greedy, bigoted, lustful, etc., thereby bringing about inequitable distributions of social benefits. Suppose Crusoe and Friday have contributed equally to the day's catch of fish, have equal appetites, and have similar metabolisms. But suppose Crusoe is much greedier: Unlike Friday, he gets a kick out of the mere fact of having a larger share of fish (or whatever). Although the most reasonable allocation of fish would be an equal division of the day's catch, an allocation made on the basis of IPUCs would give the lion's share to Crusoe, unfairly rewarding his greed.

Advocates of basing social choices on IPUCs want, I suspect, to maximize something that could plausibly be called "social welfare." Trouble is, even *individual* welfare has less to do with *preferences* —hence less to do with *preference intensities*—than is often supposed.[3]

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PHYSICALISM: ONTOLOGY, DETERMINATION, AND REDUCTION *

MATHEMATICAL physics, as the most basic and comprehensive of the sciences, occupies a special position with respect to the over-all scientific framework. In its loosest sense, physicalism is a recognition of this special position. Traditionally, physicalism has taken the form of reductionism—roughly, that all scientific terms can be given explicit definitions in physical terms.[1] Of late there has been a growing awareness, however, that reductionism is an unreasonably strong claim.[2] Along with this has

[3] See my "Von Wright's Theory of Human Welfare: A Critique," forthcoming in P. A. Schilpp, ed., *The Philosophy of Georg Henrik von Wright.*

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[1] Of course, there are different reductionist positions here, as elsewhere, corresponding to different criteria of definition.

[2] Doubts have arisen especially in connection with functional explanation in the higher-level sciences (psychology, linguistics, social theory, etc.). Functional predicates may be physically realizable in heterogeneous ways, so as to elude physical definition. Cf. H. Putnam, "Reductionism and the Nature of Psychology," *Cognition*, II, 1 (1973): 131–146; J. Fodor, *Psychological Explanation* (New York: Random House, 1968), ch. III, and *The Language of Thought* (New York: Crowell, 1975).

come recognition that reductionism is to be distinguished from a purely ontological thesis concerning the sorts of entities of which the world is constituted. This separation is important: even if physical reductionism is unwarranted, what may be called "emergence" of higher-order phenomena is allowed for without departing from the physical ontology. (In particular, anti-reductionist arguments are seen as lending no support whatever to Cartesian dualism as an ontological claim.) Moreover, there has been a tendency to suppose that reduction of terminology entails reduction of ontology, but this is mistaken. It is thus necessary to consider just how to state a reasonably precise physicalist ontological position. This is the burden of part I.

Although a purely ontological thesis is a necessary component of physicalism, it is insufficient in that it makes no appeal to the power of physical law. In part II, we seek to develop principles of *physical determination* that spell out rather precisely the underlying physicalist intuition that the physical facts determine all the facts. The goal is then to show that these principles do not imply physical reductionism. The main task here is to avoid the effects of the well-known definability theorem of Beth, to which end a natural solution is proposed.

Physicalism, so construed, consists in two sorts of principles, one ontological, the other the principles of physical determination, together compatible with the falsity of reductionism. Yet physicalism without reductionism does not rule out endless lawful connections between higher-level and basic physical sciences.[3] Both ontological and determinationist principles have the character of higher-order empirical hypotheses and are not immune from revision. Nor are they intended as final claims, for it is recognized that physical science is a changing and growing body of theory. Nevertheless, these sorts of principles can be adopted at various stages of development to assert the tentative adequacy of a physical basis for ontology and determination.

I

1. *Ontology and Reduction*. Presystematically, the physicalist ontological position is simply put: "Everything is physical." However, unless 'physical' is spelled out, the claim is hopelessly vague. Yet, as soon as the attempt is made to identify 'is physical' with satisfaction of any predicate on some list of clearly physical predicates

[3] Our position appears thus to be at odds with Donald Davidson's "anomalism". Cf. his "Mental Events" in L. Foster and J. Swanson, eds., *Experience and Theory* (Amherst: Univ. of Massachusetts Press, 1970).

