Physicalist Materialism

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1 INTRODUCTION

In [11] we laid the groundwork for a comprehensive materialism based on physical science within which the problems of ontology and of the interrelations between higher-order sciences—biology, psychology, social theory, and so forth—on the one hand and basic physical science on the other could be correctly stated and assessed. It was our aim to formulate principles of physicalism which are strong enough to incorporate the kinds of appeals to the comprehensive and fundamental character of physical science that materialists have sought to make, but which are not so strong as to imply implausibly tight and rigid connections between the higher order sciences and physics. The combination of principles explained, and in some measure defend, in [11] we titled *Physical Materialism*.

It is not the aim of this paper to recapitulate the argument of [11]. It is rather to extend and apply Physicalist Materialism to a broad range of problems of central interest in philosophy and particularly in the philosophy of science. This current paper presupposes and is a sequel to the first. For Physicalist Materialism purports to provide a general standpoint from which to approach a broad range of philosophical problems of traditional and contemporary concern. We thus intend here both to explain and support further that standpoint by developing a physicalist materialist approach to the theory of attributes, the philosophy of mind and psychology, the problem of the modalities, and the criteria of theoretical equivalence. To be sure, the treatment of these topics which follows will be neither complete nor definitive. But it should become clear that the apparatus developed in [11] lends itself readily to treating fundamental problems. There are in addition a number of topics to which Physicalist Materialism promises fruitful application which we shall here ignore completely, e.g., ethics and "methodological individualism". Nonetheless we do hope to show that Physicalist Materialism provides a theoretical position and an associated program of research which is fruitful and productive.

Physicalist Materialism combines two types of principles. There is first a principle of Ontological Physicalism, or what we have called the Principle of Physical Exhaustion, which provides a non-question-begging construction of the informal claim that everything is physical. Space does not here permit reconstruction of the formal statement of the principle but the essential idea is this: Our ontology includes at the very least all concrete referents of the terms of basic physical theory. In addition it includes every part or sum of parts of the entities initially accepted. Finally, our mathematical-physical ontology includes every object occurring at any level of an ordinary set-theoretic hierarchy taking as urelements the null set and the entities already recognized. The principle of Ontological Physicalism holds that the universe so delineated embraces everything there is.

One extremely important characteristic of this principle must be emphasized: Ontological Physicalism makes no appeal to the defining power of mathematical-physical language; in particular, the truth of Ontological Physicalism is entirely independent of the reducibility or even accidental coextensionality of non-physical terms with the (simple or complex) terms of mathematical-physics.[1] That is, Ontological Physicalism is a purely ontological principle.

Physical Determination principles comprise the second part of Physicalist Materialism. Where the informal statement of Ontological Physicalism is, "Everything is physical", the corresponding principle of Physical Determination is, "Physical facts determine all facts".

To be precise, there are two principles of Physical Determination. The principle of Physical Determination of Truth states roughly that all the truths statable in the language of mathematical-physics fix all the truths statable in any language whatsoever. Or, more precisely, where φ is the class of mathematical-physical terms (based on an adequate formulation of physical theory), and ψ includes all terms needed to formulate truths in any branch of science, and where α is a class of structures which model all scientific laws and which in addition meet certain standardness requirements (α thereby represents scientific possibility), the principle of Physical Determination of Truth holds that whenever any two models in α assign the same truth-values to φ-sentences, they also assign the same truth-values to ψ-sentences.

The principle of Physical Determination of Reference states roughly that fixing the reference (extension) of the mathematical-physical terms fixes the reference of all terms. More exactly, this principle holds that whenever any two models in α assign the same interpretation to φ-terms, they assign the same interpretation to ψ-terms as well.

Surprisingly, these determination principles are independent from each other; neither implies the other. More importantly, they are separately and jointly independent from Ontological Physicalism and from reductionism. The principles of Physical Determination do not require that any non-physical terms be definable (even in the weak sense of accidental coextensiveness) in physical terms.[2] Equivalently (as will become clear in §3), Physical Determination does not require that all attributes—properties, relations, functions, etc.—be, *modulo* reduction, physical attributes.

The principles of Ontological Physicalism and of Physical Determination together make up Physicalist Materialism. Broadly empirical in character, they are supported inductively by scientific practice. Yet they are also principles of extraordinary generality capable of playing a regulative role in scientific research. Moreover they promise clarification of longstanding and important philosophical problems. The purpose of this paper is to substantiate this last claim.

Section 2 presents concrete and instructive applications of determination principles which illustrate their usefulness. Section 3 develops the theory of attributes which Physicalist Materialism naturally incorporates. Section 4 employs the theory to clarify certain common misconceptions in the philosophy of mind and psychology. Section 5 takes up the application of Physicalist Materialism to the life sciences. Sections 6 and 7 extend our framework to two central subjects in the philosophy of science: the modalities and the notion of equivalent theories.

2 DETERMINATION WITHOUT REDUCTION: SOME EXAMPLES

To gain a better grasp of the determination relations we are proposing between physical science and total science and to see how reduction may still fail, it is useful to consult some real examples of determination without reduction from within mathematics and science.

The first is from the theory of truth for formalized languages as developed by Tarski. As is well known, Tarski proved that no sufficiently rich (interpreted) language can contain a truth predicate for that language, that is, a predicate whose extension (on the interpretation) is the set of (codes of) sentences true on the interpretation. A corollary of Tarski's theorem provides a clear illustration of determination without reduction in our sense: if a sufficiently strong theory in a language for arithmetic, say, a first-order axiom system T containing Robinson Arithmetic in a language L with symbols for zero, successor, addition, and multiplication, is extended by adding a new one-place predicate symbol, 'Tr', and for each closed sentence S of L a new axiom of the form, $\ulcorner \mathrm{Tr}(n) \leftrightarrow S \urcorner$ (where 'n' is the numeral of a code number of S on a fixed coding), the extended theory (call it "T*") contains no explicit definition of 'Tr' in terms of the vocabulary of L. But if α is the class of *standard ω-models* of this theory T*, we have: in α structures, L truth determines 'Tr' truth, and in α structures, L reference determines 'Tr' reference. Once the arithmetic truths are fixed in α, so are the 'true-in-arithmetic' truths; and once the reference of arithmetic vocabulary is fixed, so is the reference of 'true-in-arithmetic'. As is well known, α is not a theory-class, i.e., no first-order theory in a finitary language has as its models just the members of α. Note, however, that in the class, $\alpha+$, of *all* the models of the extended theory T* *reference-determination fails*, as it must by Beth's theorem, since reference-determination in $\alpha+$ coincides with implicit definability in T*. (This in fact provides a proof that there must be non-standard models of arithmetic.)

Although 'true in arithmetic' is not explicitly definable in arithmetic, it will be recalled that it is nevertheless *inductively* definable. If to the language of arithmetic a new one-place predicate symbol, G, is added, there is a formula in arithmetic containing G such that this formula comes out true in the standard model of arithmetic just in case G is assigned the set of (codes of) truths of arithmetic. (Tarski showed this, essentially, by showing how to define truth in terms of satisfaction and by showing how to give an inductive definition of satisfaction. If the object language is rich enough, this latter can be carried out in the object language. Converting the inductive definition to an explicit definition requires a stronger language, such as (a more powerful) set theory or a higher order logic.) The question naturally arises: how do truth and reference determination compare with this important weaker notion of definability. One further example concerning definability in arithmetic serves to illustrate the fact that determination relations are essentially weaker than even this weak relation of inductive definability. (For simplicity, we focus on reference determination.) The example is based on Addison's Theorem: in the language of arithmetic L plus a single monadic predicate symbol G there is no formula S such that S is true in the standard model N of arithmetic just in case G is assigned some set A of numbers such that A is definable in arithmetic (i.e., such that A is the extension in N of a formula of L with one free variable). In brief, the predicate (of mathematical English), 'set of numbers definable in arithmetic' (abbreviate this 'Df. in arith.'), is not even inductively definable in arithmetic. (For details, see [2], Ch.20.) However, in a perfectly natural sense, 'Df. in arith.' is determined by the primitive predicates of L. Let α be the standard ω-models of arithmetic, as above. Extend each m in α by adding as a distinguished item the class C of all sets X of natural numbers (from the domain of m) such that X is the extension in m of a formula $B(x)$ of L with one free variable. Let α^C be the class of all structures in α so extended. Intuitively, α^C contains all standard models of arithmetic which also have standard interpretations of the one-place predicate, 'Df. in arith.' Now the result is that *in* α^C *structures,* L *reference determines 'Df. in arith.' reference*, even though in this class of structures, L + G does not inductively define 'Df. in arith.'. Reference determination obviously holds since any two structures which assign the same (up to isomorphism) interpretations to the primitives of L must assign the same (up to isomorphism) extensions to any wff of L with one free variable, hence the same (up to isorphism) sets of natural numbers to the distinguished items C.[3]

As a final illustration, consider classical particle mechanics with its determinate past and future trajectories of particles with precise coordinates of position and momentum—the phase quantities—as given by Newton's laws of motion. As is well known, these laws are wholly reversible: all forward motions of Newtonian systems are on a par with their opposite motions backwards in time. As our second theory, consider statistical mechanics, which applies probability concepts to mechanics and explains the *ir*reversible behavior of mechanical systems with respect to the macroscopic observables of thermodynamics, such as temperature, pressure, diffusion, and entropy. Most macroscropic quantities are defined in statistical mechanics in terms of the phase quantities of mechanics plus a probability density requiring concepts of measure theory and an *a priori* distribution assumption (such as equi-probability of equal volumes of phase space). In the case of 'entropy', even more elaborate probabilistic notions (such as the coarse-grained densities of the Ehrenfests) need to be brought in to avoid outright contradiction with mechanical reversibility. Are these macro-concepts explicitly definable in the language of mechanics? This depends, of course, on how this language is specified. From the historical standpoint of Newton and his successors until at least the nineteenth century, the language of mechanics was not mathematically as rich as the language of statistical mechanics, lacking the apparatus of measure theory, predicates referring to the various types of ensembles of systems, and related concepts. (Of course, if we take the language of mechanics to include vocabulary for the theory of arbitrary Borel functions or, even more extravagantly, set theory, then the point of this illustration will be lost.) In any case, the macro-concepts of statistical mechanics are *determined* by the microscopic ones: fix two closed systems of particles identically in micro-respects and their macro-behaviors will be indistinguishable. Each system will be represented by the same trajectory in phase space. If, therefore, higher entropy regions, say, are entered at given times by one system, the same regions will be entered at those times by the other. Within physical science itself, then, we seem to have a clear case of determination which is regarded as a case of reduction only by significant addition to the original language.

