates 'is longer than' and 'has more inertial mass than', then length and inertial mass have the same ontological status – whatever that might be. Modulo, perhaps, the difference between the referents of singular terms and predicates, all referents are "equally real". We may summarize this in the following way:

(R2) All individuals and all properties mentioned in accurately construed descriptive claims of empirical theories have respectively the same ontological status.

Here 'accurately construed' means derived from the literature of the theory by the minimal reconstruction that realists find acceptable.

(1.5) So far we have just talked about realism's position on the logical form and ontological commitment of empirical theories. Nothing has been said about the truth of these theories. Realists, along with most other people, believe that some of the claims of some empirical theories are true – or at least "approximately true". Let us focus on truth claims and ignore the complexity of approximation by simply assuming that the claim "*S* is approximately true." may be sytematically understood as "*S*′ is true" where there is some effective procedure for getting *S*′ from *S*. (See [8].) Given their view about ontology (R2), this assures that the entities (the true part of) the theory is committed to "exist". What is added to the "truth claim" for the sentence by the "existence claim" for the entities referred to in it is not entirely clear to me. It appears to me that the interesting philosophical issues about empirical theories are pretty much settled when the logical form of their claims is agreed upon and thereby the role of the theory's various terms in determining the truth value of these claims. However, it does seem to me that lurking behind this existence claim is really a claim about the historical development of empirical theories. What the realist is "really" concerned about is not that the entities referred to in empirical theories "exist", but rather that they "continue to exist" while we learn more and more about them.

(1.6) The view that I have in mind here has recently been made explicit by Putnam [9], but it seems to have been held, at least implicitly, by most realists. The "cash value" of the existence claim for the realist seems to be this. At "birth" empirical theories consist of a few true claims which assure the existence of the entities they refer to. The existence of these entities "nails down" the meaning of the terms referring to them. Once we have just a few true claims about these entities, we know at least enough about the meaning of these terms to determine the truth conditions of all extensional sentences containing them. That is we know their reference. This entails that we may use these terms to say more and more about the entities to which they refer without "significantly" changing their meaning – without changing their reference. Exactly how the reference of these terms is nailed down by "a few true claims" – how many truths are required or what their logical relations must be – is not clear to me. Nor is it clear to me whether this account is intended to apply only to singular terms, or to predicates as well. But we need not be concerned about this now. The implications of this for the realism's view of the historical development of empirical theories are clear. The meaning of (at least part of) the vocabulary in empirical theories remains unchanged – nailed down by the core truths – while what we say about the referents of that vocabulary changes over time. We just say more and more about the same old things. Some of what we say may be knowledge. If so, it's just more knowledge about the same old things. In summary form:

(R3) The reference of some terms used in empirical science remain fixed while the claims of empirical theories formulated with these terms change.

(1.7) The claims R1–R3 I take to be a core or minimal version of scientific realism. It is this version I want to compare with structuralism. However, there is a somewhat stronger version of realism that may be entailed by R3 and structuralism. One holding R1–R3, might be a realist about ontology and meaning (respectively R2 and R3) and yet fail to be a realist about empirical laws. That is, one might hold that all entities referred to in the "core truths" of empirical theories had the same ontological status and that these truths tied down the meaning of terms referring to these entities, but still believe that some "non-core truths" of the theory were just "convenient fictions". Hacking [4] considers a view somewhat like this. It is not entirely clear what 'convenient fiction' means here. One reasonably clear synonym is 'not unique'. Several extensionally different "laws" formulated in the same vocabulary might be equally compatible with all existing empirical evidence and all possible emendations of it. Intuitively, the "observational consequences" of the laws are the same. We may formulate the denial of this as:

(R4) There will always be some empirical evidence that would discriminate among extensionally different empirical laws formulated in the same vocabulary.

Intuitively, the idea here is that given the vocabulary and ontology of a theory, there is a unique body of empirical laws waiting to be discovered. There can be no arbitrariness or "convention" about how one carves up the subject matter of the theory and formulates laws about it. Empirical laws, like the things they are about, have a Platonic existence independent of the cleverness (or luck) of scientists.

2. STRUCTURALISM

(2.0) Structuralism is essentially a view about the logical form of the claims of empirical theories and the nature of the predicates that are used to make these claims. It originated as an attempt to describe precisely the empirical claims of theories in which considerable mathematical apparatus is employed. Theories of mathematical physics provide its "paradigm" applications. The predicates employed in structuralist reconstructions of empirical theories are predicates in the language of set theory – set theoretic predicates – that characterize species of set theoretic structures (in the sense of Bourbaki [3]). These species of structures are essentially the mathematical structures used in the theory. Roughly, the claims of empirical theories are rendered as set theoretic versions of a Ramsey sentence. The intended applications $I[T]$ of the theory T are conceived as a sub-class of a species of set theoretic structures M_{pp} [T] – the non-theoretical structures of T. The claim of the theory is then that the members of $I[T]$ can be filled out with some additional structural elements – "theoretical" elements – to produce structures of a species $M_p[T]$ – theoretical structures of T – which also satisfy additional requirements for membership in a sub-species of $M_p[T]$, $M[T]$ – the "laws" of T. Further, the array of theoretical structures used to fill-out $I[T]$ must satisfy some further conditions on sub-classes of $M_p[T]$, $C[T]$ – the constraints of T. Most theories of any complexity have a number of claims of the sort just described associated with them at any given time in their development. The logical relations among these claims may be represented by a "specialization net" of "theory elements". (See [1].) which intuitively shows how some laws are specializations of others. In addition, theory elements of one theory may be connected in "law like" ways to those of another theory by "intertheoretic relations" – among the most important of which is the reduction relation (See [10] and [1].)

