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IMPLICATIONS OF CARNAP'S WORK FOR THE PHILOSOPHY OF SCIENCE

I. Reduction Vs. Definition

In the present essay, I intend to discuss some of Carnap's contributions to the philosophy of science, with special emphasis upon his inquiries into the status and function of scientific concepts and theories.

Carnap's theory of reduction sentences[1] offers a convenient access to our topic. That theory, it will be recalled, rejects the earlier view of the Vienna Circle, previously held also by Carnap himself,[2] that all extra-logical terms in the language of empirical science are capable of explicit definition on the basis of observation terms referring to directly observable aspects either of immediate phenomenal experience or of physical objects or events. This idea is replaced by the conception that, in general, the meaning of a scientific term permits of only partial specification by reference to observables; or, more precisely, that scientific terms have to be thought of as introducible, on the basis of an observational vocabulary that is antecedently understood, not by means of explicit definitions alone, but rather by a more general method called reduction. Just as definition is effected by means of definition sentences so reduction is achieved by sentences of a special kind, called reduction sentences; these have to meet certain formal and material requirements specified in Carnap's theory. For later reference, I give here a brief summary of those requirements.

The standard instrument of reduction is the reduction pair. A reduction pair introducing a one-place predicate '*Q*' consists of two sentences of the form

(1.1) $P_1x \supset (P_2x \supset Qx)$

$P_3x \supset (P_4x \supset -Qx)$

If '*Q*' is to be introduced on the basis of a given vocabulary *V*, then the

[1] This theory is developed in detail in TM; its central idea is outlined already in ES, and a brief elementary survey is included in LFUS.

Abbreviated titles used throughout the footnotes refer to the bibliography at the end of this may.

[2] Especially in *Aufbau*; cf. Carnap's own reference to this fact in TM, §15.

predicates other than 'Q' which appear in these sentences must either belong to V or must have been previously introduced by other reduction sentences which ultimately use only the vocabulary V. The appropriately ordered set of those reduction sentences is then said to form an introductive chain based on V.

In the special case where 'P_3' is equivalent with 'P_1' and 'P_4' with '$-P_2$', the reduction pair (1.1) may be cast into the form of a so-called bilateral reduction sentence:

(1.2) $P_1x \supset (Qx \equiv P_2x)$

and in the even more special case where 'P_1x' is universally satisfied, (1.2) may be replaced by an explicit definition sentence:

(1.3) $Qx \equiv P_2x$

A fundamental difference between definition and reduction is this: A definition sentence for 'Q' provides a condition, in terms of the given vocabulary, which is both necessary and sufficient for Q and thus makes it possible to eliminate 'Q' from any sentence in favor of its definiens. A reduction pair or a bilateral reduction sentence provides a sufficient condition and a necessary condition for Q; but the two do not coincide; thus the meaning of 'Q' is specified only incompletely, and the specifying sentences do not permit the elimination of 'Q' from all contexts in which it may occur.

The reduction pair (1.1) for example, provides the following conditions for Q:

(1.4) $(P_1x \bullet P_2x) \supset Qx$

$Qx \supset -(P_3x \bullet P_4x)$

These sentences specify only that the extension of 'Q' must fall between those of '$P_1 \bullet P_2$' and '$-(P_3 \bullet P_4)$' in the sense of including the former and being included in the latter; and unless those two extensions coincide, this determines the range of application of 'Q' only in part. In other words, (1.4) directs us to apply 'Q' to all instances of '$P_1 \bullet P_2$' and '$-Q$' to all instances of '$P_3 \bullet P_4$'; for all other cases, the question whether 'Q' or its negate applies is left open.

Suppose now that by virtue of some laws of nature, no object can be an instance of either of the two expressions just stated; in other words, suppose that

(1.5) $(x)-((P_1x \bullet P_2x) \vee (P_3x \bullet P_4x))$

holds by virtue of laws of nature. Then the criteria provided by (1.1) for the attribution of 'Q' can never be applied, and not even a partial specification of the meaning of 'Q' has been effected. Now, this possibility cannot be avoided altogether, simply because we do not know all the laws of nature. But surely it would be unreasonable to accept (1.1) as a reduction pair for 'Q' if (1.5) is a consequence of the scientific theory into which

'*Q*' is to be introduced. Carnap therefore lays down a restrictive condition which may be stated as follows:

(C) The sentences (1.1) form a reduction pair only if (1.5) is not valid,[3] i.e., is not true solely by virtue of the L-rules and P-rules governing the language in which (1.1) is formulated.

By L-rules, Carnap here understands the purely logical rules of inference; by P-rules, any additional rules that may be established by adopting certain physical statements, especially statements presumed to express universal laws, as primitive sentences of the language.[4] At the time when he set forth these ideas, Carnap considered it as a mere question of expedience which, if any, empirical statements should be given this privileged status;[5] but as the preceding argument shows, restriction (C) will serve its purpose only if it implies the following condition:

(C′) The sentences (1.1) form a reduction pair only if it is not the case that (1.5) holds by virtue of the statements which the theory at hand asserts as laws, irrespective of whether they have the status of P-rules.

One more point remains to be noted. The pair (1.4), and consequently also (1.1), evidently implies the sentence

(1.6) $(x)\ (P_1x \bullet P_2x \supset -(P_3x \bullet P_4x))$, or, equivalently,
$(x)-(P_1x \bullet P_2x \bullet P_3x \bullet P_4x)$

Carnap calls this the representative sentence of the reduction pair (1.1); it "represents, so to speak, the factual content" of the latter.[6]

The method of reduction outlined in this section can readily be extended to the cases where the term to be introduced is a predicate with more than one argument or a functor representing a quantitative characteristic, such as length.

II. Reduction and the Problem of Nomological Statements

Carnap's thesis that not all scientific terms are definable by means of observational predicates was based on his well-known analysis of disposition terms. Thus, he argued that the predicate 'soluble in water' cannot be introduced by what might appear to be the obvious definition, namely,

(2.1) $Sx \equiv (t)\ (Wxt \supset Dxt)$

where 'Sx' stands for 'x is soluble in water', 'Wxt' for 'x is put in water

[3]TM, 442.

[4]TM, 432 and LSL, sec. 51.

[5] LSL, 180.