(drawn, say, from standard physics texts) it is discovered that the simple formula, $(\forall x)$ (x satisfies some predicate on the list), fails of its purpose. Unless closure of the list under some fairly complex operations were specified, predicates of ordinary macroscopic objects would not appear, and the claim would be trivially false. Indeed, one seems already forced into the reductionist position of defining—at least in the sense of finding extensional equivalents for—all predicates in terms of the basic list. What started as a bald ontological assertion seems to involve dubious claims as to the defining power of a language. When it is contemplated, moreover, that, no matter how sophisticated the list and the "defining machinery", there are bound to be entities composed of "randomly selected" parts of other entities which elude description in the physical language, then it is evident that something is wrong with this whole approach.

There is another approach. As a preliminary, it should be stated here that no sharp distinction between physics and mathematics is being presupposed. Since we are interested in physicalism vis-à-vis the mind-body problem and the relations among the sciences, we do not wish any physicalist theses that we formulate to turn on views concerning abstract entities. For the purposes of this discussion we will assume an object language L containing a stock of mathematical-physical predicates, including those which might be drawn from texts concerning elementary particles, field theory, space-time physics, etc.,[4] as well as identity, the part-whole relation, '$<$', of the calculus of individuals, and a full stock of mathematical predicates (which, for convenience we may suppose are built up within set theory from 'ϵ'). The metalanguage in which we work includes L [and enough to express the (referential) semantics of L]. Henceforth, we shall use 'physics' to mean "physics plus mathematics" and shall speak indifferently of "physical" or "mathematical-physical" predicates.

Now a thesis that qualifies as ontological physicalism not involving any appeal to the defining power of L (or any language) asserts, roughly, that everything is *exhausted*—in a sense to be explained—by mathematical-physical entities, where these are specified as anything satisfying any predicate in a list of basic positive physical predicates of L. Such a list might include, e.g., '____ is a neutrino', '____ is an electromagnetic field', '____ is a four-dimensional manifold', '____ and ____ are related by a force obeying the equations [Ein-

[4] Obviously, there are many alternative formulations of physical theory. Nothing of present concern will turn on the specific choice of vocabulary in any way that is not obvious from the context.

stein's, say] listed', etc. There are no doubt many ways of developing such a list, depending on how physical theory is formulated. The fundamental requirement for a *basic positive physical predicate at a place* is that satisfaction of it at that place constitutes a sufficient condition for being a physical entity, clearly enough to be granted by physicalists and nonphysicalists alike.[5] Clearly, negations of primitive predicates of physics do not qualify; hence we say "positive" physical predicates. However, it is clear that certain predicates, even primitives, do not meet the fundamental requirement just stated at any place. For example, to include '=' in the list would beg the question: any nonphysicalist will agree that everything is exhausted by all the entities in the extension of this predicate! The same goes for the part-whole relation '$<$', and for set membership 'ϵ', since what are regarded as among the relata of these predicates depends quite directly on one's ontological position. Finally, we must exclude predicates of location of the form 'is at space-time point p', since it would be question-begging to say that merely having location is sufficient for being a physical object.

Assume, then, that requisite exclusions of this kind have been made and we have a list, Γ, of basic positive physical predicates with the concrete places specified. In terms of Γ we now sketch a physicalist ontology. Since 'ϵ' is not in Γ, special provision must be made for mathematical entities. The alternative we favor consists in an iterative set-theoretic hierarchy built on a ground level of concrete physical entities (plus the null set). Since the mathematical objects required by physical science can be developed within set theory, we may concentrate on the members of Γ at their concrete places (where they apply only to objects in space-time). Thus stipulating that

$V[\Gamma](x)$ iff
x belongs to the extension at a concrete place of some predicate of Γ

we may apply notions of the calculus of individuals[6] to objects x such that $V[\Gamma](x)$. In particular, where Δ is any set of predicates, it is assumed there is a unique individual that exhausts all objects satisfying $V[\Delta]$, that is,

$$(\exists !x)(\forall y)((\exists z)(z < y \,\&\, z < x) \leftrightarrow (\exists z)(\exists w)(V[\Delta](z) \,\&\, w < z \,\&\, w < y))$$

where '$<$' is the part-whole relation of the calculus of individuals,

[5] Thus, for example, magnitude-signs are typically concrete at certain places (satisfied by concreta) and abstract at others (satisfied by abstracta, e.g., real numbers).