(2.1) It should be reasonably clear to anyone who has compared a structuralist reconstruction of a particular empirical theory (See, for example, [6], [10]) with the professional literature associated with the theory that this is logical reconstruction "with a capital 'R'". For theories with considerable mathematical apparatus, the mathematics in the unreconstructed literature corresponds pretty closely with the mathematical structures in the structuralist reconstruction. But, with a few exceptions, the logical form of the structrualist rendition of the theory's claims is not apparent in anything that one finds in the textbook and journal literature. Thus one central tenet of structuralism is this.

(S1) The literature associated with empirical theories contains, at least implicitly, descriptive empirical claims about their subject matter BUT their logical form is generally not apparent.

It is important to understand that, on the structuralist view, empirical theories do make straightforward, descriptive, falsifiable claims about their subject matter. Structuralism is not just a new version of instrumentalism hiding behind a cloud of set theoretic notation. On the other hand, structuralists see the mathematical structures associated with a theory to be much more "essential" features of the theory than the claims it makes. The claims may change with the historical development of the theory, but the mathematical apparatus remains the same. Thus both structuralist and realist would agree that empirical science makes descriptive claims but disagree about the extent to which empirical scientists, speaking professionally, "mean what they say".

(2.2) What prompts the structuralist to take this arrogant attitude to the literature of empirical science? The answer is essentially "epistemological concerns". Structuralism adopts the "working hypothesis" that empirical science is a rational enterprise in the minimal sense that the claims of empirical science must be supported by evidence. Thus it should be clear what counts as evidence for the claims of the theory, and, at least at during the time the theory was taken seriously, some of what counts should have been known to those who took the theory seriously. The arguments leading from these epistemological concerns to the distinction between theoretical and non-theoretical structures and the modified Ramsey sentence form for empirical claims are well known (See [10], [2].) though evidentally not convincing to everybody. I have nothing to add to this discussion now so I will simply summarize a second basic tenet of structuralism.

(S2) It may be necessary to distinguish between theoretical and non-theoretical structures in a theory in order to exhibit the logical form of the theory's empirical claims.

(2.3) That the empirical claims of a theory are represented by a specialization net of modified Ramsey claims that may change over time has some implications for the "meaning" of terms referring to the theoretical elements.

(S3) The meaning of terms referring to theoretical elements in a theory depends on the theory's empirical claims and may change as the theory develops normally.

To see how this works, we have to have some intuitive understanding of what one might plausibly take to be the "meaning" of a term referring to a theoretical function like the mass function in Newtonian particle mechanics. (For a discussion of why the mass function is theoretical see [10].) What does 'mass' (or '*m*' as the mass function is customarily denoted) mean in Newtonian particle mechanics? For our purpose, it suffices only to know the denotation of 'mass' – its extension. A first cut is to say that 'mass' (in Newtonian particle mechanics) denotes the set of ordered pairs – ⟨particle, real number⟩ – that have acutally been "assigned" in applications of Newtonian particle mechanics. Here 'assigned' means 'shown to work together with some force functions in filling out the non-theoretical, kinematic structures to appropriate theoretical structures'. This won't quite do because, though physicists may in fact have used one array of mass values in a given application, they "could have" used others. For example, they could have measured mass in different units. So we must expand the extension of 'mass' to admit all "acceptable" assignments in actual applications. But what about the up-to-now undiscovered mass assignments – those that "would be" acceptable for up-to-now unexamined members of the intended applications of Newtonian particle mechanics? Pretty clearly they ought to be in the extension of 'mass' too. This is not quite the whole story for we have ignored the fact that some of the members of the set of intended applications are "equivalent" kinematic descriptions of the same particle mechanical system. But it is enough to provide an intuitive basis for further discussion.

(2.4) This discussion of the meaning of 'mass' assumed that the range of intended applications of Newtonian particle mechanics is fixed and remains unchanged through the development of the theory. There is some reason to think that this is not true (See [10], [12].). If the range of intended applications changes then the extension of terms referring to theoretical elements like 'mass' will generally change. Indeed, even if some "core" or "paradigm" set of applications always remains in the range of intended applications, the extension of the theoretical elements in this core set *may* change as changes are made elsewhere in the range of intended applications. It is the way the constraints on theoretical elements operate across applications that affords this possibility.

(2.5) Changes in the range of intended applications is only one way the extension of terms referring to theoretical elements may be caused to change with the development of a theory. Perhaps more apparent is the change caused by adding special laws to the basic laws of the theory. The basic laws of a theory are those which are claimed to hold for all applications – e.g. Newton's second law and perhaps the action reaction principle in Newtonian particle mechanics. The "theory element" containing these laws alone determines one extension for 'mass', given the range of intended applications. If we add the requirement that only "gravitational" forces appear in some sub-set of the range of intended applications, we impose additional requirements on the entire array of mass functions and thereby change the extension of 'mass' in Newtonian particle mechanics. Generally, every time we expand, contract or otherwise alter the net of specializations under the basic theory element of theory, we will change the extension of the theoretical elements. In particular, as the specialization net grows the extension of 'mass' could be narrowed down so much that the mass function for the entire range of intended applications was uniquely determined "up to a change in units". But there is no guarantee that this will happen.