[6]TM, 451; see also *ibid*., 444. It would seem, incidentally, that the following further requirement should be laid down for reduction sentences: An introductive chain is permissible only if its representative sentence is compatible with the theory into which it is to introduce a new term. Otherwise, the introduction of a new term might make a theory inconsistent

at time *t*', and '*Dxt*' for '*x* dissolves at *t*'; for on this definition, any object that is never placed in water would have to be pronounced soluble; clear. ly, this is one aspect of the "paradoxes", of material implication. The difficulty is avoided if '*S*' is introduced by a bilateral reduction sentence:[7]

(2.2) $(x)\ (t)\ (Wxt \supset (Sx \equiv Dxt))$

Now, underlying the attempt to define '*S*' by (2.1) is the idea that to attribute solubility, or any other disposition, to a given object is to as. sert that under specifiable conditions, the object will, as a matter of general law, respond in a certain characteristic manner. The attribution of dispositions is thus intimately bound up with the assertion of laws, as has been made increasingly clear by recent studies, especially those dealing with counterfactual conditionals. An explicit definition of '*S*' could be given if, in stating the intent of (2.1), we had some satisfactory way of specifying that '*S*' is to apply to just those cases *x* for which the definiens in (2.1) is not simply true, but true by virtue of general laws. The "paradox" just mentioned would then be avoided because the mere information that a given object, say *c*, is at no time put in water would suffice to establish

$$(t)\ (Wct \supset Dct)$$

as an empirical truth only, but not as true by virtue of general laws. The use of causal modalitiess has been contemplated for the assertion. of truth by virtue of general law; but no matter what symbolic techniques might be used for the purpose, they will be satisfactory only if it is possible to clarify the meaning of the locution "such and such is the case by virtue of general laws". To attain such clarification, it will be necessary to explicate the concept of general law or the concept of lawlike, or nomological, sentence, i.e., of a sentence which has the character of a general law except for possibly being false. So far, these concepts have proved highly resistant to analytic efforts.[9] And even if this problem is solved, there remains the further task of explicating the phrase "by virtue of general laws"; and this presents considerable further difficulties because the phrase refers not only to some suitable set of laws, but tacitly also to a set of initial and boundary conditions which, together with the laws, imply the statement said to be true by virtue of general laws.

At first glance, Carnap's method of using reduction sentences instead of definitions seems to avoid all these obstacles. Actually, however, I think that method, too, involves reference to the nomological concepts just con-

[7] TM, 440-441.

[8] See, for example, Burks, CP.

[9] On this problem, see Braithwaite SE, ch.9;Goodman, Cf; Hempel and Oppenheim LE, Part III; Reichenbach, NS. A promising novel approach to the problem of nomo- logicals is propounded in Goodman's FFF.

sidered. For, first of all, as was argued above, Carnap's requirement (C) must be construed so as to imply condition (C′), which clearly makes use of those concepts; and, in addition, Carnap would no doubt agree that a reduction pair can be admissible only if its representative sentence has the character of a statement that holds by virtue of general laws; it would be this lawlike character of its "factual content" that would justify the acceptance of the reduction pair.

For these reasons I think that the method of reduction neither resolves nor avoids the basic problem which gives rise to the difficulty pointed out by Carnap in regard to the definition of disposition terms; for that basic problem concerns the explication of the concepts of nomological statement and of truth by virtue of general laws.

III. *Reduction Vs. Operational Definition*

The great significance of Carnap's theory of reduction seems to me to lie in the fact that it initiated, and developed in considerable logical detail, a decisive departure from the earlier logical positivist insistence on the full verifiability or falsifiability, of every "cognitively significant" empirical statement by some suitable finite set of observation statements, and on the full definability of all scientific terms by means of an observational vocabulary.

That the definability requirement may be too restrictive is suggested not only by the difficulties encountered in an attempt to define disposition terms: Even if we had a satisfactory way of dealing with nomologicals—a proviso which will no longer be mentioned from here on—there would be other considerations indicating that most scientific terms should be construed as only partly defined by means of observables.

First of all, as has often been stressed in the operationist literature, an operational "definition" determines the meaning of a scientific term only with respect to the class of those cases to which the specified operational criteria are applicable; thus, e.g., the interpretation of length by reference to rigid measuring rods cannot be applied directly to microscopic or to interstellar distances. Carnap's reduction sentences offer a convenient schema for such partial operational specification of meaning.

Furthermore, for a given scientific term, there usually are available a variety of alternative "operational" criteria of application, and advances in scientific research tend to add to their number. This consideration suggests that the various criteria available for a term may be combined into one introductive chain, and that, as a rule, such a chain, however rich, will still leave room for additional partial interpretations of the term at hand. Scientific terms exhibit, in this sense, an openness of content, which is well represented if their introduction is construed as being effected by chains of reduction sentences.

Thus, Carnap's theory of reduction takes into account, and affords a logical analysis of, certain aspects of scientific concept formation which have been thrown into relief also by operationism. In doing so, it yields an explication and generalization of the suggestive but extremely vague operationist conception of definition in terms of "symbolic" and "instrumental" operations. This is achieved by Carnap's precise characterization of the sentence chains effecting the introduction of scientific terms. Reference to "mental", "paper-and-pencil", and other "symbolic" operations is here replaced by specification of the logical form of reduction sentences, and of the logical and mathematical principles governing their use. And the demand that operational definition must ultimately refer to "instrumental" operations is restated in a more general manner which avoids the suggestion that operational criteria must make reference to physical manipulation. This is done by specifying that the basic vocabulary to which scientific terms are reduced consists of observational predicates, which can be applied on the basis of direct observation, and with good intersubjective agreement, by different observers.