[6] For an exposition of the calculus of individuals, see Nelson Goodman, *The Structure of Appearance* (Indianapolis: Bobbs-Merrill, 1966), ch. II.

here understood as "spatiotemporal part." We designate this individual F(Δ). The hierarchy is defined thus:

$$R(0) = \{x \mid x = \phi \vee x < F(\Gamma)\}$$
$$R(\alpha') = \text{Power set } (R(\alpha)) \qquad (\alpha' \text{ successor of } \alpha)$$
$$R(\lambda) = \bigcup_{\beta<\lambda} R(\beta), \text{ limit ordinals } \lambda$$

These are just like the ranks, defined by transfinite induction, in set theory, except here rank 0 contains, in addition to the null set, all parts of the fusion of concrete basic positive physical predicates (as ur-elements). This heirarchy admits all required mathematical constructions, both pure and applied (i.e., defined on physical systems). In terms of his hierarchy, ontological physicalism takes the following simple form:[7]

(1) $$(\forall x)(\exists \alpha)(x \in R(\alpha))$$

The crucial step is in the use of '$x < F(\Gamma)$' in the definition of R(0). Recall that, like 'ϵ', '$<$' is not on the basic list Γ. Its use enables one to say, without begging any questions, that everything concrete is *exhausted* by basic physical objects, without thereby implying that everything is in the extension of a basic physical predicate. (1) ensures that the only further entities are sets built on R(0), and may be appropriately dubbed the *Principle of Physical Exhaustion* (not to be confounded with mental exhaustion!).

There is, in addition to Physical Exhaustion, an allied principle that merits attention under the heading of purely ontological theses. It may be called the *Identity of Physical Indiscernibles* and corresponds to one reading of the basic physicalist intuition, "no difference without a physical difference." Letting ϕ range over physical predicates and using u and v to range over arbitrary n-tuples of objects, we may express the Identity of Physical Indiscernibles thus:

(2) $$(\forall u)(\forall v)((\forall \phi)(\phi u \leftrightarrow \phi v) \rightarrow u = v)$$

Let ψ range over all nonphysical predicates (all predicates outside L needed to describe any phenomena in any branch of science). Then, in the presence of (a certain formulation of) Leibniz's laws, (2) is equivalent to

(3) $$(\forall \psi)(\forall u)(\forall v)(\exists \phi)(\psi u \mathbin{\&} \sim \psi v \rightarrow \phi u \mathbin{\&} \sim \phi v)$$

[7] Note that properties and relations are not taken as entities on the ground level, thereby avoiding any hidden reductionist claim behind the simple assertion that everything is identical with some physical entity. In a sequel to this paper, "Physicalist Materialism", forthcoming in *Noûs*, it will be shown how to construe properties and relations of any scientific sort without exceeding the physical ontology.

i.e., for every nonphysical predicate and every distinction it makes, there is a physical predicate that makes that distinction.[8]

By appropriately restricting the range of ϕ, (2) and (3) come very close to implying (1): they imply that there can be at most one entity discrete from the sum of all basic physical entities. (Details are omitted for lack of space. Suffice it to say, evidently monotheism was an advance on polytheism after all, provided God has no proper parts!) However, (2) and (3) are essentially stronger than Physical Exhaustion: the physical might exhaust everything, though physical language might be too weak to distinguish nonidenticals. What is most significant, however, is that, regardless of the appeal (2) and (3) make to the power of physical language, *none* of the principles (1)–(3) says anything about reduction or even accidental extensional equivalence between nonphysical and physical predicates. While ruling out Cartesian dualism, epiphenomenalism, and their ilk, the principle of Physical Exhaustion [like (2) or (3)] is compatible with there being no physical predicate, no matter how complex, which even accidentally picks out the extension of any nonphysical predicate, even those of biology, not to mention psychology. Insofar as reductionism has been motivated by a desire to restrict ontological commitment to the physical, it has made necessity out of a virtue.[9]