(2.6) In addition to the normal development of empirical theories just considered, structuralism provides the means of describing several varieties of "revolutionary" development in empirical science. 'Revolutionary' here is used roughly in the sense of Kuhn [5]. It is important to understand that structuralism is not committed to the view that any kind of revolutionary development has, in fact, occurred at any point in the history of science. At most, structuralism provides the formal methods to reconstruct the theories associated with scientific traditions putatively separated by "revolution". That such reconstruction reveals something other than "normal" development may be one kind of evidence that a scientific revolution has occurred. The important thing about structuralist reconstructions of revolutionary scientific change is that they seem to make it "epistemologically respectable". On the structuralist account, revolutionary scientific change is just different from normal scientific change but not, in any apparent, way "irrational". For our purpose, it is sufficient to consider only one kind of revolutionary scientific change – two successive theories that have the same non-theoretical structures, but different theoretical structures. Here the structuralist claim is:

(S4) Empirical science might reasonably develop to produce two successive theories with the same non-theoretical and different theoretical structures.

To see what this entails, consider a situation in which the "purely formal" properties of all the theoretical elements were the same in both theories, i.e. $M_p(T) = M_p(T')$, but the basic laws were different. Recalling our earlier discussion, we would have to say here that the meaning of the terms referring to the theoretical elements was different in the different theories. Slightly more interesting, are cases in which the purely formal properties of *some* of the theoretical elements remain unchanged but in the "new" theory they are accompanied by different theoretical elements, together with which they satisfy "formally similar" laws. Here again we would say that the meaning of terms referring to the formally identical theoretical elements had changed. In the case where all the theoretical elements differ it is clear that meaning change for terms referring theoretical elements has occurred. We will consider an example of this case below (Sec. 7.5) in connection with the question of meaning change for terms referring to theoretical individuals.

3. APPARENT CONFLICTS

(3.0) As formulated in the preceding two sections, the central tenets of realism and structuralism directly contradict each other only on the issue of "how much" reconstrual is needed to make empirical science epistemologically respectable (R1 and S1). We may formulate this as:

(C1) Structuralist reconstructions of empirical theories attribute claims to them whose logical form departs so widely from the logical form of claims apparent in the literature of the theory that realists find them implausible.

On other points it is difficult to bring the two views into direct confrontation. Roughly, the structuralists talk about what you see *if* you reconstruct theories according to their methodology. This appears to run counter to some tenets of realism. But since the claims of realism are formulated in a somewhat differrent vocabulary, it is difficult to be precise about the areas of disagreement. I shall begin here by noting, in a rather rough way, two other apparent disagreements. Then I shall try to sort out the genuine disagreements in a more precise way.

(3.1) Aside from the difference about the extent to which empirical scientists mean what they say, the most intuitively apparent difference between realism and structuralism is their attitude to the theoretical – non-theoretical distinction, Crudely put:

(C2) The structuralist theoretical – non-theoretical distinction between the elements of the models for a theory entails an ontological distinction between properties or individuals that the theory is about which realism rejects.

This claim lacks precision in that we are not told what the ontological distinction is, nor how it follows from the use structuralism make of the theoretical – non-theoretical distinction. But the intuitive idea behind it is rather clear. In a structuralist reconstruction of a theory the theoretical structures might be regarded as simply "conceptual devices" used to say something about the non-theoretical structures. In some cases we might be able to say the same thing without using any theoretical elements – i.e. they might be Ramsey eliminable (See [10].) In some cases we might be able to say exactly the same thing using completely different theoretical structures, i.e. there would be an element of "conventionality" in the choice of theoretical structures. (See [11].) Even though these situations do not seem to arise in the reconstruction of any "real life" empirical theories, the mere possibility of their arising might be taken to indicate that theoretical structures have an ontological status significantly different from non-theoretical structures.

(3.2) Finally, realism and structuralism appear to collide on the extent to which the meaning of some of the vocabulary of empirical science changes over time.

(C3) Structuralism views the meaning of terms referring to theoretical elements as possibly changing in both normal and revolutionary development of empirical science in a way that realism rejects. Structuralism is committed to a kind of "contextualism" for the meaning of terms referring to theoretical elements that is incompatible with the realist's view that the reference of all predicates and singular terms in an empirical theory is nailed down "near" the beginning of of the theory's development. On the structuralist view, the extension of terms referring to theoretical elements typically continues to change so long as the theory grows. It becomes fixed only when the theory ceases to be a part of the "research frontier".

4. THEORETICAL PROPERTIES

(4.0) To examine these apparant conflicts between realism and structuralism, it seems expedient to focus on C3. If the realists objections to the theoretical – non-theoretical distinction can be made precise at all, it seems that precision will come in the implications this distinction has for the meaning of terms referring to theoretical elements. To this end, we need first to become a bit clearer about the concept of "meaning" in structuralist reconstructions. Then we need to be more precise about which meanings remain fixed and which change over time in structuralist reconstructions of the temporal development of theories.