In one respect, however, this explication of operationist ideas deviates essentially from the conceptions advanced by P. W. Bridgman, the originator of the idea of operational analysis. Bridgman has repeatedly insisted that every scientific term should be introduced by one single operational criterion of application. Even when two different procedures (e.g., optical and tactual methods of measuring length) have been found to yield the same results, they should be regarded, according to Bridgman, as specifying different concepts (e.g., optical and tactual length); and these should be distinguished terminologically, for the presumption that both methods yield the same results is based inductively on past evidence, and it is "not safe" to forget that new, and perhaps more precise, experimental findings may prove it spurious.[10]

Now, acceptance of two different criteria of application for one term does indeed commit us to a universal generalization which later findings may induce us to abandon. In the case of a reduction pair, that generalization is given by its representative sentence. But the inductive risk incurred in accepting it does not constitute sufficient grounds to accept Bridgman's position. For even when a term is used on the basis of just one operational criterion, its application to any one particular case already amounts to asserting a generalization. Thus, e.g., one of the operational criteria of application for the phrase "piece of mineral x is harder than piece of mineral y" is given by the scratch test: A sharp point of x must scratch a surface of y, but not conversely. But this criterion has universal form: *Any* sharp point that exists or might be produced on x

10 Cf. Bridgman, LMP, 6 and 23-24; OA, 121-22; PC, 255.

must scratch *any* flat surface that exists or might be produced on *y*. Therefore, to assert of just one particular piece of mineral that it is harder than a certain other piece of mineral is to assert a generalization and thus to incur an inductive risk. Hence, the standard invoked in Bridgman's argument would disqualify as "not safe" even the application, to just one single instance, of a concept introduced by just one single operational criterion of application.[11]

Thus, the promise of inductive safety which Bridgman's procedure holds out in return for an enormous proliferation of terms proves specious, and it appears to be both more economical and more in keeping with scientific procedure to allow a scientific term several criteria of application. This is precisely the conception systematically developed in Carnap's theory of reduction.

Accordingly, introductive chains fuse two functions of language which have often been considered totally distinct: the specification of meanings and the description of facts. And indeed, the introduction of fruitful new concepts in science is always intimately bound up with the establishment of new laws, as is shown quite clearly already in Carnap's early little work, *Physikalische Begriffsbildung*, which presents a lucid elementary analysis of the operational and the logical aspects of concept formation in physics.

IV. *Interpretative Systems*

But once we grant the conception of a partial experiential interpretation of scientific terms through a combination of stipulation and empirical law, it appears natural to remove the limitations imposed by Catnap upon the form of reduction sentences and introductive chains. Suppose, for example, that the predicate 'Q' has been introduced by the sentence (1.2), and that then, in view of supporting empirical evidence, the general sentence

$$(x)\ (Qx \supset P_3x)$$

is added to the theory at hand. This broadens the range of interpretation for 'Q'; for while (1.2) enables us to apply 'Q' or its negate only to objects which have the property P_1, the new sentence makes the negate of 'Q' applicable to any object with the characteristic '$-P_3$', no matter whether it also possesses P_1. Thus, though the new sentence does not have the form of a bilateral reduction sentence or of a reduction pair, it provides an additional criterion of application for 'Q'. And generally, addition of a new sentence to a given theory will usually affect the possibilities of (affirmative or negative) application of some of the theoretical terms.

[11] A fuller statement of the observations here outlined on operationism is given in Hempel, AO, secs. 1, 2, 3.

This reflection militates in favor of broadening the conception of introductive or interpretative sentences, and indeed, Carnap's own writings contain several specific suggestions to this effect. Already in *The Logical Syntax of Language*, Carnap mentions the possibility of introducing "a new descriptive symbol . . . as a primitive symbol by means of new P-primitive sentences,"[12] i.e. by the specification of extra-logical postulates involving the term in question. In a later study of the logic of physical theories, Carnap specifically describes an alternative to the introduction of "abstract", i.e., theoretical, terms on the basis of "elementary" or observational ones; namely, the formulation of a physical theory as an axiomatized system whose primitive terms are highly abstract, and in which less abstract terms, and finally elementary terms amounting to an observational vocabulary, are then introduced by explicit definition.[13] —And more recently, Kemeny and Carnap have proposed a method of partly determining the meaning of a set of terms by the specification of suitable "meaning postulates", which limit the range of the possible interpretations of the terms in question.[14]

The following, more general, conception of interpretation is constructed in such a way as to include all these procedures, as well as the use of introductive chains, as special cases.

(D 4.1) Within a specified framework, let T be a theory characterized by a set of postulates in terms of some finite set of primitives, V_T, which will be called the *theoretical vocabulary*; and let V_B be a second set of terms, to be called the *basic vocabulary*, which shares no term with V_T. A finite set J of sentences will then be said to constitute an interpretative system for T with the basis V_B if (a) J is logically compatible with T; (b) J contains no extra-logical term that is not an element of V_B or V_T; (c) J contains every element of V_B and V_T essentially, i.e., J is not logically equivalent to some set of sentences in which at least one term of V_B or of V_T does not occur at all.

For example, the logical framework might be that of the first-order functional calculus with identity; all the theoretical terms, predicates of various degrees; the basic terms, predicates which are antecedently understood, and which refer to directly observable physical properties and relations. This is, in fact, one of the principal cases with which Carnap's theory of reduction is concerned.

As a rule, an interpretative system will not be purely stipulative in character; it will usually imply sentences in terms of V_B alone which are not logical truths within the given frame. The representative sentences of introductive chains illustrate this possibility.

[12] LSL, 819.
[13] FLM, sec. 24.
[14] Kemeny, Rev and EM; Carnap, MP.

In what sense, and to what extent, does an interpretative system specify an interpretation of *T*? We will consider first the interpretation of the *terms* in V_T and then that of the *sentences* expressible by means of them.

For a given theoretical term, an interpretative system *J* may establish a necessary and sufficient condition in terms of V_B. For a one-place theoretical predicate '*Q*', for example, this is the case if *J* logically implies a sentence of the form

(4.2) $$(x)\,(Qx \equiv Kx)$$

where '*Kx*' is short for a schema containing 'x' as the only free variable, and containing no extra-logical constants other than those in V_B. One might be inclined, in this case, to say that (4.2) provides a translation, or even a definition, of '*Q*' in terms of V_B; but it should be borne in mind that for the same predicate '*Q*', the system *J* may well provide several sentences of the form (4.2), with "translations" or "definientia" which are not logically equivalent, but only equivalent relative to *J*, in the sense that any one of them is deducible from any of the others conjoined with *J*.

But it may be the case that for a given theoretical term, *J* establishes only a necessary and a different sufficient condition in terms of V_B, or just one of these kinds of condition; and finally, for some or even all of the theoretical terms, *J* may establish neither a necessary nor a sufficient condition in terms of the basic vocabulary.

We now turn to the interpretation given by *J* to those sentences which are expressible in terms of V_T alone, no matter whether they belong to *T* or not; any such sentence will be called a V_T-sentence.