2. *The Status of the Ontological Principles.* Let us take physical reductionism to be the claim that, in the theory consisting of all the lawlike truths of science (stated in an adequate language), including, of course physical theory, every scientific predicate is definable in physical terms. That is, for every n-place predicate P, the laws of science entail a formula of the form

$$(\forall x_1) \ldots (\forall x_n)(Px_1 \ldots x_n \leftrightarrow A)$$

[8] N.B. (3) corresponds to one reading of "no difference without a physical difference"; another vastly different reading corresponds to the result of rewriting (3) with '$(\exists\phi)$' preceding '$(\forall u)(\forall v)$'. This [call it (3′)] says that, for any nonphysical predicate, there is a physical predicate that makes all the distinctions it does. By first-order quantifier logic, (3′) implies $(\forall\psi)(\exists\phi)(\forall u)(\psi u \leftrightarrow \phi u)$, provided ψ is neither universal nor null, i.e., that every such nonphysical predicate is extensionally equivalent to a physical predicate—a weak form of reductionism! (3), however, is much weaker, implying no form of reductionism. A better example of the value of logical paraphrase would be hard to find!

[9] Failure to recognize the independence of ontological and reductionist theses undermines much work in philosophy, particularly in the philosophy of mind. The psychophysical identity thesis is the ontological claim that every psychological entity is a physical entity, i.e., that every former entity is identical with some latter entity. This is entirely compatible with the irreducibility of psychology to physics and with psychological properties not being physical properties (although being mathematical-physical *entities*). This point is elaborated in our "Physicalist Materialism," *op. cit.*, n. 7.

where A is a (finite) sentence containing only physical vocabulary as nonlogical terms and occurrences of n distinct variables, $x_1, \ldots, x_n$. This is a "strong" form of reductionism because it asserts not merely that the extensions of all scientific predicates are physically expressible, but also that the equivalences are lawlike. The equivalences are provable in scientific theory and are therefore logical consequences of its laws. Yet even this strong form of reductionism is compatible with ontological dualism.

To see this, consider a very simple theory, Σ, containing just two nonlogical one-place predicates, P and Q, and the following nonlogical axioms:

$$(\exists x)(\exists y)(x \neq y \,\&\, (\forall z)(z = x \vee z = y))$$
$$(\exists x)(Px \,\&\, (\forall y)(Py \rightarrow y = x))$$
$$(\exists x)(Qx \,\&\, (\forall y)(Qy \rightarrow y = x))$$
$$(\forall x)(Px \vee Qx)$$

that is, Σ asserts that there are exactly two objects and that exactly one object is a P and exactly one object is a Q and everything is either a P or a Q. Now in Σ, the following is provable:

$$(\forall x)(Qx \leftrightarrow \sim Px)$$

In other words, Q is definable in terms of P. Yet, this doesn't guarantee that all objects are, or are exhausted by, P-type things. In fact, in every model of Σ, there are two disjoint subsets of entities, one P-type, the other Q-type.[10]

Although the Principle of Physical Exhaustion is a necessary component of physicalism, it is hardly sufficient, in that it says nothing about the scope or power of physical laws. The same may be said for the Identity of Physical Indiscernibles, since quantification therein is restricted to the actual world.[11] All these principles are too weak in that they give no expression to the fundamental physicalist claim that physical phenomena *determine* all phenomena.

II

The intuitive notion to be explicated, then, is that of one realm of facts determining another. A relation of determination has been thought to hold in many cases of scientific interest, such as between facts about the past and facts about the future, the natural and the

[10] Of course, an even simpler theory with the same property is '$(\forall x)(Qx \leftrightarrow \sim Px)$' itself.

N.B. Nothing essential turns on there being only two predicates. If use is made of certain relative terms, clearly within physical vocabulary as conceived by traditional reductionist positions, e.g., predicates of location, then parallel arguments can be constructed for theories containing any finite number of predicates.