3 ATTRIBUTES: ONTOLOGICAL VS. IDEOLOGICAL STATUS

We have not thus far mentioned universals beyond sets and predicates. In particular we have said nothing of properties, relations, attributes and their ilk. Yet from the theory thus far expounded a clear and natural theory of such intensional entities easily emerges. It is worth briefly developing this account not only for its own sake but also in order to deflect certain misconceived potential objections to our general point of view.

As a preliminary point it should be noted that a set α of structures *representing* scientific possibilities does not exceed the actual in its ontology. The structures which represent scientific possibilities *actually* exist "high up" in the set-theoretic hierarchy. (see below, §6.) The domain of such a structure is in every case simply a subset of what there (actually) is. In the structure, sets of n-tuples of members of this domain are assigned to the primitive n-place predicates of the language of science. To be sure, in every structure representing a non-actual scientific possibility, one or more n-place predicates have been assigned to sets of n-tuples which are not (as a matter of actual fact) their extensions.

To return to attributes, universals generally are in the range of *universalizing functions*, where we understand a universalizing function to be a function from predicates (in a language) to the universals they express, a function which, at a minimum, assigns predicates to the same universal only if the predicates are coextensional. Thus the *most* discriminating universalizing functions assign predicates to the same universal just in case the predicates are *identical*. Predicates themselves are evidently among the most discriminating universals. And the *least* discriminating universalizing functions assign predicates to the same universal just in case they are *coextensional*. Extensions are thus among the least discriminating universals.

There are of course many other kinds of universals less discriminating than predicates and more discriminating than extensions. For example, when predicates are assigned to the same universal in virtue of their putative synonymy, universals at the level of discrimination of meanings are specified. In fact, the discrimination criterion would seem to provide only a partial ordering of the various kinds of universals which might be postulated.

We are here concerned with a particular kind of universal: properties and relations—generally attributes—in the sense which science lends them. For these purposes, two predicates are to be assigned the same universal just in case, as a matter of scientific necessity, these predicates apply to precisely the same things. That is, two predicates express the same attribute just in case, in every member of α (the set of structures representing scientific possibility) they have the same interpretation. Thus here—to use the inexact but hackneyed example—temperature *is* the very same magnitude as mean molecular kinetic energy, synonymy differences notwithstanding.

Now on this construe of the identity conditions for attributes, ideal candidates will occur to any aficionado of possible-worlds semantics. We can simply identify the attribute expressed by a predicate with the function from members of α to the extensions which that predicate is assigned in each. Thus two predicates will express the same attribute just in case they have the same interpretation in each structure representing a scientific possibility. The same device can of course be employed to represent universals with powers of discrimation different from scientific attributes by using sets of structures other than α, as long as the universalizing function is no more discriminating than those functions which assign predicates to the same universal just in case they are logically equivalent.

The identity conditions for these universals are perfectly straightforward. Functions (here attributes) are identical just in case they assign the same arguments (here structures representing scientific possibility) to the same values (here extensions). And, as the reader has no doubt already recognized, there is a more manageable sufficient condition: Two predicates, F and G, express the same attribute if and only if the universal generalization of $\ulcorner Fx_1 \ldots x_n \leftrightarrow Gx_1 \ldots x_n \urcorner$ is a law of science. It is this which connects the topic of attributes to that of reducibility.[4]

On the account of attributes here sketched the *ontological* status of attributes is clear. With the principle of Physical Exhaustion, every attribute is a mathematical-physical *entity*; ontologically, attributes are mathematical-physical. But there is in addition what we can call the *ideological* status of attributes to be considered.[5] Given a certain vocabulary φ, we can regard any attribute expressed by a predicate with essential occurrences of members of φ as a φ-attribute. Thus an attribute expressed by psychological predicates is a psychological attribute and an attribute expressed by physical predicates is a physical attribute.

This distinction, here given prominence, between the ontological and ideological status of entities, is elementary but of great importance. Failure to observe it has led to much confusion in metaphysics, especially in the philosophy of mind. The two types of status correspond to very different semantic relations. An entity's *ontological status* concerns into what extensions of ontological kind predicates the entity falls. For us, the broadest such predicate is 'is mathematical-physical', as spelled out in detail in [11]. Others less embracing, marking important ontological distinctions which we recognize, include 'is abstract', 'is concrete', 'is (or is not) a hereditarily pure set', and, depending on how scientific theories are best formulateud, 'is an event', 'is an elementary particle', 'is exhausted by elementary particles', 'is a person', 'is a process', 'is a social system', 'is a state of a system', 'is a physical magnitude', and so forth. For us, such ontological kind terms as 'is a soul', 'is an entelechy', 'is a phenomenal raw feel not identifiable with any mathematical-physical entity as specified in [11]' all have null extensions.[6] Nevertheless, such terms would mark ontological statuses of any entities that were to satisfy them. The relevant semantic relation is simply satisfaction (of ontological kind predicates, however these are specified). In contrast, ideological status concerns the semantic relation of *expression*—of an attribute by a predicate—or, more generally, the relation between the argument and the value of a universalizing function. Whereas all entities have some ontological status (possibly multiple, depending on what are admitted as ontological kind terms), only universals have ideological status, this being given by the *kinds of predicates* of which the universal in question is the value of universalizing functions. In the case of an attribute, its ideological status is given by specifying the kind of predicate which expresses it, according to some prior *classification of predicates*, generally according to a division among scientific disciplines (e.g., psychological predicates, physical predicates, and so forth). Such classification of predicates changes with time and is affected by many factors, only some of which may be of scientific importance. Moreover, an attribute may have multiple ideological status. If we grant [being H_2O] = [being water], then this attribute is both chemical and ordinary-macroscopic. If 'is in pain at *t*' is lawlike coextensive with a (complex) physical predicate, then on our criterion of scientific attribute identity, [being in pain] is both a psychological and a physical attribute, that is, it has both these ideological statuses since it is *expressed* by both types of predicates.

Confusion threatens when a property or attribute is called "material" or "mental" without specification of whether it is the ontological status or rather the ideological that is in question. If it is the former, the matter turns primarily on the ontological status of the *objects possessing or exemplifying the property*. (Of course, it turns ultimately on what kind of entity the attribute is. But in many contexts a theory of attributes is not being presented or discussed and their classification is allowed to turn on the consideration just mentioned. Along with this is the fact that the question, "what sort of entities are attributes?", appears frequently to be more convention-laden than the corresponding question concerning the exemplifying objects.) If it is the latter, at issue is the *kind(s) of predicates* (from what scientific discipline or domain of discourse) *expressing the property*. Thus, for a paradoxical sounding but extremely important example, *a property may have the ideological status of being mental but not physical and yet have the ontological status of being physical but not mental*! On our view, this happens *whenever* any psychological predicate P is such that it is not lawlike coextensive with any physical predicate: the attribute expressed by P is mental but not physical (ideologically), but given the Principle of Physical Exhaustion, it is physical but not mental (ontologically) in virtue of being possessed solely by physical objects. In fact, given our set-theoretic construal of attributes, every attribute for a mathematical-physicalist is (ontologically) a mathematical-physical *entity*.

When we speak of an attribute as 'mathematical-physical' or 'mental' (without the word 'entity'), we are speaking of its ideological status—of what sort of predicates express it. As just indicated, given Ontological Physicalism, every attribute is a mathematical-physical *entity*, but only those attributes are mathematical-physical *attributes* which are expressible by mathematical-physical predicates. Thus, if general physical reductionism is false (as we believe it to be), then there are attributes which are mathematical-physical entities which are not mathematical-physical attributes. It is failure to recognize this prospect which underlies so much of the perplexity in discussions of the identity theory in the philosophy of mind.