For a sentence *S* of this kind, *J* may yield an "equivalent" in terms of V_B; i.e., there may be a sentence *S′* in terms of V_B alone such that *J* logically implies the biconditional[15]

(4.3) $$S \equiv {\sim}S'$$

This will be the case, for example, whenever *J* provides an "equivalent", in the sense of (4.2), for each of the extra-logical terms in *S*.

A biconditional of type (4.3) might be viewed as affording a translation of *S* into the basic vocabulary; but again it must be remembered that in this sense, a V_T-sentence may have several translations which are not logically equivalent.

In some cases, *J* will provide, for a given V_T-sentence, a necessary condition and a different sufficient condition in terms of V_B, or just one of these, or neither a necessary nor a sufficient condition.

We must now consider certain objections which have been raised

[15] Here as well as in a few other places in this essay, connective signs are used autonymously.

against the introduction of theoretical terms by means of reduction sentences, and which can be extended to the more general conception of interpretation here suggested.

In reference to introductive chains, the criticism may be put as follows: Let '*Q*' be a predicate introduced solely by the bilateral reduction sentence (1.2), and let *c* be some particular object. Consider the expression '*Qc*'. If *c* happens not to have the property P_1 then *c* belongs to the class of objects within which no meaning has been assigned to '*Q*'. Hence '*Qc*' is not a meaningful sentence; not, as a consequence, is its negation. Therefore, also '*Qc* v -*Qc*' is meaningless rather than a truth of logic, and in a similar way other principles of logic break down when applied to sentence-like expressions containing '*Qc*' as a constituent. If, on the other. hand, *c* does have the property P_1, none of these dire consequences arise. But whether *c* does or does not have the property P_1 is a factual question; hence, the admission of predicates introduced by reduction sentences seems to make the significance of sentences and the applicability of the principles of logic contingent upon matters of empirical fact. Now, it is by no means impossible for a language to have this characteristic; in fact, it appears to be quite a normal aspect of everyday discourse, where significance often depends upon empirical aspects of the given context. Yet, in a formalized language for the use of science, this feature would be very awkward indeed.

This awkwardness can be avoided, however, by specifying, for the language system at hand, purely syntactical rules of sentence formation and logical inference. These rules may be chosen in the familiar. manner so as to qualify both '*Qc*' and '-*Qc*' as well-formed formulas, or sentences, and to countenance the applicability of all the usual rules of inference to sentences containing them-irrespective of any semantical questions, such as whether 'P_1c' is true or not.

But can those sentences be considered not only as properly constructed formulas of what Carnap would call the calculus underlying the theory, but also as significant statements each of which is either true or false? If for a given V_T-sentence *S*, the interpretative system *J* yields no equivalent V_B-sentence, then we cannot state a truth criterion for *S* (i.e., a necessary and sufficient condition for the truth of *S*) in terms of that part of the scientific vocabulary which was assumed to be antecedently understood. But in that event, is it possible at all to understand the sentence *S* and significantly to assert or to deny it?

In considering the issue of the "significance" of partially interpreted theoretical sentences, we will have to distinguish three concepts of significance, which may be roughly characterized as (a) pragmatic intelligibility; (b) empirical significance in the vague sense of relevance to potential empirical evidence expressible by means of V_B; (c) semantical significance in the sense of being true or false. We will now briefly examine theoretical sentences in these three respects.

A scientist understands the language of the theories in his field even though he is not able to give, for each theoretical expression, an equivalent in, say, the "observational" terms used in laboratory reports. He knows how to use the terms and sentences of the theory and how to connect them with expressions in terms of the observational vocabulary. In a formal reconstruction, the proper "how to" is expressed by the rules governing the use of the various expressions. In the case of the expressions that can be formed by means of V_T, those rules include the rules of the logical framework within which *T* is formulated, and the inferences made possible by the interpretative system *J*. These rules, we noted earlier, will not in general provide every V_T-expression with an equivalent in terms of V_B, but they may convey upon a V_T-sentence *S* empirical significance in the sense of enabling *S* to establish deductive connections among certain V_B-sentences. And the establishment of such connections, which permit the prediction of new empirical phenomena on the basis of given ones, is one of the principal functions of scientific theories. As a brief reflection shows, *S* will have this characteristic just in case *S* in conjunction with *J* logically implies at least one V_B-sentence which is not implied by *J* alone. It would be quite ill-advised, however, to require of a scientific theory that every one of its sentences which is not a purely logical truth must individually possess empirical significance in this sense; what matters is the capacity of the whole theory to establish connections, by virtue of *J*, among the empirical V_B sentences, and this capacity may be high even when many sentences of *T* lack individual empirical import.

To turn, finally, to the question of semantic significance: Let *T* be interpreted by a system *J* which does not furnish for every V_T-sentence an equivalent in terms of V_B. Then it is nevertheless quite possible to provide a necessary and sufficient condition of truth for every sentence expressible in terms of the theoretical vocabulary. All that is needed for the purpose is a suitable metalanguage. If we are willing to use a metalanguage which contains V_B, V_T, and *J*, or translations thereof, then indeed each V_T-sentence has a truth criterion in it, namely simply its restatement in, or its translation into, that metalanguage. Carnap has made essentially the same point in regard to the possibility of stating semantical rules of designation for the terms of a theory with only partial observational interpretation.[16] Incidentally, this observation bears upon a controversial issue in recent methodological discussion: It reveals as futile the attempt to base a distinction between genuine theoretical

[16] FLM, 62.

constructs and mere intervening or auxiliary terms on the idea that the former but not the latter have "factual reference", or designata in the semantical sense.[17]

Let us note here with Carnap[18] that the semantical criteria of truth and reference which can be given for the sentences and for the terms, or "constructs", of a partially interpreted theory offer little help towards an understanding of those expressions. For the criteria will be intelligible only to those who understand the metalanguage in which they are expressed; and the metalanguage must contain either the theoretical expressions themselves or their translations; hence, the latter must be antecedently understood if the semantical criteria are to be intelligible. Fortunately, however, a partially interpreted theory may be understood even when full semantical criteria of truth and reference are not available in a language which we previously understand. For if we know how to use the terms of V_B we may then come to understand the expressions in terms of V_T by grasping the rules which govern their use and which, in particular, establish connections between the "new" theoretical vocabulary and the "familiar" basic one.

V. *On the Avoidability of Theoretical Terms in Science*

If scientific theories establish predictive connections between the data of experience, and if it is only by reference to such data that their soundness can be appraised, why could not the formulation of theories be limited to the vocabulary which is used to state the pertinent empirical data? Might not the use of theoretical terms be entirely avoided without prejudice to the objectives of science?