[11] Cf. Carnap's explication of determination in his *Introduction to Symbolic Logic and Its Applications* (New York: Dover, 1958), p. 211.

ethical, the instrumental or observational and the theoretical, and elsewhere, including (as we here urge) the physical and all facts. Although frequently identified with definability or reduction (save the case of past and future), determination, as will be seen, is an independent matter.

1. *Determination.* If one kind or realm of facts determines another, then, at a minimum, the truth values of sentences expressing facts in the latter realm cannot vary without variance of the truth values of sentences expressing facts of the former kind. What cannot happen happens under no scientifically possible circumstances. Circumstances are possible if they are compatible with what is fixed. A model-theoretic characterization of determination is in order.[12]

For generality, assume we are working within a family of languages such that any term appearing in more than one has the same interpretation in each. Let ϕ and ψ stand for various sets of nonlogical terms and let α be a set of structures representing scientific possibilities. We may now formulate the notion of a complete ϕ characterization of the world uniquely determining a complete ψ characterization. Recall that two models are elementarily equivalent—m eleq m'—if the same sentences are true or valid in each, and that the restriction or reduct of a model m to a certain vocabulary L—$m|$L—is the structure derived from m by omitting the interpretation of all terms not in L. Thus we have

(4) In α structures, ϕ truth determines ψ truth
iff
$$(\forall m)(\forall m')((m,m' \in \alpha \;\&\; m|\phi \text{ eleq } m'|\phi) \rightarrow m|\psi \text{ eleq } m'|\psi).$$

The intuitive appeal of this notion is clear. Given a full characterization of things in ϕ terms, one and only one full characterization in ψ terms is correct. Once the ϕ facts have been established, so are the ψ facts.[13]

This notion of determination has a number of trivial and uninteresting applications which it would be tedious to discuss explicitly or exclude. In the interesting cases, α is a specifiable subset of the models of a theory T which consists of lawlike truths, ϕ and ψ are

[12] For details on model theory relevant to what follows, see J. Shoenfield, *Mathematical Logic* (Reading, Mass.: Addison-Wesley, 1967), ch. 5; G. Boolos and R. Jeffrey, *Computability and Logic* (New York: Cambridge, 1974), chs. 17–19, 23, 24; and M. A. Dickmann, *Model Theory of Infinitary Languages*, I, *Aarhus Lecture Notes Series no. 20* (1968/9), ch. 1.

[13] This and following notions of determination have a number of interesting applications, explored in our "Physicalist Materialism," *op. cit.*, n. 7. Determinism in physics is not a special case of (4), but rather of a somewhat more general principle, here omitted for lack of space. See "Physicalist Materialism."

each subsets of the vocabulary in which T is stated, and ψ is not a subset of ϕ. More strongly, T will contain sentences with essential occurrences of terms of both ϕ and $\psi - \phi$. Thus the theory T *connects* the ϕ terms and the ψ terms, which is to say that determination involves "bridge laws" connecting the determining phenomena with the phenomena determined. Notice that determination would hold trivially if all models of the theory T were elementarily equivalent or, even more strongly, if T were categorical.

Thus far we have spoken of the determination of one kind of fact or one kind of truths by another. Can we come closer to the world? Precisely the same sentences can be true in two structures that differ enormously in other respects, for example in cardinality. Reference determines truth, as common sense assumes and Frege and Tarski clarified, but truth does not determine reference. In reference different terms differentially correspond to the world, determining truths that fail differentially so to correspond.

It is natural to maintain that, just as models are indistinguishable with respect to truth if the same sentences are true in each, i.e., if they are elementarily equivalent, structures are indistinguishable with respect to reference if each term has the same reference in each, i.e., if they are identical.[14] Thus corresponding to (4) we have

(5) In α structures, ϕ reference determines ψ reference
iff
$$(\forall m)(\forall m')((m,m' \in \alpha \,\&\, m|\phi = m'|\phi) \rightarrow m|\psi = m'|\psi).$$

That is, if any two structures in α agree on the references they assign to the ϕ terms; i.e., their restrictions to the ϕ vocabulary are identical; then they agree on the references they assign to the ψ terms; i.e., their restrictions to the ψ vocabulary are identical.[15]

A question concerning the relative strength of these notions remains: What is the connection between (4) and (5)? Perhaps sur-

[14] If α is closed under automorphic images, then (5) is equivalent to the condition that any bijective map between domains of m amd m' which is a ϕ-isomorphism is a ψ-isomorphism. Otherwise the latter requirement may be stronger, depending on α. An analogous point has been noted by J. Earman in his discussion of Montague's treatment of determinism in physics in "Laplacian Determinism, or Is This Any Way to Run a Universe?" this JOURNAL, LXVIII, 21 (Nov. 4, 1971): 729–744, p. 738, n. 11.