(4.1) To begin, note that the individuals in a structuralist reconstruction of a theory are a part of the non-theoretical structure. Terms referring to these individuals remain untouched by the meaning change that affects those referring to theoretical elements. More precisely, the structuralist account of the logical form of the theory's claims is neutral with respect to the question of meaning change for the theory's singular terms. It is compatible with a realist view (R3) for these terms. But it does not entail the realist view. The meaning of these terms could change for reasons completely unrelated to structuralism.

(4.2) So the meaning change entailed by structuralism is confined to terms referring to "theoretical properties". But even here closer examination reveals that it is not manifestly incompatible with realism. Typically we think of the specialization net under the basic theory element as steadily growing as we learn more and more about the the special laws that govern the behaviour of various parts of the range of intended applications. In this case of "steady progress", the extension of the terms referring to theoretical elements typically grows smaller and smaller. A "strong" realist (one who holds R4 as well as R1 – R3) might think of this steady progress as somehow "determined by the nature of things" and "inevitable", so that this might appear to be something like "converging on the real meaning" of these terms. For the strong realist, the special theoretical laws that hold in various sub-sets of the range of intended applications are "there" whether or not scientists working with the theory find them. These "ideal laws" determine the "real extension" of the theoretical elements. If scientists working with the theory are clever (or lucky) enough they will ultimately discover *all* these ideal laws and thereby discover the (real) extension of the theoretical elements.

(4.3) At first glance, the view gains some plausibility by noting that it treats theoretical properties in empirical science somewhat like ordinary properties. However it is that we come to know the meaning of the predicate 'is black', it is pretty clearly not by being shown a list of the members of its extension. Among the ways we learn more about the extension of 'is black' is discovering laws containing it – e.g. 'All ravens are black.' This does not appear to be much different than learning more about the extension of 'mass' by discovering the law of momemtum conservation. In the first case, knowing the law legitimates taking ravenhood as an "indicator" of blackness; in the second, it legitimates calculating particle mass rations from velocity changes in collisions. In the case of 'is black' it is not too implausible to suppose that empirical laws (some yet undiscovered) containing it completely determine its extension. But even here we might opt for maintaining the truth of "favored" laws (e.g. those connecting 'is black' with certain physical theories) at the cost of changing our views about the extension of the predicate – say by deleting some mutant ravens with a slight brownish cast. The point is that the frequently suggested interaction between meaning change and belief change in everday language may as well appear in rather highly mathematicized empirical science. The structuralist reconstruction of such theories provides a means of describing this interaction in a precise way though it does not commit one to the view that it occurs.

(4.4) I am not sure that the view just sketched. (R4 realism) would be acceptable to all realists. It seems to be in the "general spirit" of realism, but it may be a somewhat stronger version of realism than many realists would want to buy. In particular, some realists might be satisfied with a version of realism in which all individuals and properties mentioned in empirical theories were taken to be equally "real", but laws about these possibly just "convenient fictions". That is they would hold R1 – R3, but not R4. They would allow that different theoretical laws formulated in the same vocabulary might be identical in their non-theoretical content. Using the same theoretical vocabulary, there could be different ways of carving up the range of intended applications into sub-sets and assigning theoretical laws to them that yielded the same content at the non-theoretical level. One way of understanding the implications of structuraslism for realism is then this. Assuming structuralism is true, if one wants to be a realist about the meaning of terms referring to theoretical elements (an R3 realist), them one must also be a realist about theoretical laws (an R4 realist).

5. THEORETICAL INDIVIDUALS AS THEORETICAL PROPERTIES

(5.0) In structuralist reconstructions of empirical theories the theoretical – non-theoretical distinction is drawn between properties. The individuals in the base sets of the set-theoretic structures always fall on the non-theoretical side. How then do structuralist reconstructions deal with the standard examples of "theoretical individuals" – molecules, electrons, genes etc.? First, let us note that the concept of "theoretical individual" may not be completely clear. Structuralism has offered a (not entirely non-controversial) account of how to distinguish theoretical from non-theoretical properties in a given theory. Some general way of distinguishing theoretical from non-theoretical individuals, theory dependent or not, is not, to my knowledge, available. In this paper I will confine my discussion to commonly recognized examples of theoretical individuals without saying anything about *how* one recognizes such individuals. There appear to be basically two ways of handling these examples within the structuralist approach. One is to recognize that the existing exposition of the theory is misleading in speaking of the theoretical element as an individual. The claim of the theory is more easily understood by treating it a theoretical property of non-theoretical individual. The claim of the theory is more easily understood by treating it a theoretical property of non-theoretical individuals. Genes appear to yield to this treatment. The other way is to treat the "pre-theoretic" description of the applications in which theoretical individuals are introduced as one "theory" *T′* which reduces the theory *T* in which these applications are handled by the introduction of theoretical individuals. Molecules and electrons appear to yield to this treatment. I shall consider each of these approach in a bit more detail.