The idea of avoidability here invoked requires clarification. We will distinguish three conceptions of avoidability which have received attention in recent methodological research. They are arranged in order of increasing inclusiveness: Whenever (a) applies then so does (b), and whenever (b) applies then so does (c), whereas the converses of these statements do not hold.

(a) *Definability*. The terms of a theory T might be said to be avoidable if they are all definable in terms of a specified observational vocabulary, V_B.

(b) *Translatability*. The terms of T might be said to be avoidable if every V_T-sentence is translatable into a V_B-sentence.

(c) *Functional replaceability*. The terms of T might be said to be

[17] For presentations and critical discussions of this idea, see, for example, MacCorquodale and Meehl, HC; Feigl, EH; and the discussion *of* the latter article, with reply by Feigl, in the symposium "Existential Hypotheses" in *Philosophy of Science*, XVII (1950), 164-195.

[18] FLM, 62.

avoidable if there exists another theory, T_B, couched in terms of V_B, which is "functionally equivalent" to T in the sense of establishing exactly the same deductive connections between V_B-sentences as does T.

The ideas of positivism and physicalism as dealt with in Carnap's writings are directly pertinent to the questions of definability and translatability. The earlier form of the positivistic thesis, espoused by Carnap in *Der logische Aufbau der Welt*, asserted that every extra-logical term of empirical science is definable by means of perception terms and that, as a consequence, every sentence in the language of science is translatable into a sentence in terms of perception predicates. When Carnap developed his theory of reduction, he replaced this conception by the weaker one that all scientific terms are reducible to perception terms; as a consequence, the translatability thesis was abandoned.[19] Concomitantly, Catnap propounded an analogous revision of the earlier version of the physicalistic thesis, which asserted the definability of all terms of empirical science by means of the observational and theoretical vocabulary of physics, and which implied a corresponding thesis of translatability. The revised version maintains instead that all extra-logical terms in the language of empirical science are reducible to the physical vocabulary, and thence in turn to those terms in the language of physics which stand for directly observable properties or relations of physical objects.[20]

But to what extent "definitions", "translations", and reductions of the kind here contemplated are possible can be ascertained, in general, only by means of empirical research and not by logical analysis alone. In the case of definability, for example, the question at stake is not whether all scientific terms are in fact introduced by explicit definition in terms of observables; patently, they are not. The question is rather whether suitable definitions could be constructed. And this is a matter of extending the system of accepted scientific statements in such a way that it will imply, for every theoretical term *t*, a universal statement analogous to (4.2) which provides a necessary and sufficient condition for t in terms of observables; for the extended system of accepted scientific statements could then be reformulated in such a way as to give to those statements the status of definitions for the theoretical terms. And whether or to what extent the requisite extension of current scientific knowledge can be achieved will have to be determined on the basis of empirical research. In regard to translatability, the empirical aspect of the problem is reflected in Carnap's own emphasis that a theoretical sentence and its "translation" need be only physically, rather than . logically, "equipollent"; i.e., the two sentences may be mutually deducible,

[19] See, for example, ES, sec. 3; TM, sec. 15.

[20] For the narrower version, see PhSp; CPs; LSL, 320. For the revised form. see ES, sec. 3; TM, sec. 15; LFUS, Part IV; FLM, sec. 24.

not by virtue of the rules of logic alone, but relatively to a system of physical laws which serves as an additional premise for the deduction.[21] And, as was noted earlier, even the establishment of introductive chains presupposes the availability of supporting laws, namely of the corresponding representative sentences.

In sum, then, the questions with which the narrower and wider theses of positivism and physicalism are concerned are partly empirical in character, and they cannot, therefore, be answered with finality on purely analytic grounds.

In a somewhat more recent publication,[22] Carnap raises the issue of the avoidability of theoretical terms in a slightly different form. "Would be possible," he asks, "to formulate all laws of physics in elementary terms, admitting more abstract terms only as abbreviations?"[23] The first part of this question suggests the third of the conceptions of avoidability which were mentioned above. Carnap answers in the negative, and, interestingly, on empirical grounds: It turns out—and "this is an empirical fact, not a logical necessity"[24]—that the use of elementary, i.e., observational, terms does not lead to a powerful and efficacious system of laws; for virtually every law stated in a concrete vocabulary is found to have exceptions, whereas with the help of abstract terms, it has been possible to formulate increasingly comprehensive and exact laws.

However, as has been shown by Craig,[25] it can be proved on purely logical grounds alone that in a very comprehensive class of cases, theoretical terms are avoidable in sense (c). As far as it bears upon our problem, Craig's result may conveniently be stated with the help of some of the concepts introduced in the preceding section. For the purpose at hand, it will be useful to consider the postulates of a theory T together with the sentences of an associated interpretative system J as constituting the postulates for a system T', which we will call an interpreted theory; the union of V_T and V_B will be called $V_{T'}$.

Craig's result may now be formulated as follows: Suppose that within the logical framework of the first-order functional calculus with identity, a system T' has been formulated by an effective (constructive) specification of a finite or infinite set of postulates in terms of an effectively specified extra-logical vocabulary, $V_{T'}$ which may contain a finite or an infinite number of individual constants and a finite or infinite number of predicate constants. Let $V_{T'}$ be divided, by means of some effective, but other-

[21] See, f, ex., Cps, 49-46.
[22] FLM, sec. 24.
[23] *Loc. cit.*, 64.
[24] *Ibid.*
[25] See Th and RAE. A highly condensed and considerably generalized statement of the principal results of Th has been published by Craig in AS.

wise arbitrary, criterion, into two mutually exclusive subsets, V_T and V_B. Then there exists a general method (i.e., one applicable to all cases of the kind just characterized) of constructing a new system, T_B, whose postulates are expressed in terms of V_B alone, and whose theorems are exactly those theorems of T' which contain no extra-logical constants other than those contained in V_B.

As a consequence, the new system is functionally equivalent to T' in the sense specified earlier. For let some V_B-sentence, say S_1, imply another, S_2, by virtue of T', i.e., let T' together with S_1 logically imply S_2. Then T' implies the conditional $S_1 \supset S_2$, and since the latter is a V_B -sentence, it is implied also by T'_B, by virtue of the theorem just stated. Hence, T'_B together with S_1 logically implies S_2. Thus, T'_B establishes all those deductive connections between V_B-sentences that T' can establish. The converse follows similarly. Hence, T' and the "new" system are functionally equivalent.