[15] One further type of determination principle along these lines is interesting, that of ϕ-reference determining ψ-truth in α structures. This is weaker than (4) but still makes a substantial determination claim. It allows us to exploit our presumed confidence in the scientific respectability of the determining vocabulary ϕ—confidence that its terms clearly refer to elements in a well understood part of our ontology—without our needing to grant a similar respect for the vocabulary of ψ. We grant that the vocabulary of ψ can be used to state truths, truths which are determined by the referential facts in ϕ terms, without claiming that the references of the ϕ terms precisely determine references for the ψ terms as well.

prisingly, the answer is "none." As they stand, they are model-theoretically independent: there are α, ϕ, and ψ such that, in α structures, ϕ reference determines ψ reference but ϕ truth does not determine ψ truth. The commonplace about reference determining truth does not here apply. Yet, for an extremely important class of structures, those sets consisting of all and only the models of some theory T, (5) so restricted does imply (4).

If ϕ is construed as the vocabulary of mathematical physics, ψ as *all* the vocabulary by means of which truths can be stated, and α as a set of structures representing scientific possibility, then (4) and (5) constitute *Principles of Physical Determination*.

If α is to represent scientific possibility, it must at least be the case that every member of α models all the laws of science. The question can then be raised whether this condition is sufficient as well as necessary. If it were, we could in every occurrence simply replace 'α' by '$\{m{:}m$ models $T\}$' where T is the whole of scientific theory, or (more elegantly) reformulate our principles of physical determination directly to refer to this body of theory.

In the next section we shall argue that there is reason to believe that scientific theory, at least insofar as it is formulable without recourse to an infinitary language, has models which would *violate* principles of physical determination and which therefore, assuming as we do that principles of physical determination hold, must be excluded by other means. Fortunately, simple means are available to this end which allow us to construct (instead of assume as an unanalyzed primitive) the requisite notion of scientific possibility.

2. *Reduction and Determination.* If for simplicity we assume that our language contains only predicates as nonlogical terms (an assumption which can easily be relaxed), then

> A primitive n-place predicate P is definable in terms of a vocabulary ϕ in α structures
>
> iff
>
> there is a (finite) sentence A containing no nonlogical terms not in ϕ and with occurrences of n distinct variables, $x_1, \ldots, x_n$, such that every structure in α models $(\forall x_1) \ldots (\forall x_n)(Px_1 \ldots x_n \leftrightarrow A)$.[16]

It should be noted that definability claims are nor *per se* claims of synonymy. Definability is a clear notion; synonymy is not. But neither are they simply claims of coextensiveness. As before, α is to be a set of structures representing scientific possibility; at a mini-

[16] The order of the quantifiers should be noted: It is not simply that, in each structure in α, P is coextensive with *some* primitive or complex term formulated in ϕ terms; rather, more strongly, there is a term formulated in the ϕ vocabulary such that P is coextensive with it in *every* structure in α.

mum, every member of α is a model of the laws of science. Definability is thus a kind of lawlike coextensiveness.

The notion of reducibility with which we are here concerned is that obtaining when all the terms of the vocabulary to be reduced are definable in the reducing vocabulary. That is,

(6) In α structures, ϕ reduces ψ
iff
$(\forall P)(P \in \psi \rightarrow P$ is definable in terms of ϕ in α structures).[17]

If ϕ is construed as the vocabulary of mathematical physics, ψ as *all* the vocabulary by means of which truths can be stated, and α as a set of structures representing scientific possibility, then (6) constitutes the Principle of Physical Reductionism. (A more stringent notion, which one might call "effective reducibility," would require that every term in the reduced vocabulary be definable in a recursively enumerable set of definitions.)