(5.1) Clearly the most straightforward way to handle a putative theoretical individual is to treat it as something we already think we know how to handle – a theoretical property. This appears to work for genes in classical population genetics. In this theory the individuals are "populations" and "time sequences" whose non-theoretical properties are stochastic processes of "observable traits" or "phenotypes". Generally, these processes are non-Markov. "Genes" are introduced as additional "theoretical traits" or "genotypes" of the same non-theoretical "populations". Roughly, the claim of the theory is that some array of genotypes plus a relation to phenotypes can be found so that the genotypic stochastic process is Markov and the relation to the phenotypes yields the observed, non-Markov phenotypic stochastic process. In this example, there is a very natural way to avoid speaking of genes as theoretical individuals, even though existing expositions of the theory do not commonly adopt this way. One gets rid of the theoretical entity at little cost in fidelity to the existing exposition.

6. THEORETICAL INDIVIDUALS AND REDUCTION

(6.0) The second way of dealing with theoretical individuals intuitively amounts to identifying (via a reduction relation) the "macroscopic" individuals of one theory *T′* with the "microscopic", "theoretical" individuals of another theory *T*. In some cases, *T′* will be a mature empirical theory which lends itself naturally to structuralist reconstruction. In other cases, *T′* will not be an empirical theory in any ordinary sense. Rather it will be an everyday language description of some kinds of intended applications of *T*. In these cases, a structuralist reconstruction of *T′* may appear rather unnatural.

(6.1) To see how this works in detail it is expedient to consider first a familiar example of the case where both T' and T are mature empirical theories. Consider the example of classical rigid body mechanics (T') and Newtonian particle mechanics (T). (See [10] pp. 234 ff. for a detailed discussion this example.) Here T' reduces to T via a reduction relation ρ in which the individual of T' – rigid bodies – correspond to sets of individuals of T – particles. Though we do not usually think of the Newtonian particles that "make up" classical rigid bodies as "theoretical individuals", the logical structure of this situation seems to be the same as in those situations where individuals like "molecules" and "electrons" are introduced. Had it been that classical rigid body mechanics developed prior to Newtonian particle mechanics, then the discovery of the latter theory and the ρ-relation might have had genuine "explanatory force". The Newtonian particles might have been taken seriously to be newly discovered "things" that "make up" rigid bodies.

(6.2) In this example, both T' and T are mature empirical theories reconstructed with the help of theoretical elements. Ignoring the theoretical elements, the reduction relation ρ maps some sub-set B_{pp} of M_{pp} many–one onto M_{pp} in such a way that ρ ($B_{pp} \cap$ Con (K)) $\subseteq$ Con(R'). (The ρ-relation here is the converse of the R-relation of [10] pp. 221 ff.) Thus every intended application of rigid body mechanics (member of I') may be "conceived" as a set of Newtonian particles in (generally) several ways, but there are intended applications of Newtonian particle mechanics that are not "identified with" rigid bodies. The "cash value" of the reduction relation is that those particle mechanical systems that correspond to rigid bodies and satisfy the laws of T ($B_{pp} \cap$ Con(K)) are identified with rigid bodies that are among those which satisfy the laws of T' (Con(K')). Roughly, rigid bodies are "reconceptualized" as certain kinds of Newtonian particle systems. Those Newtonian particle systems of this kind which, in addition, satisfy the laws of Newtonian particle mechanics "make up" rigid bodies that satisfy the laws of classical rigid body mechanics.

(6.3) It appears that other situations in which the "microsopic" individuals of the reducing theory are prime candidates for "theoretical individuals" may be treated in a precisely analogous way. Consider the introduction of molecules (theoretical individuals) in motion to explain the behavior of confined gases. Here the gaseous systems in question may be regarded as intended applications of specializations of classical equilibrium thermodynamics (See [6].). These specializations correspond to the ideal gas law, van der Waals' gas law, etc. For concreteness, suppose we want to use molecular motion to explain the behavior of ideal gases. Then the specialization of classical equilibrium thermodynamics corresponding to the ideal gas law is T'. The reducing theory T in this case is statistical mechanics. To my knowledge, the details of this reduction relation have not been cast in the structuralist formalism. But it does seem roughly clear how it would go. Just as in the case of classical rigid body mechanics, ρ would map some sub-set of M_{pp} many-one onto M_{pp}'. Here the M_{pp} would be sets of particle kinematic systems together with a probability distribution over the σ-algebra of their sub-sets. Intuitively, each ideal gas system would correspond to a single set of "molecules" with many different probability distributions over particle kinematics systems containing these molecules. The ρ-relation would also establish a correspondence between thermodynamic properties of ideal gases and properties of the ρ-corresponding probability distribution over particle kinematic systems, e.g. temperature would ρ-correspond with mean kinetic energy. The "laws" of statistical mechanics would be essentially certain restrictions on the nature of the probability distributions. Statistical mechanical systems satisfying these laws would be ρ-related to thermodynamic systems satisfying the ideal gas law.

(6.4) Both the cases of reduction we have just considerd are examples of what I have called "close reduction" ([10] p. 225). Intuitively, it is reduction that relates both theoretical and non-theoretical concepts in the reduced and reducing theories. In these examples, both the reduced and reducing theories are mathematically elaborate enough to be clear candidates for structuralist reconstruction. In other cases the "reduced theory" may not be so mathematically elaborate or amenable to precise description. In particular, any plausible reconstruction of it it may lack theoretical elements. Nevertheless, I suggest that even in these cases the "weak" reduction relation is the appropriate tool for describing the logical relation between the "theories". Here what we do is "reconceptualize" the intended applications described in "pre-theoretical" language as models for the non-theoretical structures of the theory. More precisely, I think that whenever we describe the intended applications of a theory $T = \langle K, I \rangle$ in everyday, non-T, vocabulary we must fill out the claim of T

(A) $I \in \mathrm{Con}(K)$

in something like the following way. Reconstruct the everyday vocabulary as theory $T' = \langle K', I' \rangle$ and Con $(K') = I'$. Then claim for some specific reduction relation ρ that

(B) $\rho(T', T)$ and $\bar{\rho}\uparrow(I') \cap \mathrm{Con}(K)\ \Delta$.