Thus, Craig's result shows that no matter how we select from the total vocabulary V_T' of an interpreted theory T' a subset V_B of experiential or observational terms, the balance of V_T', constituting the "theoretical terms', can always be avoided in sense (c).

Craig has shown that this result can be extended to a great variety of logical frameworks, including functional calculi of higher order.[26] There are at least two reasons, however, which would make it distinctly inadvisable for science to avail itself of this possibility of avoiding theoretical terms. One of these was provided by Craig himself: He showed (1) that the "new" theoretical system constructed by his method always has an infinite set of postulates, irrespective of whether the postulate set of the original theory is finite or infinite, and (2) that his result cannot be essentially improved in this respect, for there is no general method which will yield, for any given system T', and any choice of V_B, a corresponding T'_B with a finite postulate set whenever a functionally equivalent theory with a finite postulate set exists. This means that the scientist would be able to avoid theoretical terms only at the price of forsaking the comparative simplicity of a theoretical system with a finite postulational basis, and of giving up a system of theoretical concepts and hypotheses which are heuristically fruitful and suggestive—in return for a practically unmanageable system based upon an infinite, though effectively specified, set of postulates in observational terms. Needless to say that this price is too high for the scientist, no matter how welcome the possibility of such replacement may be to the epistemologist.

But I think there is yet another reason why science cannot dispense with theoretical terms in this fashion. Briefly, it is this: The application

[26] See AS.

of scientific theories in the predication and explanation of empirical findings involves not only deductive inference, i.e., the exploitation of whatever deductive connections the theory establishes among statements representing potential empirical data, but it also requires procedures of an inductive character, and some of these would become impossible if the theoretical terms were avoided. Under this broader conception of the function of a scientific theory, then, T'_B is *not* functionally equivalent to T'.

To amplify and illustrate: It is an oversimplification to conceive of scientific theories as establishing deductive connections between "observational sentences" if the latter are thought of as statements which describe potential results of direct observation, and which have the form of singular (i.e., non-quantified) sentences in terms of a basic observational vocabulary, V_B. To be sure, a hypothesis expressible in the simple form of a universal generalization in terms of observational predicates does establish deductive connections of that sort; for example, the hypothesis '$(x)(P_1x \supset P_2x)$', where 'P_1' and 'P_2' both belong to V_B, permits the deduction of the observational sentence 'P_2c' from the observational sentence 'P_1c'. But in general, the connections which theoretical principles establish among observational sentences are of a more complex kind. By way of a somewhat oversimplified illustration, consider the hypothesis

(5.1) The parts obtained by breaking a rod-shaped magnet in two are again magnets.

Let us assume that the predicate 'Magnet', being a disposition term, is not included in V_B, but is connected with certain V_B-terms by sentences which reflect its dispositional character. To avoid inessential complications, we will suppose that there is just one such sentence, to the effect that if an object *x* is a magnet (if *Mx*) then whenever a small piece *y* of iron filing is brought into contact with *x* (whenever *Fxy*) then *y* clings to *x* (then *Cxy*). In symbols:

(5.2) $$Mx \supset (y)(Fxy \supset Cxy)$$

Here, the relational predicates '*F*' and '*C*' will be assumed to belong to V_B.

Under these conditions, does the hypothesis (5.1) establish any logical connections among observational sentences? From the initial information:

(5.3) Objects *b* and c were obtained by breaking object *a* in two, and *a* was a magnet and rod-shaped

we are clearly able to deduce, with help of (5.1), such observational sentences as

(5.4) If *d* is a piece o£ iron filing that is brought into contact with *b* then *d* will cling to *b*.

However, the premise, (5.3), of this deduction is not a V_B-sentence since it contains the non-observational sentence '*a* was a magnet', or '*Ma*'. Nor is (5.3) deducible from other V_B-sentences, for (5.2) specifies only a necessary, but not a sufficient, condition for '*M*' in terms of V_B. Thus, if the deduction of (5.4) from (5.3) is to be utilized in establishing logical connections strictly among observational sentences, then we must first perform an inductive step leading to (5.3) from a suitable set of observational sentences. The essentially inductive part of this procedure is the establishment of '*Ma*' i.e., the acceptance of this sentence on the basis of some confirmatory set of observational sentences. For example, '*Ma*' might be accepted if the given set of accepted observation statements includes or implies a considerable number of instances of the statement form '$Fay \supset Cay$', and none of the form '$Fay \cdot {\sim}Cay$'; for these lend inductive support to '$(y)(Fay \supset Cay)$', which, in turn, by virtue of (5.2), partially supports '*Ma*'. Thus, the hypothesis (5.1) may be said to lead us, in virtue of (5.2), from certain observational sentences-the instances of '$Fay \supset Cay$'—to predictions of the type (5.4), which again are observational sentences; but the transition requires, apart from deduction, also certain inductive steps. But this deductive-inductive connection becomes unavailable if our "theory", which here consists of (5.1) and (5.2) only, is replaced by its functional equivalent in terms of V_B; for that equivalent, as can be seen without much difficulty, consists of analytic sentences only.

To restate the basic idea in more general terms: The sentences among which scientific theories establish purely deductive relationships normally have the status, not of singular, but of generalized sentences in terms of the observational vocabulary. Hence the transition, by means of the theory, from strictly observational to strictly observational sentences usually requires inductive steps, namely, the transition, from some set of observational sentences to some non-observational sentence which they support inductively, and which in turn can serve as a premise in the strictly deductive application of the given theory. And, as our example suggests, the inductive-deductive connections mediated by a theory T' may be lost when T' is abandoned in favor of T'_B: this point provides, I think, a further systematic argument in favor of the use of theoretical terms in empirical science.

VI. *The Experiential "Basis" of Science*

Observational sentences, which serve to state the empirical evidence by which scientific theories are tested, have sometimes been conceived as referring to the most immediate and entirely incontrovertible deliveries of our experience, and as being capable, in consequence of this character, of being either affirmed or denied irrevocably, with definite certainty. The system of observational sentences which have been accepted on the basis of immediate experience would then constitute a bed-rock foundation for the edifice of scientific theory.