Although some assumption as to the mathematical-physical determination of all truth and, probably, all reference is a regulative principle of scientific theory construction, a general assumption of the reducibility of all terms (and thus, all theory) to mathematical-physical terms (and thus, theory) is unwarranted and probably false. The physicalism that appears plausible has two components: ontological physicalism—the Principle of Physical Exhaustion—and Physical Determinationism, a unified thesis which we choose to call *Physicalist Materialism.*

A word is here in order extending our earlier point that ontological physicalism is formally independent from reductionism. As a moment's reflection on "parallelism" will verify, ontological physicalism is likewise independent from physical determinationism. This will, however, give no comfort to dualists. In the absence of positive arguments for extra entities, Occam's razor (sound scientific procedure) will dictate commitment to the sparser ontology. And, physical determination being given, such positive arguments would seem difficult if not impossible to find.

[17] Although this notion of reduction applies directly to the linguistic primitives of the language reduced, it extends in a natural way also to the sentences, including the laws, formulated in that language: If in α structures, ϕ reduces ψ, then every law formulated in whole or in part in ψ terms (including the "bridge" laws) is a definitional equivalent of a law formulated in purely ϕ terms. Thus reduction of terms implies reduction of laws, and thus, for example, physicalist reduction is incompatible with nonontological "emergence" theses which claim that, although evolution adds no nonphysical entities to the universe, it does introduce lawlike regularities that can be captured only by nonphysical laws. (A weaker "epistemological" emergence thesis, which claims only that the physical reductions of laws formulated in the nonphysical vocabulary will be independent of the physics previously known, is not excluded.)

This is not the place to argue the truth of this version of physicalism. The aim is to characterize the position so as to make evident its plausibility and consistency, and, further, to make clear the independence of any and all these principles (ontological and determinationist) from physical reductionism and even from the mere coextensiveness of nonphysical with physical terms. Therewith it will have been demonstrated that anti-reductionist arguments are irrelevent to the truth of physicalism.

That such a position has not been previously, to our knowledge, presented in the relevant literature, is surprising. Ontological physicalism and anti-physical reductionism are both widely held, and many have hinted at notions like physical determinationism. To be sure there is an argument, based on an application of Beth's renowned definability theorem, which might appear to render simultaneous support for determinationism and anti-reductionism impossible. But it seems unlikely that his argument has dissuaded many, since, once again to our knowledge, this argument has not been previously noticed.

Beth's theorem shows the equivalence of what logicians have long distinguished as implicit and explicit definability in a theory. All the terms in ψ are *implicitly defined* by the terms in ϕ, in a theory T, just in case

$$(\forall m)(\forall m')((m,m' \text{ model } T \;\&\; m|\phi = m'|\phi) \rightarrow m|\psi = m'|\psi)$$

that is, just in case

$$(\forall m)(\forall m')((m,m' \in \{m{:}m \text{ models } T\} \;\&\; m|\phi = m'|\phi) \rightarrow m|\psi = m'|\psi)$$

This is of course an instance of (5), and thus equivalent to

(7) In $\{m{:}m$ models $T\}$ structures, ϕ reference determines ψ reference.

All the terms in ψ are *explicitly defined* by the terms in ϕ, in a theory T, just in case

(8) In $\{m{:}m$ models $T\}$ structures, ϕ reduces ψ.

Thus what Beth's theorem shows is that (7) and (8) are model-theoretically equivalent (where T is a first-order theory of a noninfinitary language), that is, that with respect to sets of structures which are all and only the models of (such) a theory, determination of reference is equivalent to reducibility.

But, in the general case in which the set of structures α is not necessarily all and only the models of some theory T, determination of reference is not equivalent to reducibility. Although (6) entails (5), the converse does not obtain. Thus if one holds that some models of the laws of science are "nonstandard" models that do not represent scientific possibilities, then one can endorse principles of physical determinationism including determination of reference without claiming that all scientific facts are reducible to the mathematical-physical.