Here '$\bar{\rho}\uparrow(I')$' denotes the set of all members of Pot (M_{pp}) whose $\bar{\rho}$-images are I'. Intuitively, ρ tells us how to redescribe the members of I' to make them members of M_{pp}. Generally these redescriptions will not be unique. But the second conjunct says that at least some of them are in the content of K. Had classical rigid body mechanics been more loosely formulated – perhaps just a collection of concepts for talking about rigid bodies without any genuine laws, or at least without "theoretical laws", we might have regarded this "theory" as just a way of characterizing certain intended applications of Newtonian particle mechanics. Then there would be a clear sense in which just conceptualizing these applications as partial potential models (M_{pp}'s) for Newtonian particle mechanics should be depicted by a reduction relation.

(6.5) Using the reduction relation to describe the reconceptualization of phenomena described in everyday, pre-theoretical language seems to be the appropriate way to handle the introduction of "electrons" as individuals in applications of classical electrodynamics. Roughly, cathode ray phenomena, electric currents in wires, oil drops between condenser plates constitute intended applications for a specialization of classical electrodynamics – described in pre-theoretical vocabulary. The specialization T here is the one in which the force law is the Lorentz force and the masses and charges of all the particles are integral multiples of some unit mass and unit charge. We may reduce these "theories" T', to T by introducing reduction relations ρ_i that make the individuals in the T'_i correspond to sets of individuals in T. That we can make these models for the specialization with appropriate choice of masses and charges intuitively establishes the existence of a unit of charge with a constant mass. This is not quite the whole story here. To tell the whole story involves introducing the constraints appropriate to the specialization and would take us somewhat too far into the details of a reconstruction of classical electrodynamics.

7. THEORETICAL INDIVIDUALS AND THEORY CHANGE

(7.0) The question of whether, on the structuralist, view, terms referring to theoretical individuals change their meaning with the historical development of theory admits no simple answer. To consider the question in adequate detail would exceed the space limitations of this article. In this section I will only sketch what I think would be the correct approach to the question. For those theoretical entities like genes that are most naturally reconstructed as theoretical properties, the answer is clear. The meaning of terms referring to the theoretical property in the reconstructed version of the theory that "corresponds to" the theoretical entity in the unreconstructed version changes in just the ways described in Sec. 4 above.

(7.1) For theoretical individuals introduced via reduction relations with other theories (or "pre-theories"), the answer is less evident. First, it is not entirely clear just which terms refer to these individuals. The term

(A) $'\bar{\rho}\uparrow(I') \cap \mathrm{Con}(K)'$

appearing in (6.4–B) refers to the set of all sets of structures containing theoretical individuals that may be used to "redescribe" members of I' in a way that satisfies the laws of the theory T. For $x \in I'$, the term

(B) $'\rho\uparrow(x) \cap (\hat{\rho}\uparrow(I') \cap \mathrm{Con})K))'$

refers to the set of all structures containing theoretical individuals that may be used to redescribe x in a way that, together with suitable redescriptions of other members of I', satisfies the laws of theory T. Generally they are, some further talk is needed to refer to the theoretical individuals. Something like

(C) $'\pi_i(\rho\uparrow(x) \cap (\hat{\rho}\uparrow(I') \cap \mathrm{Con})K)))'$

where π_i is the "projection function" that picks out the element of the M_{pp}'s that contains the theoretical individuals is needed to refer to the set of theoretical individuals that ρ-correspond to x. Except in the unusual case that this set is a singleton, it is difficult to see how to go further and refer uniquely to single theoretical individuals. This suggests we most often refer to "kinds" of theoretical individuals rather than to individuals of this kind. For example, electrons are the kind of theoretical individual needed to make cathode ray phenomena (among other things) applications of classical electrodynamics. Thus it appears that the most enlightening question to ask here is whether the meaning of terms referring to *kinds* of theoretical individuals changes as theory changes. That is, we should focus our attention on terms of the form

$$\text{(D)} \qquad `\cup\{\, y \mid y = \pi_i(\rho\uparrow(x) \cap (\bar{\rho}\uparrow(I') \cap \mathrm{Con})K)))\ \text{and}\ x \in I'\}'$$

Let us, for convenience, call terms of the form (D) 'theoretical individual kind terms' or, for short TIKT's. Intuitively, a TIKT for a given pre-theoretically described set of intended applications I' denotes the set of all theoretical individuals that could be used in some way to make members of I' into $M\rho\rho$'s.