4 THE MENTAL

The identity theory has received a number of non-equivalent formulations. In its least misleading version it is the claim that every mental or psychological entity is a physical entity. That is, the identity theory states that the referents of the terms used to describe mental or psychological phenomena are exhausted by the ontology of mathematical-physics. This is a strightforward ontological claim. In the jargon of metaphysics it is the proposition that mental substance(s) is (are) material substance(s).[7]

To avoid confusion it is crucial to realize that this ontological identity theory is entirely compatible with the view that some or all mental or psychological attributes are not mathematical-physical attributes. For the latter will be true if some mental or psychological terms are irreducible to mathematical-physical terms. This could hold, given Ontological Physicalism, even though all mental and psychological attributes (some or all of which are not physical attributes) are mathematical-physical entities. In this case, there are mental or psychological attributes which are part of the physical ontology without being part of the ideology, i.e., the intentions of the terms, of mathematical-physics. In summary, anti-reductionism provides no support whatsoever for Cartesianism.[8]

Of course in contrast to the terminology just developed, some have chosen to mean by "the identity theory" an ideological thesis which explicitly or implicitly requires reduction. Here recall that even the claim that every mental or psychological term is coextensive (however accidentally) with some physical term (however complex) is not required by the ontological identity theory. Confusion particularly threatens when such views are given an ontological formulation

The ontological and the ideological are connected in the theory of attributes. In our view, outlined above, attributes are to be regarded as identical, i.e., are (ontologically) the same entity, just in case they are expressed by terms which are coextensional by scientific necessity. Thus if attributes or complexes containing attributes are in the extensions of psychological terms, e.g., if 'believes' relates people to attributes they believe true of things, the irreducibility of such terms to mathematical-physical language will insure that at least some of the things mental or psychological terms are true of do not have physical ideological status.

Consider for example the view according to which events are commonly referents of mental or psychological terms and are in addition to be construed as ordered triples of concreta, times, and attributes of those concreta at those times. (Cf.[14]. This is not our preferred theory of events; intensionalizing events is philosophical revision of science, to be avoided if possible.) Ontological materialism being given, concreta, times, and attributes are all mathematical-physical entities, as are ordered triples of such. Thus events in this sense—even though they be the referents of mental or psychological terms—are ontologically physical.

But are these mental events—which are mathematical-physical entities—appropriately dubbed physical *events* as well? The question is whether to treat 'event' like 'entity', i.e., as combining with adjectives ('psychological', 'physical',etc.) to form ontological characterizations, or like 'attribute',i.e., to form ideological characterizations. We need not argue for a preferred answer here. We are agreed that there is no reason to expect that all mental and psychological attributes are physical attributes, i.e., general reductionism is implausible. We can even agree that there is a way of using the term 'event' according to which, given irreducibility, mental and psychological events are distinct from physical events. What must not be missed is the fact that this option would in no way whatsoever contradict the identity theory as a claim about the ontological status of mental events. Mental events would remain physical entities if not physical events.

Physicalist Materialism thus holds that all mental or psychological entities are physical *entities* but does not maintain that all mental or psychological terms are reducible to the language of mathematical-physics nor (equivalently) that every mental or psychological attribute is a mathematical-physical attribute. Using the familiar type/token distinction, one could say that Physicalist Materialism holds that all tokens (and for that matter types) are mathematical-physical entities, but that some types may well not be expressed by predicates of mathematical-physical theory. Reduction is equivalent to identifying the types of the reduced theory with types of the reducing theory. Such type identity can fail, that is a theory T can fail to be reducible to another T', even though every token of the types of theory T is also a token of some type or other of the theory T'.

Here it is important to realize that this position does not commit one to psychophysical anomalism, the view that there are no psychophysical laws. (Cf.[4].)For the irreducibility of mental or psychological terms to mathematical-physical terms is entirely compatible with such terms appearing jointly and essentially in psychophysical laws. Irreducibility does not exclude all psychophysical laws but rather only laws of certain logical forms. (To be exact, irreducibility is incompatible with the existence of sets of laws which would imply definitions of the *ex hypothese* irreducible terms.) Thus Physicalist Materialism is neutral on the question whether non-physical phenomena (phenomena described in non-physical vocabulary) can receive purely physical explanations.

In fact, not only is Physicalist Materialism compatible with the existence of psychophysical laws; such laws will be needed in the characterization of the structures representing scientific possibility unless the notion of "standard" interpretation is forced to carry very great explanatory weight. For, recall that scientific possibility is represented by a set of structures which model all scientific laws and which in addition conform to certain standardness requirements, some of which are well known. (See [11]: 563). In the absense of *any* psychophysical laws, it is quite obscure what non-question-begging appeal to standard interpretations of predicates would provide the needed exclusion of structures violating physical determination. Taking the notion of scientific possibility as primitive would deprive Physicalist Materialism of most of its explanatory power.

In summary, Physicalist Materialism should relieve psychophysical theorists of apparently opposed camps of burdens which they need not bear. Identity theorists inclined toward materialism need not search for a scheme which reduces, if only "in principle", all mental and psychological talk to physical talk. Nor need they take the desperate eliminationist line according to which the terms in question don't really refer at all. Ontological Physicalism is an identity theory without such requirements. Nor is reduction required in order to make clear sense of dependence (or what some have called "supervenience") of the mental and psychological on the physical. Physical Determination is sufficient in this regard.

5 THE LIFE SCIENCES

An interesting parallel area of application of Physicalist Materialism is that of the life sciences. Full treatment of this topic would require a separate paper. Very briefly it should be indicated that the principles of Physicalist Materialism here developed afford an explication of a kind of holist non-reductionist materialism that many find attractive but have found difficulty articulating.

Matters are complicated by the fact that some of the historical debates between vitalists and materialists and within the materialist camp itself have turned on issues which cut across those here given prominence. In addition to the issues of Ontological Physicalism and reductionism in our sense, a distinct principle that can be called "inorganicism" has divided theorists. Roughly, inorganicism holds that the forces sufficient for explaining inorganic matter suffice to explain organic matter as well.

A moment's reflection shows that failure of inorganicism need not violate the principles of Physicalist Materialism. If, for example, spatio-temporal juxtaposition of macro-molecules uniformly gave rise to force fields not accountable as vector sums of what are now recognized as basic inorganic physical forces, then the natural course would be to include the theory of such forces within basic physical theory. (Strictly speaking, this has nothing to do with ontology; the question is, which arguably "force-like" functions—all of which are mathematical-physical entities—are required in physical explanation.) *Modulo* initial conditions, contemporary physics with its four basic forces does specify the relevant location properties of macro-molecules. A form of vitalism which postulates a new organic force (in the sense of a vector function on space-time points) should thus be seen as calling for a revision of physics. Physicalist Materialism should not be construed so as to rule out every such eventuality.

To be sure, historically there have been virulent forms of vitalism which violate either Ontological Physicalism or Physical Determination or both. (For background on these issues see [1], Ch. IV, especially 103ff. For one presentation of positions which apparently violate Physicalist Materialism see [21].)

Within the materialist camp a major point of contention has been over what may be called "atomism", according to which explanatory properties of biological wholes can be ascertained though experiments on their parts in isolation. (This debate has often taken the form of a dispute over *in vivo* vs. *in vitro* methods.) Not surprisingly, given its epistemic character, this issue of atomism (vs. "holism" or "contextualism") is logically independent from inorganicism, Physicalist Materialism, and reductionism. To be sure, atomism in its purest form would support inorganicism and would seem to support a reductionism program. At any rate, *PhysicalistMaterialism is compatible with a full contextualism.*

It would appear that attention to the distinctions here emphasized among ontological, determinationist, and reductionist principles would help to shed light on the many complex and interesting issues and controversies in this area.

6 MODALITIES

The purpose of this section, details aside, is to indicate that the modalities can, for scientific purposes, be adequately incorporated within the framework of Physicalist Materialism as thus far developed. The central problems here are those of, first, providing means for construing "essentialist" claims which seem reasonable, and second, detailing how the possible can be represented within the actual mathematical-physical ontology. Underway, an interesting dilemma for modalists appears and a Physicalist Materialist solution is sketched.

The set α of structures representing scientific possibility together with the relation $R = \{\langle m,m' \rangle | m,m' \in \alpha\}$ (interpreted as "m' is accessible from m") forms a natural model structure for the modal system S_5. All members of α are on a par; there seems to be no reason for restricting accessibility. Scientific laws are necessary truths in virtue of holding in every structure in α. Non-lawful statements of fact are contingent. In particular, lawful sentences such as "heat = mean kinetic energy of molecules" (or a corresponding biconditional linking predicates) are necessary. If two predicates express the same attribute (in our sense of scientific attribute, see §3), the universal biconditional linking them is a law, hence a necessary truth. Again, necessity does not imply analyticity or any special meaning connection.

Two important questions naturally arise: (1) What further necessary truths are there? In particular, are we committed to essentialist claims? (2) How can α fully represent scientific possibility without exceeding the actual mathematical-physical ontology?

On (1), as has been ably argued, commitment to the coherence of quantified modal logic does not require commitment to any interesting version of essentialism. (cf.[19].) The question of essentialism turns on the particular content of α— on the laws of science along with restrictions on what is to count as a standard interpretation of scientific language. As we have already urged ([11]:563), mathematical standardness is a reasonable restriction for natural science. Further, as argued, it suffices to block any inference from physical determination to physical reductionism. If *no* further standardness requirements are made, essentialist claims of the Putnam-Kripke variety concerning individual concreta will come out false. Even if "water = H_2O" is necessary, "This bit of water is composed of H_2O molecules" is not, if there is a structure in α containing that very bit in which the predicates 'is water' and 'is composed of H_2O molecules' are reinterpreted so as not to apply to it. Even "This horse (named 'Bootstraps') is a horse" would not be necessary: a structure containing Bootstraps could interpret 'horse' so as not to apply to Bootstraps without violating scientific law. If such essentialist claims are to be sustained, it must be through further standardness requirements on α. It is up to essentialists to motivate such requirements.