This conception, however, is a fiction. The language of actual science contains no statements of this kind; and, what is more important, it would be unwise to allow for such sentences even in a logical reconstruction, a theoretical model, of the language of science. For, given any observational sentence *S*, it is possible to describe potential observational findings whose actual occurrence would indirectly disconfirm S and might indeed make it reasonable to reject *S* even if that sentence should previously have been accepted as stating some actual datum of immediate experience.

Carnap, espousing certain ideas propounded by Popper,[27] early rejected the idea of a privileged class of "protocol sentences" conceived as terminal statements in the process of empirical verification, as final arbiters in the test of all scientific theories. Any evidence statement is capable of further test, and statements serving as evidence, just like all other scientific statements, are established, i.e., incorporated into the total system of accepted statements, only "until further notice", with the proviso that they may be reappraised, and indeed rejected, in the light of additional evidence. On pain of an infinite regress in the process of confirmation, it is indeed inevitable that at any time, some statements must be accepted immediately, i.e., without the mediation of other, supporting, statements; but this does not imply that some statements are such that at any time, they must be accepted immediately. Thus, in the construction of the system of statements that constitutes the *corpus* of scientific knowledge, there are no absolutely primary sentences. Popper has expressed this idea in a suggestive metaphor: "The empirical basis of objective science has thus nothing 'absolute' about it. Science does not rest upon rock-bottom. The bold structure of its theories rises, as it were, above a swamp. It is like a building erected on piles. The piles are driven down from above into the swamp, but not down to any natural or 'given' base; and when we cease our attempts to drive our piles into a deeper layer, it is not because we have reached firm ground. We simply stop when we are satisfied that they are firm enough to carry the structure, at least for the time being."[28]

It is sometimes argued that empirical knowledge must ultimately be based upon a system of statements which are certain because otherwise no empirical statement could even be probable.[29] However, the attribution of probabilities to scientific hypotheses does not require that the senten-

[27] Cf. Carnap's acknowledgment and summary, in PS, sec. 2, of certain ideas which Popper had suggested to him on the subject. and which were subsequently presented and developed by Popper in LF and LSD (cf. especially secs. 1-8, and 25-30 of either book).

[28] LSD, 111.

[29] For an instructive discussion of this issue, see the symposium, "The Experiential Element in Knowledge," which consists of the following papers: Reichenbach, PR; Goodman, SC: Lewis, GE.

ces on which the attribution is based should be certain or irrevocable; it suffices that they be at least temporarily accepted as presumably true. Then—to the extent that the theory of logical probability makes possible the ascription of numerical values—each hypothesis can be assigned a definite probability relative to the system of accepted statements; if the latter is changed, the hypotheses will still have probabilities, though possibly of different numerical value.

VII. *A Remark on Analyticity and Testability*

As we have noted, Carnap denies the privileged status of irrevocability even to those sentences which purport to convey the results of direct observation or immediate experience; no statement accepted in empirical science is taken to be immune from reconsideration and possible rejection. Referring also to Duhem and Poincaré, Carnap emphasizes in addition that strictly speaking a statement in a scientific theory cannot be tested in isolation, for it will yield consequences capable of confrontation with experimental or observational findings only when conjoined with a variety of other accepted statements of the theory; thus, basically, it is always an entire theoretical system that is under test.[30]

In regard to our earlier characterization of a scientific theory, this observation may serve as a reminder that the distinction between the theory proper, T, and its interpretative system *J* is a somewhat arbitrary matter since the sentences of both sets have essentially the same function and the same status. For (1) it is only in conjunction with J that T implies consequences in terms of V_B; (2) *J* no less than *T* may contain sentences expressed in terms of V_T alone, such as the "meaning postulates" mentioned earlier; and (3) when discrepancies between predictions and experiential data call for a modification of the predictive apparatus, suitable adjustments may be effected not solely by changing *T*, but alternatively also by changing *J*. This suggests that we assign to the sentences of *J* a status analogous to that of the postulates of *T*; they are postulates in terms of a primitive vocabulary which is the union, V_T', of V_T and V_B; and together with the postulates of *T*, they determine what was called above an interpreted theory, *T'*.[31]

This conception, which seems to me a natural extension of Carnap's own, makes it increasingly difficult, however, to single out, as Carnap has endeavored to do, a special class of sentences which are analytic in the

[30] LSL, 318.

[31] In particular, reduction sentences thus mine m be conceived as postulates. The possibility of construing them in this manner was pointed out quite early by Leonard in Rev.—More recently, Carnap has suggested a method of assimilating reduction sentences to meaning postulates; this idea is discussed at a later place in the present essay.

wider sense of including, in addition to the truths of formal logic, also certain other sentences, namely those which are true by virtue of the meanings of their extra-logical constituents. Sentences of either kind would be certain in the sense of being incapable of disconfirmation by empirical evidence; they would be devoid of factual content. Without entering into a detailed discussion of the various complex issues here involved, I wish to present here but one consideration, which grows out of the preceding discussion, and which exhibits a difficulty in preserving the idea of analyticity with respect to the theoretical sentences of science.

In *Testability and Meaning,* after countenancing the use of only partially defined terms, Carnap faces the problem of setting up a criterion of analyticity for sentences containing such terms. His criterion is, in effect, as follows: Let *S* be a sentence containing an essential occurrence of one non-basic predicate, '*Q*'; and let this predicate have been introduced by a set *R* of reduction pairs, which may include bilateral reduction sentences. Then *S* is analytic just in case (1) *S* is logically implied by *R,* and (2) the representative sentence *S′* of *R* is analytic. Sentences which, like *S′*, contain only basic extra-logical terms are qualified as analytic in effect if they are truths of formal logic.[32]

In more intuitive terms: *S* is said to be analytic if it can be deduced from the sentences specifying the meaning of '*Q*', and if the latter have no factual content. This criterion of analyticity is unavailing, however, once the conception of an interpreted theory has been generalized in the manner suggested earlier. For the idea underlying the criterion would then direct us to say that a V_T'-sentence *S* is analytic if (1) *S* is logically implied by *T′*, and (2) *T′* has no factual content, i.e., logically implies no V_B-sentences which are not analytic. But, as was noted in section 5, if *T′* establishes any deductive connections among V_B-sentences at all, then it does not meet the second of these conditions. Hence, in this case, a V_T-sentence can be analytic only if it contains all its V_T-terms inessentially, i.e., if it is a truth of formal logic. Thus, the only sense in which the concept of analyticity remains applicable to the sentences of a scientific theory is the nar-