(7.2) The first thing about TIKT's that demands attention is that they do not always refer to a non-null set. They succeed in non-null reference only in the case that the claim of the theory for the intended applications in question is true. The second thing to note is that, when they succeed in non-null reference, they do not generally succeed in "unique" reference. For example, if I' is the set of intended applications for rigid body mechanics then the relevant TIKT does not refer to *the* Newton particles that comprise rigid bodies. For there is more than one way to view members of I' as sets of Newtonian particles that satisfy the laws of Newtonian particle mechanics. Perhaps this is one of the reasons we think that these Newtonian particles are a less clear-cut example of theoretical individuals than molecules or electrons. One thing we may require of theoretical individuals is that they be "in principle" uniquely determined. That is, if we knew all about the intended applications I' where the theoretical individuals were employed, there would be essentially only one way to choose an array of M_{pp}'s containing them. That this requirement is satisfied in the case of molecules in kinetic theory or electrons in classical electrodynamics is far from obvious. It is however an interesting question whose answer awaits a precise reconstruction of the relevant theories and reduction relations.

(7.3) First, let us consider only the case where the theoretical individuals are uniquely determined and the intended applications I' in which they appear fixed. (Note that were I' to change the TIKT would, strictly speaking, change too so that the issue of meaning change would not arise.) May the reference of the TIKT here change with the "normal" historical development of the theory T via specialization? It does not appear that it could so long as the constraints in the specializations operate only on theoretical elements. Of course the theoretical elements relating these theoretical individuals (e.g., the theoretical functions of which they are arguments) could change in the course a developing specialization net in just the same way as it might for ordinary individuals. For example, if a specialization net developed under a basic theory element for statistical mechanics with theory elements corresponding to various "gas laws" in thermodynamics, it *might* be necessary to "recalculate" molecular masses to preserve the truth of the net's claim as it developed. Some might be attracted to the view that the T-theoretical properties of theoretical individuals are "essential" properties, e.g. having a certain mass (modulo change in units) is an essential property of electrons. Formally, this view takes terms like

$$\text{(A)} \qquad `\bar{R}\bar{a}\bar{m}(\bar{\mathrm{p}}\uparrow(I') \cap \mathrm{Con}(K))'$$

to denote theoretical individual kinds. On this view, the question of meaning change for terms referring to theoretical individuals is essentially the same as the question of meaning change for theoretical properties discussed above in Sec. 4.

(7.4) Now let us consider the case where the theoretical individuals are not uniquely determined by I' – keeping in mind that this case may not occur in "real life". Here it is pretty clear that the denotation of TIKT's could change as the theory T developed through specialization. Intuitively, some choices of theoretical individuals that were possible in the basic theory element could be ruled out in specializations. For example, requiring that the Newtonian particles making up a rigid body satisfy certain force laws would rule out many, otherwise acceptable, candidates since the particles would have to be in "static equilibrium" under these forces. Of course, just as in the case of theoretical properties, one might maintain that the "real" denotation of the TIKT's was determined by the, perhaps yet to be discovered, "real" special laws. On this view, the discussion of Sec. 4.2 applies here as well.

(7.5) Let us now consider the question of meaning change for TIKT's when the theory T undergoes "revolutionary" change. For example, do terms referring to electrons in classical electrodynamics refer to the same thing as terms referring to electrons in special relativistic electrodynamics? In this example, structural differences between the two theories begin to appear at the kinematic level and are maintained at the dynamical level. At the differential topological level the two theories have the same structure. (See [11].) This suggests that an interesting case of "revolutionary" change to consider is one in which the structural change occurs only at the theoretical level. Formally, we have the same M_{pp}'s in T^1 and T^2 but $M_p{}^1 \neq M_p{}^2$. In the electrodynamics example, the M_{pp}'s are differential topological structures and the M_p's are respectively Galilean and Minkowski kinematic structures. Generally, the non-theoretical contents of T^1 and T^2 will be different, but may intersect. Assuming the pre-theoretical description I of the intended applications and the reduction relation ρ are the same, then the relevant TIKT's can have the same denotation only if the denotation of both lie wholly within the intersection of the contents of T^1 and T^2. Initially, this requirement appears rather unlikely to be satisfied and this suggests that meaning change is rather likely to occur. But a closer look at the electrodynamic example reveals otherwise. Here both theories are reconstructed as specialization nets under different basic theory elements. The basic theory elements have trivial laws, i.e. $M_p = M$. The specializations correspond to kinematic measuring instruments, i.e. clocks, rods (at least in the case of the classical theory) and free particles and have non-trivial laws characterizing the behavior of these "instruments". Those intended applications that are not claimed to be some kind of measuring instrument are just required to be extendable to theoretical models for the basic theory element in a way that makes the measuring instruments in them (if any) models for the appropriate specialization. Intuitively, this requires that the kinematic properties in these applications be determined by "appropriate" measuring instruments. Roughly, we can not generally expect the same things to be both Galilean and Minkowskian measuring instruments. But things that aren't measuring instruments at all may be assigned kinematic properties in either theory. Thus, provided we don't claim our electron applications I to be measuring instruments in one or the other theory, we can expect to find their theoretical redescriptions in the contents of the basic theory elements of both theories. This suggests that the meaning of TIKT's in many interesting cases may remain unchanged through revolutionary change.

8. IDENTITY OF THEORETICAL ENTITIES IN DIFFERENT THEORIES

(8.0) It is sometimes claimed ([4]) that theoretical entities come to be regarded as "real" in contrast to "fictitious constructs" because the same theoretical entity appears in different, well confirmed theories. What can be made of this claim within the structuralist account theories?