Essentialists have typically maintained that essential predication cannot be accounted for in terms of linguistic habits and conventions. Without deciding this issue, we raise one problem that Kripkean essentialists have yet to solve. '$\Box Fa$' is supposed to hold in a world w if every w' such that wRw' and the denotation of 'a' is in the domain of w' satisfies 'Fa'. The crucial additional restriction is that 'a' be rigid, that is, that the denotation of 'a' be the same in all worlds (where 'a' denotes). (See [15]: 269, ff.) Otherwise we get Quinean paradoxes: essential predications turn on the way we designate the object. Now Kripke handles Quinean objections by appeal to our fixed ideas of what we quantify over—the objects we countenance. Of *these* we may entertain modal and counterfactual claims. ([15]:267, passim.) The problem of transworld identity is blocked from the start by appeal to the innocuous assumption that we know what we're talking about. On deeper reflection, however, matters are not so simple.

Assume we have a concrete material object, say Bootstraps ('b' for short), and assume that b is exactly exhausted by actual spatio-temporal parts, $p_1 \ldots p_n$, rigidly picked out by these designators $\ulcorner p_i \urcorner$ (let us assume we understand "rigid designation" for the parts, for the sake of argument). Then, by hypothesis we have

(1) $b =$ the (spatio-temporal) whole composed of just $p_1 \ldots p_n$

true in the real world. Abbreviate the right side 'wh'. In any world, 'wh' designates the nominalistic sum (in the sense of [9]: Ch. 2) of the rigidly designated parts, whatever other predicates that sum happens to satisfy. Given our way of speaking, 'wh' disignates "different (*ordinary*) objects" in different worlds. The very same parts might have been dispersed so as not to have constituted a horse (just as the same horse might have had different parts). The Kripkean essentialist must either (i) deny (1) or (ii) explain why 'wh' is non-rigid in a way that doesn't simply amount to a claim about how we happen to individuate ordinary objects. Denying (1) is out of the question for a materialist who understands the part-whole relation (remember: the p_i were chosen so as exactly to exhaust b spatially *and* temporally).[9] But if 'wh' has as good a claim to rigidity as 'b', then we have irreconcilable essential predications: we have, e.g., $\Box$Horse(b) & $\Diamond\sim=$ -the-sum-of-$p_1 \ldots p_n(b)$; and also $\Diamond\sim$Horse(wh) & $\Box$=-the-sum-of-$p_1 \ldots p_n$(wh). Moreover, if the argument for 'wh' being non-rigid turns on the fact that we are not interested in tracing objects via composition, then it fails to sustain non-linguistic (and non-epistemic) essentialism. *Rigidity* (and, therefore, essential predication) *would have to be relativized to some preferred ways of tracing objects*. And the charge of arbitrariness of (non-relativized) essential predications would appear difficult to rebut in view of the fact that we can and sometimes do trace objects according to their composition!

Let us turn to the second point, how α can represent scientific possibility without exceeding a mathematical-physical ontology. We hold to the view called "Actualism", that quantified modal logic does not involve quantification over, or reference to, non-actual possibilia. In particular, reference is a relation, and if a symbol (or speaker, or speech-act) refers to any entity x, then $(\exists y)(y = x)$, x exists (i.e., is actual). Given the Principle of Physical Exhaustion, quantifiers in modal contexts, as anywhere, range over the (actual) mathematical-physical universe (or a subset thereof). Thus, structures in α actually exist: the domain of any such is a subclass of what there is; in the structure, sets of n-tuples of members of this domain are assigned to the primitive n-place predicates of the language of science. As already noted, in every structure representing a scientific possibility which is *not* actual, either the domain is a proper subclass of the actual, or some n-place predicate has been assigned a set of n-tuples which is not in fact its extension (or both).

Any actualist must confront the problem of representing possible worlds with ontologies of which the actual is a proper subclass, e.g., worlds enabling sentences to come out true such as

(2) There might have been more F,

where F is replaced by a predicate of concreta, such as 'horses' or 'matter-energy', and so forth, and where it is understood that the possibility envisioned includes as much of everything else as actually exists. This may be called "the problem of expanded universes". Now it might turn out that such claims need not be regarded as true, that is, that scientific laws permit expanding but not expanded universes. Surely we cannot assume this is the case. Our scheme for scientific use of modal logic ought to accommodate such apparent possibilities, especially if it is to be applicable in scientific contexts at various stages of theoretical development. There are at least two strategies for representing expanded universes that deserve consideration here.

I *Temporal branching strategy*: Interpret sentences of form (2) as part of a story to the effect that some actual G's might have become or developed into F's. The truth of the original sentence turns on the truth of the story, i.e., on whether it is compatible with all laws and standardness requirements on α. Clearly this meets the demands of Actualism. Indeed, many such claims can be so represented; however, it is unlikely that all can. (Consider, e.g., "there might have been matter-energy extending the actual space-time manifold and it might have been spontaneously generated as a vacuum fluctuation (allowed by quantum theory)".)[10]

As an alternative, we may adopt II *The abstract representation strategy*. Here we let abstract objects in the mathematical-physical ontology, i.e., pure sets, stand in as representations of extra entities of the sort F in question. Less picturesquely, we admit structures m into α which assign to F some pure sets in addition to the actual extension of F. Since, in employing modal sentences such as (2), we are not saying of any actual things that they might have been F, and since there is (from our actualist standpoint) no possibility of saying of a "particular non-actual" that "it" is F, there should be nothing to offend intuition about employing abstracta in representative roles, as this strategy demands. However, care must be taken if outright contradiction is to be avoided.

Suppose we use 'Fx' for 'x is a horse' and, to guarantee truth of (2), we interpret F in a structure m in α as $\{x| Fx \vee x=\phi\}$, i.e., to the actual extension of 'F' is added one more object, the null set. Let 'Mx' abbreviate 'x is a set'. In our overall scientific theory, we also want to affirm

(3) $\Box(\forall x)(Fx \rightarrow {\sim}Mx)$,

"Necessarily, no horse is a set." Under ordinary Kripkean-Tarskian semantics, if 'M' in the structure m is assigned the class of all (actual) sets, we will have $m \models (\exists x)(Fx \;\&\; Mx)$, falsifying (3). And if 'ϕ' is construed as designating in m the null set, we would have, $m \models F\phi$, hence, in the real world, "the null set might have been a horse"!

There is, fortunately, a technically satisfactory way of avoiding all such anomalies. As the above suggests, we must not assign 'M' all actual sets in a structure m used to represent expanded universes. Instead, in keeping with mathematical standardness requirements, we can assign M a set theoretic structure of pure sets isomorphic to the real world universe of sets but beginning at some point of higher rank than the null set. In fact, there is no limit to how far up we may begin. For any ordinal β, all sets of rank $<\beta$ could be omitted or used as possibilia-representations, and any set of rank β could be construed as the null set in that structure, serving as the ground element of a pure set-theoretic hierarchy isomorphic to the actual one. (Indefinitely many sets of arbitrarily high rank outside the new "embedded" hierarchy also become available for re-interpreting predicates; or they may be omitted from the domain entirely.)

But now, it may be asked, don't we still falsify true statements about mathematical objects, e.g., $\Box{\sim}F\phi$, or $\Box M\phi$, or $(\forall x)(Mx \rightarrow \Box Mx)$, and so forth? No; if we are re-interpreting

'M', we must systematically re-interpret all mathematical reference. Thus, for example, 'ϕ' in any m in α designates the initial point of the set-theoretic hierarchy in *that* structure (and that point need not be the null set). In general, our structures m must assign to any mathematical predicate (singular term) the image of its actual extension (denotation) under a 1-1 $\in$-isomorphism, $\Im_m$, from the real universe of sets to the universe of sets in m. Thus, to evaluate modal sentences containing any predicate A with mathematical places (say, the first n places), we have in the inductive definition of satisfaction a clause such as

(4) $G \models \Box A(c_1, \ldots, c_n, c_{n+1}, \ldots, c_{n+m})$

iff

$(\forall m)(m \in \alpha \rightarrow m \models A(\Im_m(c_1), \ldots, \Im_m(c_n), c_{n+1}, \ldots, c_{n+m}))$,

where G is the actual world, $c_1 \ldots c_n$ are mathematical constants and $\Im_m$ is the $\in$-isomorphism from the actual class of sets to the class of set in m. (A similar clause can readily be framed for satisfaction of wffs with free variables by sequences.)

Given these rules, sentences such as $\Box{\sim}F\phi$, $\Box M\phi$, $(\forall x)(Mx \rightarrow \Box Mx)$, etc., all come out true as desired, no matter how many "extra" concreta are represented by sets in expanded universes. The reader familiar with current debates over modalities will be inclined to call this a "counterpart interpretation" with respect to the abstract part of the mathematical-physical ontology. Formally, that is what it comes to, but it stems not from views as to the impossibility of rigid designation but rather from the aim of achieving a rich enough scheme for representing scientific possibility within an actualist framework.