Nor does such a position commit one to accepting the notion of scientific possibility as an unexplicated primitive. One can specify α as that subset of the models of the laws of science in which certain predicates receive standard interpretations. One can require, for example, that the vocabulary of pure arithmetic receive its standard interpretation, thus specifying a set of structures representing scientific possibility which, as is well known, is not capturable as all and only the models of a first-order theory in a noninfinitary language, even when the theory itself fails to be recursively enumerable in virtue of containing every truth of arithmetic.

Which models of the laws of science must be excluded in order to delineate a set of structures representing scientific possibility is itself a scientific question. Further mathematical notions, e.g., set-theoretic, may plausibly be held standard, likewise resulting in a set of structures not capturable as all and only the models of a theory.[18]

The syntactically specifiable notion of a theory plays a crucial role in the Beth theorem and hence in the subcase in which determination and reducibility are equivalent. The absence of a general equivalence between determination and reducibility is somewhat clarified if it is noticed that the notion of reducibility is essentially tied to that of theory but determination is not. Reduction requires the existence of syntactic entities, the definitions, which license the elimination in principle of certain theory and description.[19]

[18] There is an obvious connection between this issue and those raised by Kripke concerning rigid designation and Lewis concerning counterparts. Cf. *supra*, n. 14.

[19] Thus if in α structures, ϕ reduces ψ, there is an easily specifiable theory (not necesssarily recursively enumerable) within which every definition composing the reduction of ψ to ϕ is provable. This is true whether or not α, the set of structures to which the reduction is relativized, is itself directly specifiable as the models of such a theory. Given α, we can specify the theory

$$\bigcap\{\gamma\colon (\exists m)(m \in \alpha \;\&\; m \text{ models } \gamma)\}$$

that is, the intersection of the theories of each of the models in α, a theory which contains every definition required for the reduction of ψ to ϕ. In fact (6) is *equivalent* to

$$\text{In } \{m\colon m \text{ models } \bigcap\{\gamma\colon (\exists m')(m' \in \alpha \;\&\; m' \text{ models } \gamma)\}\},\ \phi \text{ reduces } \psi.$$

That is, if reducibility holds for a set of structures, then, and only then, it holds for the set of models for all sentences true in each member of that set of structures, even though the former may be a proper subset of the latter. No such principle holds for determination; determination with respect to α can coexist with indetermination with respect to the set of all structures modeling every sentence true in every member of α.

Determination, in contrast to reducibility, has nothing directly to do with the existence of a theory containing or permitting the proof of certain kinds of sentences. To emphasize the extreme, the determination of ψ reference by ϕ reference in α structures is compatible with *no* term in ψ being even *accidentally* coextensional with a term constructed out of the ϕ vocabulary. That is, (5) does not entail that an instance of (6) holds where α in the latter formula is replaced by a reference to (the unit set of) some member of α.

In summary, it has been shown how to construct both the ontological principle of physical exhaustion and independent principles of physical determination which together, it is submitted, constitute the major claims of physicalism. The principle of the physical determination of reference threatened to collapse to reducibility in view of Beth's definability theorem. However, as the work of Gödel and others would suggest, the power of our symbolic systems is such that full theoretical characterization of scientific possibility in any manner that would license the inference from determination to reduction is not to be expected.

For some purposes, the prevalence of nonstandard interpretation, the powerlessness of our most useful theories directly to pin down the possible, are grounds for discouragement. From a certain perspective, however, the present case is entirely the opposite. Physicalism in no way dictates the course of progress in the higher-level sciences. Reductions are indeed frequently constitutive of such progress. But the truth of physicalism is compatible with the utter absence of lawlike or even accidental generalized biconditionals connecting any number of predicates of the higher-level sciences with those of physics.

Finally, without specifying the forms of laws to be sought by the higher-order sciences, the principles of physicalism here sketched do, it is suggested, play a regulative role. They do so by incorporating certain standards of adequacy—exhaustiveness of ontology, and determination of truth and reference—by which the claims of a physics as a comprehensive and most fundamental level of scientific theory may be assessed. These principles constitute a substantive and realistic sense for the goal of unity of science.

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