(8.1) What does it mean to say the same entity appears in two different theories? First, consider non-basic elements. For example, what does it mean to say that the mole-number function appearing in classical equilibrium thermodynamics is the same as the mole-number function appearing in Daltonian stoichiometry (See [6], p. 106)? On the structuralist account of theories, this is explicated in terms of what Moulines has called an "intertheoretic relation" [7]. Generally and roughly, an intertheoretic relation is a one-one correspondence σ between sub-sets of the elements of models of T_1 and T_2 together with a general set-theoretic relation λ and a relation ρ between the potential models (M_p's) of T_1 and T_2 so that in ρ-related models (M's) σ-corresponding elements are λ-related. (Note that reduction, equivalence and theoretization are all special cases of intertheoretic relations.) Thus we may say elements e_1 and e_2 in the models for T_1 and T_2 are "the same" if there is an intertheoretic relation $\langle\sigma,\lambda,\rho\rangle$ between T_1 and T_2 so that λ is the identity relation on sets and $\sigma(e_1, e_2)$. In our example, σ relates the mole number function in stoichiometry to the mole number function in thermodynamics while ρ relates models of stoichiometry to models of thermodynamics that intuitively "contain the same amounts of the same chemical compounds".

(8.2) On this understanding of what it means for the same element to appear in different theories, is it likely that the same element will be a theoretical element in more than one well confirmed theory? In the example of stoichiometry and thermodynamics this is not the case. In the Moulines reconstruction of classical equilibrium thermodynamics the mole number function is non-theoretical – just because it is "imported" from stoichiometry. Though, to my knowledge, no structuralist reconstruction of Daltonian stoichiometry has appeared in the literature, preliminary considerations indicate that it would appear as a theoretical element in such a reconstruction. Likewise in the theoretization relation, elements which appear in both related theories either appear as non-theoretical in both or as theoretical in one and non-theoretical in the other.

(8.3) A little reflection reveals that this is no accident. For the kind of intertheoretic relation required for an element to be regarded as "the same" in two theories is just the kind that is a necessary condition for a theory-independent determination of the element (See [10] and [2].). If there is an intertheoretic relation between well confirmed theories of this sort then it permits theory-dependent determinations of this element from knowledge of other elements in one theory to be carried across from this theory to the other thus providing theory-independent determinations of the corresponding element in the other. This suggests that the only way the same element may appear as theoretical in two different theories is that there are no methods of determining it in either theory. Now there is no formal reason why this can't happen. Indeed, it is possible to formulate theories with non-trivial non-theoretical contents where the theoretical elements do not admit of determination in any models. But there do not appear to be any "real life" examples of such theories. Intuitively, this seems to be because the absence of determination possibilities would make us view such theoretical elements as "artificial constructs" if not as "lacking empirical content".

(8.4) These considerations suggest that the same theoretical property is just not likely to appear in two well confirmed theories. But what about theoretical individuals? Examples of the same kind of theoretical individuals appearing in different specializations in the same theory net are relatively easy to find. Electrons appear (distinguished by their charge and mass) in a variety of putative applications of classical electrodynamics – cathode ray phenomena, oil drop experiments, models of atomic structure (ultimately an unsuccessful attempt at applying classical electrodynamics). It is somewhat more difficult to find clear-cut examples of the same theoretical entities appearing in different theories with different potential models. What about the molecules of Daltonian stoichiometry and the molecules of kinetic theory? The problem with this example is that it is far from clear that "molecules" must appear as individuals in any discussion of applications of Daltonian stoichiometry. Indeed, the clearest formulations of this theory seem to get on without them. What about, electrons and ions appearing in the electrochemical theory of aqueous solutions? Are not the electrons here the same kind of theoretical individual that appears in applications of classical electrodynamics and the ions "essentially" the same kind of theoretical individual that appears in applications of statistical mechanics to gaseous systems. This is an interesting, but still somewhat problematic example. Here the problem is how to formulate the theory in question – electrochemical theory of aqueous solutions. Intuitively, it appears to be a kind of "hybrid" theory importing concepts from a variety of other theories – electrodynamics and/or the theory of electric currents, stoichiometry and perhaps statistical mechanics. Whether a precise formulation of the theory and its intertheoretic relations with other theories would provide clear examples of the same kinds of theoretical individuals appearing in applications of different theories is not evident.

(8.5) Assuming that we could find some clear examples of the same theoretical individuals appearing in applications of theories with different partial models, what might the formal properties of these examples be like? Intuitively, how would we recognize the fact that we were dealing with the same kind of theoretical individual in the applications of the different theories? To do this it would appear that the theories would have to "share" some non-basic elements. There would have to be some non-basic elements in the two theories that were identical in the sense defined above. Roughly, theoretical individuals in applications of the two theories would be of the same kind iff they have the same values for the shared elements. For example, classical electrodynamics and the electrochemical theory of aqueous solutions might share the elements "charge" and "mass". Electrons would be recognized as the same kind of theoretical individual in applications of both theories because they were attributed the same values of these shared functions in these applications. On this account, one of the dubious features of this example is immediately apparent. While electronic charge might be determined by electrochemical means, it does not seem that electronics mass may be. If we want to keep this intuitive example, we may have to weaken our suggested criterion for the same kinds of theoretical individuals.

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NOTE

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