With respect to a given mode of individuating objects (such as the two considered above under our first question), we see nothing wrong with "Haecceitism", the view, roughly, that modal claims may meaningfully be entertained of actual objects "rigidly designated" (so that it is meaningful to say that the same object occurs in many worlds). (Cf.[12].) However, while it is true that if no other assumptions are made, the Haecceitism/Anti-Haecceitism distinction is independent of the Actualism/Possibilism distinction, once we require representation of expanded universes, this independence breaks down. If strategy I for representing expanded universes fails and strategy II is the only alternative (given Actualism), then Actualism rules out a complete Haecceitism—the latter must be relaxed for part of the ontology along lines sketched here.

Note, finally, that in giving up "Haecceitism" with respect to the mathematical, we are not giving up mathematical *reference*. It is only in modal contexts that the reference of mathematical vocabulary is affected by our rules; and the results accord well with the view that the necessity of mathematical truths derives from mathematics' concern with structure, with what would hold of *any* objects satisfying certain structural conditions. In our class α of structures for scientific possibility, some members contain interpretations of mathematical vocabulary that are "non-standard" from the standpoint of absolute reference only—not from the standpoint of structure. In a set of structures for mathematical possibility, many more structures, non-standard in both respects, would naturally be included. Strategy II thus appears to be consistent with reasonable views in the philosophy of mathematics.

7 THEORETICAL EQUIVALENCE

The principles and methods thus far developed lend themselves to a novel treatment of a difficult problem in the philosophy of science: formulating appropriate conditions under which theories are to be regarded as equivalent for scientific purposes. This problem is of definite importance with regard to the issues of under-determination of theories by observation, conventionalism, theoretical realism, and the impact of arguments to the effect that there are incommensurable theories (that is, theories between which no admissible adequate translation exists).

The traditional empiricist standard of theoretical equivalence, provided by the postivists, is based on the verification theory of meaning. According to Reichenbach, two theories are equivalent just in case they are observationally equivalent in the sense of entailing the same observational consequences.[11] This is a standard of equivalence in "content" or "meaning" whose adoption has the effect that apparently different accounts of any phenomena which entail the same observation sentences can differ only in conventional matters such as "descriptive simplicity". Many deep problems with this standard have been recognized, not least of which is the fact that, taken seriously as a standard of synonymy, it requires intolerable revisions of the familiar and useful semantics of first order logic. (Cf. [8].) If attention is focused on first order theories with their ordinary model-theoretic semantics, standards of theoretical equivalence may be formulated which attempt to spell out the intuitive condition that equivalent theories be inter-translatable. (Here "theory" means just deductively closed set of sentences.) One recent effort runs thus:

(5) Theories T and T' (framed in distinct languages, L and L′) are equivalent iff they have a common definitional extension. ([8])

In other words, if $D_{T'}$ (D_T) is a set of definitions of the extralogical T' (T) vocabulary in terms of the T (T') vocabulary, then the condition requires that $T \cup D_{T'}$ be logically equivalent to $T' \cup D_T$. Everything hinges on the criterion of definition required. If mere truth (in the actual world) of universal biconditionals is the standard, then theories will be equivalent on the basis of accidental coextensiveness of predicates. (Even this is a concession to Glymour, who imposes no semantic requirements on the "definitions", with the result, for example, that any two syntactically similar theories, representable by the same canonical logical paraphrases, would turn out equivalent.[12]) More plausibly, the definitions might be required to be lawlike, or true in all structures representing scientific possibility. In this case, (5) becomes equivalent to

(6) T equivalent to T' iff
V_T reduces $V_{T'}$ and $V_{T'}$ reduces V_T and $T \cup D_{T'}$ is logically equivalent to $T' \cup D_T$,

where V_T is the extralogical vocabulary of T, etc., and "reduces" is understood in the sense of [11]. Note that the last conjunct is required here, unlike in the definition of Physical Reductionism in [11], because we are considering arbitrary theories, whereas before we were concerned with the totality of physical laws (all laws formulable in physical vocabulary).

Proponents of (6) need not take it as an explication of theoretical *synonymy*; they need not even be committed to such a notion, unlike the positivists who needed a theory of meaning for definite epistemological purposes (to demarcate the scientific in terms of testability, to resolve problems of justification raised by the prominence of unobservables in modern physics, and so forth). Rather (6) appeals directly to a notion of lawlike coextensiveness which is in fact distinct in important ways from ordinary notions of "informational equivalence". Even coextensiveness in all "logically possible worlds" is markedly distinct from informational equivalence (by pretheoretic intuitive standards). The criterion in question equates, e.g., all terms with null extensions in all "worlds", so that, e.g., 'surface both red and green all over' and 'even prime number greater than two' would be translates! (The fact that these terms are complex *in English* is irrelevant.) The gulf is even wider in virtue of taking structures representing scientific possibility as the standard for reduction.

Once claims of synonymy are dropped, however, it is reasonable to ask whether (6) is not too strong. From a realistic standpoint, the postivist criterion is clearly too weak, equating theories solely on the basis of agreement on the observational part of the vocabulary, however this might be demarcated. But once the focus shifts from "meaning" to "lawful connection", it may well be asked whether term by term reductions, or even translation of whole sentences (by whatever means), are really necessary for theoretical equivalence.

In fact, the apparatus developed above in connection with the principles of Physical Determination provides a means of defining intuitive standards of theoretical equivalence without appeal to reductions or translations. Just as we considered formulations of the idea of one realm of facts determining another, we can analogously formulate the idea of several realms of facts mutually determining one another. To take the simplest case, two distinct bodies of theory may express two realms of facts which determine one another in the sense that variation in one realm is impossible without variation in the other.

Given theories T and T' in vocabularies V and V' respectively (which may be supposed disjoint without loss of generality) and a class α of structures for T and T' (i.e., of similarity type which includes $V \cup V'$), we define

(7) T and T' are α-theoretically equivalent

iff

$$(\forall m)(m \in \alpha \rightarrow (m|V \models T \leftrightarrow m|V' \models T')),$$

that is, the reduct to T vocabulary of any structure in α is a model of T just in case its reduct to T' vocabulary is a model of T'. Where α is taken to be a set of structures representing scientific possibility, (7) will be called *basic theorectical equivalence*. Intuitively, basic theoretical equivalent theories are true in the same scientifically possible worlds; they determine the same model set in the totality of relevant structures.

This principle equates any two theories comprised wholly of scientific laws whose satisfaction restricts the class α of relevant structures. Interesting applications of (7) would usually involve evaluating two newly presented theories in terms of a set of structures limited only by a background of laws already established (or hypothetically entertained) at a given stage of scientific development. The relevant class α thus varies with particular applications and, in general, would shrink in proportion as the body of known scientific laws grows. By supplementing (7) with further conditions, however, many counterintuitive equivalences given by (7) alone are avoided.

Principle (7) is rather weak in that it places no further requiremment on the reducts of structures than that they stand or fall together as models of the respective theories. Tighter relations of theoretical equivalence are obtained by adding to (7) either of the following:

(8) T and T' truth co-determine one another

iff

$$(\forall m)(\forall m')(m, m' \in \text{mod}(T \cup T') \cap \alpha \rightarrow (m|V \text{ eleq } m'|V \leftrightarrow m|V' \text{ eleq } m'|V'))$$

(9) T and T' reference co-determine one another

iff

$$(\forall m)(\forall m')(m, m' \in \text{mod}(T \cup T') \cap \alpha \rightarrow (\forall f)(m|V \underset{\text{f}}{\sim} \text{m}'|V \quad m|V' \underset{\text{f}}{\sim} \mu'|V'))$$

where 'mod ($T \cup T'$)' denotes the set of models of the union of the theories, α represents scientific possibilities, '$m|V$' denotes the restriction of structure m to vocabulary V, 'eleq' means elementary equivalence, and '$\underset{f}{\approx}$' denotes isomorphism under one-one mapping f. (Attention is restricted to cases where the intersection of these sets of models is non-empty.) These parallel the principles of truth determining truth and reference determining reference above, except for the restriction to models of the theories in the antecedents. To drop this restriction would be to require that V (*vocabulary*) truth determine V' truth or that V reference determine V' reference independently of the theories in question, making all theories in these vocabularies co-determinative. (Note also that such unreasonably strong principles (without the antecedent restriction) still do not imply (7), which must be adopted in any case and to which (8) or (9) may be added.) Let us call the conjunction of (7) and (8) the Standard of Truth Co-determination and the conjunction of (7) and (9) the Standard of Reference Co-determination. What they say over and above (7) is that, within the class of standard models of the theories, fixing the truths (reference) in the language of either fixes the truths (reference) in the language of the other.[13]

Co-determination standards avoid counterintuitive consequences of (7), e.g. holding equivalent a set of laws of physics and a set of laws of psychology. Although, on our view, physics determines psychology, psychology clearly does not determine physics. (Consider any two different physical worlds in which no sentient beings exist.)

What is the relationship between (7) and the Co-determinattion standards on the one hand and (6) on the other. While (6) implies all the others (under proper choice of α), clearly (7) alone is weaker than (6) since it involves only standard structures and not all logical possibilities. Moreover, just as Physical Determination principles do not imply Physical Reductionism, the Co-determination standards do not imply (6). The Beth Theorem does not equate them for the same reasons already presented.

Are there any examples from science of co-determinative theories which are nevertheless not inter-reducible? (What about (classical or quantum) statistical mechanics and thermodynamics?) This is an interesting question requiring further investigation.

If the suggested standards of theoretical equivalence are satisfactory, it follows that inter-translatability is not a requirement for theories to determine the same reality. More strikingly, even incommensurable theories, between which no satisfactory translation is possible, could in principle be equivalent in the sense of co-determining one another. A given set of real world structures may be describable in incommensurable ways without this in any way undermining the coherence of maintaining, from within a particular theory, of course, an objective common subject matter.

CONCLUSION

The illustrations and applications of Physicalist Materialism here given are by no means exhaustive. In addition, there are a number of important topics which should lend themselves to fruitful treatment along these lines. For example, naturalism in ethics has typically been presented as a reductionist claim. The evident failure of theorists to provide acceptable definitions of moral terms in natural terms has provided non-naturalism and non-cognitivism their strongest argument. That truth in ethics is determined by non-moral facts is a plausible alternative worth pursuing.[14]

Another example would be the issue of "methodological individualism." Seen from the perspective of Physicalist Materialism, confusion over the distinctions among ontology, determination, and reduction, seems to reach epidemic proportions in the literature on this topic.

On a still more general plane, the kinds of distinctions here employed afford new and possibly illuminating comparisons among general philosophical programs. For example, phenomenalism might be construed as claiming determination instead of reduction. To be sure, unforeseen deficiencies as well as advantages of such programs might thereby be seen to emerge.[15]

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NOTES

[1]In [11], we took reducibility of higher order theory (in ψ vocabulary) to physical theory (in φ vocabulary) to be simply lawlike explicit definability of all ψ predicates in φ terms (that is, provability, in the theory of all scientific laws formulable in $\varphi \cup \psi$, of universal biconditionals of the form $(\forall x_1)\ldots(\forall x_n)\,(\psi_i\,(x_1\ldots x_n) \leftrightarrow A)$, A a φ wff with the same free variables as ψ_i; or, equivalently, coextensiveness of each ψ predicate with some such φ wff in all models of such laws; or, equivalently, coextensiveness of each ψ predicate with some such φ wff in all relevant models α of such laws where α meets the condition that truth of any sentence S in every m in α is sufficient for S to be a scientific law). This departs significantly from classical logical empircist reductionist standards of *relative interpretability* (of ψ theory, $T\psi$, in φ theory, $T\varphi$) in two respects that deserve mention here. In skeleton, $T\psi$ is relatively interpretable in $T\varphi$ iff (i) there exist definitions (universal biconditionals) of $T\psi$ primitives in $T\varphi$ vocabulary and (ii) all translates of $T\psi$ theorems via the definitions are derivable in $T\varphi$. Different standards of relative interpretability result from imposing different requirements on the definitions mentioned in (i). In some well-known formulations, it is required that the definitions be "well-established" (e.g., [17]: 352 ff.). This recognizes implicitly that the definitions in a reduction are generally to be regarded as "real definitions", meeting some semantic requirements beyond the usual syntactic requirements (eliminability and non-creativity, cf. [22]: 152-63) which apply to "nominal" as well as "real"

definitions. The strongest such requirement made by logical empiricists would seem to be coextensiveness in the actual world (truth of the material biconditionals). Elsewhere, it is urged that some weaker semantic requirement of isomorphism be adopted. (Cf. [9], Ch. 1, and [10] for motivation and comparison of such requirements.) At the extreme, it is sometimes argued that *any* semantic requirement is superfluous—that satisfaction of the derivability condition (ii) is sufficient justification of the definitions. (Cf.[13]: 12) In this latter case, we get the notion of *formal relative interpretability* illustrated by well-known "reductions" in pure mathematics (e.g., number-theory or analysis to set theory).

The first major difference between our notion of physical reducibility (which we do not endorse but regard as the relevant reductionist standard) and all of these is that ours requires *lawful coextensiveness* of the definitions. Although this has all the disadvantages of the problematic notion of "nomological", it is not difficult to demonstrate that all of the weaker standards just mentioned are too weak to be relevant in many scientific contexts. This is obvious in the weakest case (no semantic requirements), since any T_2 will be relatively interpretable in a given T_1, provided merely that each axiom of T_2 can be represented by the same logical paraphrase as some theorem of T_1 (taking each primitive T_2 predicate to a distinct predicate letter and preserving syntactic sameness and distinctness throughout all T_2 axioms and their T_1 "translates"). In particular, given set theory as part of the mathematical-physical theory, virtually any consistent theory will be formally relatively interpretable in the latter. For discussion of ways in which the strongest of the "relative interpretability" standards is too weak, see the Appendix. (For special problems concerning the intermediate isomorphism standards, cf. [10].)

The motivation for formal relative interpretability as an approach to reduction seems to us to derive from now dubious epistemological views, especially an instrumentalist view of scientific theories. If, for example, theories are viewed as partially interpreted formal calculi, there would seem to be no direct semantic requirement to impose on "definitions" of theoretical terms of the theory to be reduced. From the standpoint, however, of realism with respect to theories at all levels of scientific inquiry (including semantics), the requirement of lawful coextensiveness of definitions seems an appropriate and natural condition for reducibility.

The second difference is that a reducing *theory* as well as vocabulary is fixed in advance by reference to given laws, in the case of physicalism, by reference to given physical laws ($T\varphi$). If further laws expressible in φ vocabulary are not derivable from $T\varphi$, this constitutes a violation of this version of physicalism. On our version of physicalist reductionism, the possibility is left open of adding new laws expressible in the language of physics to physical theory. If "physicalist reductionism" is taken as the claim that all scientific laws are, modulo good translation, logical consequences of physical laws, and "physical law" is taken to apply to any scientific law expressible in φ vocabulary, then our single lawlike definability requirement suffices for physical reducibility.

This is no doubt oversimplified. Due to the mathematical richness of the mathematical-physical language, "laws" may be φ-expressible which nevertheless are so ill-integrable with ongoing physical theory (either with respect to their form, or due to the character of revisions of physics that might be required, especially revisions in the ontology that might have to be invoked to account for the new "laws") that their discovery might count as refutation of physicalism. For example, if a new macro-force (describable in the language of physics as a vector-valued function of space-time) could be explained in terms of a new micro-force and it could be explained why this latter never showed up at the level of the old micro-forces, we would become *more*, not less, convinced physicalists. Cf. Section 5 below, relating these matters to biology.

[2]This is true despite the well-known definability theorem of Beth. See [11]: 562-3 for details.

[3]These mathematical examples of (reference) determination without reduction are based on theories formulated in first-order non-infinitary languages. As

explained in [11], the effect of Beth's definability theorem (equating implicit with explicit definability) is avoided by restricting consideration to a class α of models of the theory in question which is not a theory-class, i.e., not all and only the models of a first-order, non-infinitary theory. Presupposed throughout is the fact that we can and do refer to such classes of models by means of ("fully interpreted") terms of our meta-language, mathematical English.

The situation, if these restrictions to first order, non-infinitary languages are dropped, is complicated. Beth's theorem holds for a restricted class of infinitary logics (strictly, only for $L_{\omega_1\omega}$ permitting countable conjunction and disjunction and finite strings of quantifiers). It has occurred to some that the principle of physical determination of reference could be expressed as implicit definability of all (finitary) predicates in physical terms in an appropriate infinitary theory. Concerning such suggestions, two remarks are in order. First, the fact that, in the case of $L_{\omega_1\omega}$, this would entail explicit definability of all terms in physical terms does not mean that reducibility is implied, since defining formulas will generally include infinitary ones. Traditionally, the point of reduction has been to show the dispensability of reduced vocabulary; infinitary definitions do not constitute genuine reduction. Secondly, it is important to realize that examples parallelling those for arithmetic with respect to the class of standard models are forthcoming at all infinitary levels, even though the very same examples do not carry over (since, e.g., a single infinitary sentence (of $L_{\omega_1\omega}$) can be used as an $\aleph_0$-categorical theory capturing the standard models of arithmetic). One example that appears to illustrate the essential divergence of reference determination from explicit definability at all infinitary levels is as follows: let T be the theory for two disjoint well-ordered sets formulated in $L_{\omega_1\omega}$. T implicitly defines (reference determines) a relation between the two parts of any model which gives the unique isomorphism of one onto an initial segment of the other. Yet this relation cannot be explicitly defined by any formula in any $L_{\kappa\lambda}$ (let alone $L_{\omega_1\omega}$). (We are indebted for this example to Edward Fisher of the Department of Mathematics, University of Wisconsin (personal communication).)

If the restriction to first-order languages is dropped, there are two cases to consider: (1) standard higher-order logics (where, in the case, for example, of second order logic, the higher-order quantifiers range over *all* subsets of the domain of any interpretation); and (2) non-standard higher-order logics (where extra interpretations are admitted in which higher-order quantifiers may range over restricted classes of subsets). In the former case, completeness, compactness, and Beth's theorem all fail. (A counterexample to Beth's theorem for standard second-order logic is 'Gödel number of a true second-order sentence of (the standard model of) arithmetic'. This *is* implicitly definable in standard second-order arithmetic, but by Tarski's Theorem, it is not explicitly definable.) In case of non-standard higher-order logics, Beth's theorem can be deduced from Craig's Interpolation Lemma in the usual way (compactness holds), but there are many badly non-standard models. In the case of arithmetic, for example, every non-standard first-order model can be obtained as the reduct of a non-standard second-order model. Thus, without going into the question whether physical reductionism in the sense of explicit definability in *higher-order* theory is any more plausible than the sorts of (first-order) physical reductionism explicitly considered, we can be confident that there is no more reason to identify scientific possibilities with all and only the models of a theory employing non-standard high-order logic than there is to make this identification with all and only the models of a first-order theory. Therefore, the strategy proposed for severing determination from reduction in the case of first-order languages works just as well in the case of (non-standard) higher-order languages.

[4]It has been suggested by some that this criterion for the identity of scientific attributes is too weak. (For example, Hilary Putnam in [20]:251.) The worry seems to be that a generalized biconditional law of science connecting a primitive term of another discipline with mathematical physical terms would not lead us to identify the attributes expressed unless it were part of a general reduction of the science in question.

We certainly do agree that there are perfectly respectable universals (which some might even choose to call 'attributes') which are more discriminating than scientific attributes in our sense. (Meanings discriminated by synonymy relations may be among these, though this is explicitly *not* what Putnam had in mind.)

Nevertheless this worry seems unfounded. Imagining an *isolated* generalized biconditional law of science reducing a single term of another science to physics is very difficult. For unless a systematic and general reduction of that science is forthcoming, there would surely be no reason to regard the isolated biconditional as a law. In fact, there would likely be no reason to believe it true. To be sure, the epistemological issue of what we would have reason to believe is not the same as that of what are, as a matter of fact and regardless of our knowledge, nomological truths.

There are certainly contexts of inquiry in which it is requisite to render the criterion for attribute identity stricter. In such situations, the set α representing scientific possibility should be expanded to comprehend structures which we would otherwise exclude. At the extreme, α can be regarded as including every structure. Here attributes will be identified (and predicates will express the same attribute) only if they are logically equivalent.

[5]This distinction, with some modifications that will emerge, goes back to that of W.V. Quine's, in [23].

[6]Note that, whereas many mentalist kind predicates (e.g., 'is a thought', 'is a sensation') may have to be regarded as null given our ontological framework, this does not at all mean that typical sentences of mentalese containing these words are not interpretable as true within mathematical physicalism. The issue here is whether an adequate paraphrase *on the level of mentalese* can be given in which the only expressions construed as referring have mathematical-physical entities as referents. *This concerns only matters of logical form of mentalese and has nothing to do with reduction to a behavioral or physical vocabulary*. For one proposed canonical paraphrase of the sort physicalism may require, see [18]: 99.

[7]This ontological identity theory will not be confused with the extremely implausible "elimination" view according to which no mental or psychological term really refers at all.

[8]To be sure, 'reducible' and its cognates can be used, in a sense different from our own, to make an ontological claim. To claim that one ontology is reducible to another is to claim at least that the former is a subset of the latter. If the 'ability' suffix is given its due, it will in addition be claimed that it is provable, in some true theory, that this subset relation holds.

Every such ontological thesis is equivalent to an identity thesis since

$$\psi \subseteq \varphi$$

is equivalent to

$$(\forall x)(x \in \psi \rightarrow (\exists y)\ (y \in \varphi \ \&\ x = y)).$$

For example, the Principle of Physical Exhaustion, the claim that everything is a mathematical-physical entity, is equivalent to the claim that everything is such that there is a mathematical-physical entity with which it is identical. Or, to use a more narrow example, the identity thesis in the philosophy of mind is the thesis that every mental entity is a mathematical-physical entity, i.e., that every mental entity is such that there is a mathematical-physical entity such that the former is identical with the latter.

These excruciatingly elementary considerations would not bear emphasis were not such identity theses constantly misunderstood as either being or implying reduction claims of an entirely different sort. It should be understood at a minimum that

$$Fx \ \&\ Gy \ \&\ x = y$$

is logically independent of

$$(\forall z)(Fz \longleftrightarrow Gz),$$

e.g., it can be the case that every mental event is a physical event and that in particular x is a pain-event and y is an event of (say) C-fiber stimulation and x is identical with y *even though* it is not the case that every pain-event is an event of C-fiber stimulation and vice versa. And it should be understood that although

$$x = (\iota x)Fx \;\&\; y = (\iota y)Gy \;\&\; x = y$$

does imply

$$(\forall z)(Fz \longleftrightarrow Gz),$$

the former, and thus the latter, can obtain even though the generalized biconditional is not a consequence of scientific law or a necessary truth in any other putative sense. That is, the former can hold even though the condition for the identity of the attributes of F-ness and G-ness fails to obtain.

One can sum up these considerations by saying that ontological reduction theses are independent of other, non-ontological or ideological reduction theses.

[9]Thus, suppose that at age three, Bootstraps lost a piece of his tail (call it 'p'), but that this piece continued to exist in its own right for one more year before succumbing to the ravages of desication. Then it is not the whole of p that constitutes a part of Bootstraps, but rather that temporal stage of p right up to the moment of detachment. Indeed, the spatio-temporal boundaries of Bootstraps are vague. They are to be thought of as settled in advance, however the reader prefers; *then* a suitable list of spatio-temporal parts whose sum exactly exhausts Bootstraps is to be thought of as specified "rigidly". Of course, many, perhaps infinitely many, ways of doing this exist. To each corresponds a distinct "individual concept" or way of tracing the given actual object (Bootstraps) through "possible worlds". And to each corresponds a different set of properties that would then be said to be "possessed essentially" by the object.

[10]For an alternative, more complex approach similar to the temporal branching strategy, perhaps capable of dealing with this sort of case, cf. [16].

[11]For a recent alternative approach to theoretical equivalence closer to the logical empiricist's standard than our own, but similar in lying between mere observational and full logical equivalence (relative to some observation/theoretic division) see [25].

[12]If no semantic requirements whatsoever are imposed on the definitions, this notion of equivalence is simply mutual formal relative interpretability and is open to the objections raised in the first footnote.

[13]Note that where T and T' are complete theories, (8) adds nothing to (7). Of course, interesting scientific theories are generally not complete. Non-lawful sentences, such as typical statements of initial and boundary conditions, are not decided by scientific theories, but must be fixed in the same way by (reducts of) any two elementarily equivalent structures in α.

[14]An important meta-ethical position which endorses the determination of the ethical by the natural while rejecting reductionism has been developed H-N. Castañeda in [3]. To be sure, Castañeda's ontological views depart significantly from Physicalist Materialism.

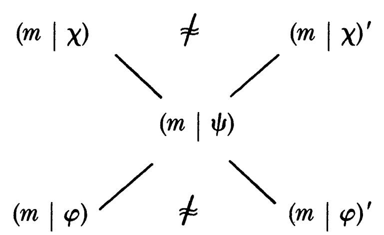
[15]Special acknowledgement is due to the Editor of *Noûs*, H-N. Castañeda, and the referee, for very helpful comments on an earlier draft of this paper.

APPENDIX

PHYSICALISM AND THE INDETERMINACY OF TRANSLATION

In [7], Michael Friedman rightly distinguishes epistemological and ontological theses of indeterminacy of translation, stressing that it is a claim of the latter sort that Quine has sought to develop in his attack on classical (Fregean) semantics. Quine has, in effect, argued that this view of language—with its commitment to propositions, concepts, and so forth—is in violation of physicalism and must be rejected by thoroughgoing physicalists along with the "myth of the mental museum." Obviously, assessment of this whole matter depends crucially on what "physicalism" is taken to be. As Quine has indirectly noted ([24]: 3), the purely ontological component of mathematical-physicalism—in our terms, the Principle of Physical Exhaustion—is not at issue, since, given the apparatus of set theory, mathematical-physical entities serving perfectly well as propositions, concepts, etc., would be readily available within the mathematical-physical ontology of [11], viz., as equivalence classes of various syntactic objects (themselves perhaps best taken as set-theoretic constructs), provided the *appropriate* equivalence relations can be made sense of. As Friedman notes, the issue is—pre-systematically put—one of physical determination: does classical semantics require objective distinctions of fact which are not determined by the totality of "truths of physics"? ([7]: 355). He then argues, persuasively, that at best Quine has supported the claim that classical semantics is in violation of "behavioral determination", that the totality of behavioral facts does not determine all putative semantic facts. The physical facts, however, encompass far more than the behavioral facts, and Quine's main arguments to the effect that non-behavioral physical facts are irrevelent to semantics are found inconclusive at best.

It should occur to the reader that the notions of truth and reference determination of [11] are applicable in this context and can be used to illustrate graphically the gap Friedman finds Quine unable to fill. (Throughout this discussion, differences between truth and reference determination will not matter, save for purposes of expository convenience apparent from the context.) Where φ, ψ, and χ represent physical, behavioral, and semantic vocabularies, respectively, we have: φ Determines ψ (abbreviated "φ Det ψ") and, granting Quine's case against behavioral determination, $\sim(\psi \text{ Det } \chi)$. But from these premises, it does not follow that $\sim(\varphi \text{ Det } \chi)$. To illustrate: if every case of failure of "ψ Det χ" can be diagrammed thus:



then there need be no violation of "φ Det χ". Friedman's assessment of Quine's arguments that any excess of φ over ψ (physical over behavioral) is irrelevant to translation is unperturbed by substituting our explication of physical determination for his own.

One of the strengths of Friedman's approach is that he recognizes that traditional physicalist reductionism is an unreasonably strong standard of physicalism. In particular, if functionalist views about higher order (psychological, linguistic, etc.) states are along the right lines, then, since internal neural conditions may vary "*ad libitum*" without semantic effect (provided sufficient "behavioral relations" are preserved), finitary definitions meeting even weak semantic criteria of higher order state descriptions in physical vocabulary may well not exist. As Friedman sees, this should not violate physicalism. He is thus led to formulate a standard of "weak reducibility" to physics, designed to accommodate functionalism and give expression to physical determinationism. It is both meet and instructive to offer here some comparisons of this interesting weak reducibility principle with our principles of physical determination.

For Friedman, a higher order theory $T\psi$ is *weakly reducible* to physical theory, $T\varphi$, just in case there is a mapping β (a "physical realization") from ψ primitives to sets (possibly infinite) of φ terms such that (i) every ψ primitive ψ' is coextensive with the "disjunction" (possibly infinite) of $\beta(\psi')$ (i.e., every space time point q satisfies ψ' just in case q satisfies some member of $\beta(\psi')$); and (ii) in every model m of $T\varphi$ (physical theory), $T\psi$ comes out true under the "translation" induced by β. (Friedman defines *satisfaction* and *truth* of ψ formulas *under* β in the obvious way, so that no appeal to formulas of infinite length is actually necessary. It is sometimes intuitive and space-saving, however, to speak of infinitary definitions. In the countable case, clause (ii) is then equivalent to provability of all translates of $T\psi$ theorems in a suitable formulation of $T\varphi$ in the language $L_{\omega_1\omega}$ (allowing countably infinite disjunction and finite strings of quantifiers).)

How does weak reducibility compare with our principles of physical determination? In terms of model theoretic strength, there is no simple comparability. Three salient differences merit attention, however:

(1) Note that weak reducibility is just like relative interpretability (the first version, cf. above, note 1) except that the definitions are permitted to be infinite. Thus, the difference noted above (note 1) concerning the demarcation of "physical law" is a significant differ-

ence here as well. While we appeal to a theory (all scientific laws) to tie down the class α of structures representing scientific possibility, we allow higher-order laws adequately expressible in φ vocabulary but not derivable from what may at some preferred time be called "physics" to be added to physical theory. In contrast, Friedman would count any such case as a violation of physicalism (cf. his requirement (ii)).

(2) While Friedman's admission of infinitary "definitions" departs decisively with the traditional reductionist aim of showing the eliminability-in-principle of non-physical vocabulary, still he requires such definitions meeting the weak criterion of coextensiveness (possibly accidental), thereby restricting attention to models of physical theory. While stronger than our principles in some technical respects (our principles do not require even these weak, infintary definitions, cf. note 3), it accommodates a *weaker* position on the issue of what vocabulary needs to be interpreted beyond the "actual world." In formulating our determination principles, we allow for the prospect that there may be, fully compatible with physicalism, scientific laws in ψ terms not translatable in *any* decent way into physical language. Thus, our structures, α, interpret ψ as well as φ vocabulary without presupposing translatability. (Friedman's physicalism would seem attractive to one who believes that "nomological" really consists in "reducibility to physical laws," these latter being characterized by their form, or simply picked out by ostension. (For an expression of this position, see [20]: 252ff.)) Further, as will be discussed, weak reducibility may allow in principle violations of physical determination to escape notice due to the accidental character of the reducing definitions.

(3) Whereas we require φ truth and reference to fix ψ truth and reference in a significant *cut-down* of all the models of scientific theory—a cut-down not capturable as a (first-order, non-infinitary) theory-class—Friedman makes the *stronger* requirement that *all* models of physics must satisfy the higher-order theory $T\psi$ (modulo weak translation). This treats as relevant models in which, for example, number theoretic structure is interpreted as an ω sequence followed by an infinite line of blocks, each isomorphic to $\ldots,-2,-1,0,1,2,\ldots$, with the blocks densely ordered as the rationals. God only knows what probability measures, metric tensors, and expanding galaxies may look like in some of these models. Note, in any case, that the worthy aim of "keeping things recursively enum-

erable" is given up by us when we restrict, for example, to standard interpretations of arithmetic. It is also given up by Friedman when he moves, in effect, to truth of infinitary formulas in all models of physics.

Points (2) and (3) merit further discussion. Friedman's formulation of his definability requirement (i) has the advantage of avoiding problematic reference to "lawful coextensiveness." Nevertheless, by allowing accidentally coextensive, infinitary definitions, weak reducibility appears to be *too weak* in two important respects. First, it could well assign priority to a higher level theory consisting of weakly reducible, non-nomological truths as compared with a rival theory on the same level, in reality superior in explanatory power and in accordance with physical determination albeit *not* weakly reducible. That is, *weak reducibility may lead physicalists to wrong decisions concerning choice of higher level theories*. To see how this can happen, consider an accidental truth of a theory in ψ terms, say of the form $(\forall x)(\psi_1(x) \rightarrow \psi_2(x))$. This may get weakly reduced merely because bad, accidentally coextensive φ-definitions of ψ_1 and ψ_2 yield a φ-sentence true in all models of physics. Given the richness of φ vocabulary, it will often be possible simply to "list" the extensions (now, even if they are infinite) of ψ_1 and ψ_2 (in the manner of the trivial sorts of definitions of 'denotation' and 'valence' illustrated in [5]). It might be thought that Friedman's second requirement (truth in all $T\varphi$ models) rules out such pseudo-reductions. But in the example envisioned, this is not so since the translate of the ψ-law above would be a valid formula of logic with identity (and physical constants)! It would be of the form (possibly requiring infinite disjunction):

$$(\forall x)(x=c_1 \vee x=c_2 \vee \ldots \rightarrow x=c_1 \vee x=c_2 \vee \ldots \vee x=d_1 \vee x=d_2 \vee \ldots),$$

obviously true in all models of physics. It might somehow be required instead that φ-laws figure essentially in the "proof" of any φ-translate of ψ-theorems. But physical connections are plentiful enough so that this is no guarantee against the troublesome phenomenon of pseudo-reduction.

Second, weak reducibility may be too weak in allowing in principle violations of physical determination to escape notice, by essentially the same mechanism of bad translation. Assume we have an extremely simple higher level theory which affirms a distinction in two higher level respects, i.e., it consists of the single sentence

$$\sim(\forall x)(\psi_1(x) \longleftrightarrow \psi_2(x)).$$

The question for physicalism is whether there is any physical difference which is the basis of this alleged ψ-difference. Construed in terms of weak reducibility, the answer will be 'yes' so long as there are extensional equivalents of ψ_1 and ψ_2 in φ terms whose extensions are distinct in all models of physical theory. Again, if lists are used such distinctness may follow from logic, or logic together with elementary physical principles (assuming the ψ extensions are *in fact* distinct). Imagine applying such a method to the case of present interest, classical semantics. The predicates 'refers to rabbits' and 'refers to undetached rabbit parts', held distinct by the theory, can be physically defined by lists of their (putative) extensions (using acoustical descriptions, if necessary), and these are readily shown distinct on the basis of physics. Does this show that classical semantics is not committed in this case to a distinction without a physical distinction? Hardly. On our view, what one must ask is whether semantics countenances as scientific possibilities two φ-identical structures m and m' such that, e.g., m assigns {'rabbit', 'Hasen', 'lapin',. . . } to 'refers to 'undetached rabbit parts' and m' assigns {'undetached rabbit part', ungetrenntes Hasenteilchen', 'partie integrale d'un lapin',. . . } to the same predicate. Of course, what one must really ask is this sort of question with respect to two entire referential schemes. (Note, however, that if the predicate in question is split into two relativized predicates, 'refers to undetached rabbit parts relative to $f(g)$', where $f(g)$ is what Field calls a partial interpretation (cf. [6]: 209ff.), then the assignments in question to these different predicates, respectively, would not constitute any violation of physical determination.) The answer to this question may well be 'no,' but it cannot be decided by the above weak reducibility approach.

Finally, on point (3), Friedman's standard has the advantage that "all models of (current) physics" is far clearer than "all structures representing scientific possibilities." But, in addition to the consequences already noted concerning discovery of emergent forces, there may well be higher level laws using functional vocabulary which cannot be caught in physical language and theory, even allowing infinitary definitions, although truth and reference determination hold in the class of *relevant* structures. If functional predicates are not *lawlike* definable in φ terms, as functionalists have argued, it would be exceptional at best for φ-translates of ψ-laws to be φ-laws. (Such exceptions were called upon above in connection with point (2). Modifications in the relative interpretability approach designed to rule out such exceptions (i.e., which move toward nomological definitions) appear only to exacerbate the present problem).

Reductionists have a response to such a predicament: *ipso facto*, since all translates (based on coextensive definitions) turn out not to be (consequences of) laws of physics, the putative higher-level ψ-law was really not a law after all. This reasoning is to be deplored. Lacking though we are in any clear account of "nomological", there appears to us nothing irrational, unscientific, or aprioristic in regarding *some* higher level generalizations as at least approximate expressions of laws while at the same time failing to see the pertinence of physical reducibility to these judgments.