[32] TM, sec. 10, especially 451-453. Note that if *S* is a bilateral reduction sentence for '*Q*'—and is thus an element of *R*—then the first condition will be trivially satisfied, and therefore *S* will be analytic just in case the representative sentence of *R* is analytic. Carnap by an oversight asserts instead that "every bilateral reduction sentence is analytic, because its representative sentence is analytic." (*loc. cit*., 452.) If this did follow from his criterion then it would vitiate the latter; for if *R* consists of the two bilateral reduction sentences '$P_1x \supset (Qx \equiv P_2x)$' and '$P_3x \supset (Qx \equiv P_4x)$', each of them would qualify as analytic, and yet they jointly imply the sentence

(*S′*) $(x)\text{-}(P_1x \bullet P_2x \bullet P_3x \bullet \text{-}P_4x \vee P_1x \bullet \text{-}P_2x \bullet P_3x \bullet P_4x)$

which is in terms of basic predicates solely and not a truth of logic, hence not analytic. (See also my discussion of this point in CS, pp. 71-72.) Actually, Carnap's general criterion implies only that each of the two reduction sentences for '*Q*' is analytic just in case *S′* is analytic; for *S′* is the representative sentence expressing the factual content of *R.*

row one of truth by virtue of being an instance of a logically valid schema.

Recently, Carnap has suggested[33] an interesting variant of the method of introducing predicates by reduction sentences. Suppose that a predicate '*Q*' has been introduced by a set *R* of reduction sentences whose conjunction is R'. Let S' be the representative sentence of *R.* Then clearly R' is logically equivalent to S'. ($S' \supset R'$). While S' expresses the factual content of *R,* the sentences $S' \supset R'$ is non-factual in this sense: all those of its logical consequences which are expressible in terms of basic predicates alone are truths of formal logic. Carnap's new method consists in introducing '*Q*', not by *R,* but by $S' \supset R'$ alone, i.e., by making the latter sentence a meaning postulate of the language at hand. This procedure has two advantages, from Carnap's point of view: (i) It separates the two functions of language which are fused in reduction sentences, namely, the assertion of empirical fact and the specification of meaning; and (ii) it permits a neat and quite general characterization of analyticity; the analytic statements of a language are those which are logically implied by the meaning postulates.

This new procedure gives rise, however, to the question as to the meaning and the rationale of the distinction that is made here between meaning postulates and empirical postulates. Suppose for example, that in axiomatizing a given scientific theory a certain sentence is declared to be a meaning postulate. What peculiar characteristic is attributed to it by that characterization? What distinctive status is being conferred upon it? Inviolable truth in any conflict that might arise between the theory and pertinent experiential data suggests itself as an essential characteristic of meaning postulates; for presumably, such postulates are intended to specify, in part or in full, the meanings of their constituent extra-logical terms by the stipulation that those terms are to be used in such a way as to safeguard the truth of the meaning postulates under all circumstances. But, as was pointed out earlier, there are good reasons to think that-with the possible exception of the formal truths of logic and mathematics—any statement once accepted in empirical science may conceivably be abandoned for the sake of resolving a conflict between the theory and the total body of evidence available. Hence it would seem that, apart from purely logical or mathematical truths, there can be no scientific statements that satisfy the condition here contemplated for meaning postulates. And is it questionable, therefore, whether there is any aspect of scientific method or of scientific knowledge that would constitute an explicandum for the analytic-synthetic dichotomy in regard to the statements of empirical science.[34]

[33] MP, 71.

[34] For a fuller critical discussion of that dichotomy, see Quine, DE; White, AS; Pap, RS.

Similar considerations apply to the notions of testability and empirical significance. As long as theoretical terms are conceived as being introduced by chains of reduction sentences based upon an observational vocabulary V,, it is possible to speak of individual sentences containing theoretical terns as being confirmable by reference to V_B-sentences. And the experiential import or significance of a sentence *S* of this kind may be taken to be represented by the class of all non-analytic V_B-sentences which are implied by *S* in conjunction with the reduction sentences for the theoretical terms in *S*; the sentence *S* would then be devoid of empirical meaning if that class was empty.

In the broadened conception of an interpreted theory, this idea has no useful counterpart. We would have to say that the experiential import of *S*, relative to a given interpreted theory *T'*, is expressed by the class of all non-analytic V_B-sentences implied by *S* in conjunction with *T'*. But this would render the notions of testability and experiential significance relative to a given scientific theory, and it would assign to all sentences of *T'* the same experiential import, represented by the class of all V_B-sentences implied by *T'*. These peculiarities are symptomatic of the fact, which was mentioned earlier, that testability and empirical significance are attributable, not to scientific statements in isolation, but only to interpreted theoretical systems.

An empiricist interested in preserving the notion of empirical significance as testability by experiential findings could not derive much comfort from the circumstance that the testability requirement is still applicable at least to entire theoretical systems. For thus applied, the requirement is extremely weak. For example, an "empirically significant" theory would remain so under enlargement by any set of sentences which leaves its deductive import in regard to V_B-sentences unchanged. Thus, a significant theory *T'* would remain significant if to its postulates we added a set of further postulates couched exclusively in terms of additional theoretical predicates, none of them contained in either the basic or the theoretical vocabulary of *T'*. An example of this procedure would consist in adding, to contemporary physical theory, an axiomatized metaphysics of Being and Essence; the outcome would be an empirically significant system.

Nor can we forestall this consequence by requiring that an empirically significant theory must contain no sentence—other than purely logical or mathematical truths—whose elimination would leave the experiential import of the theory (i.e., the set of all its consequences in terms of V_B) unchanged. For this requirement would prohibit the use of theoretical terms altogether, since as long as *T'* has not been reduced to an equivalent of T'_B it still contains statements which violate the requirement under discussion.

As these considerations suggest, the value of a scientific theory is not determined solely by the range of the connections it establishes among the data of our experience, but very importantly also by the simplicity of those connections. The problem of giving a precise explication of this aspect of scientific theories presents a new and challenging task for the philosophy of science.[35]

The neat and clean-cut conceptions of cognitive significance and of analyticity which were held in the early days of the Vienna Circle have thus been gradually refined and liberalized to such an extent that it appears quite doubtful whether the basic tenets of positivism and empiricism can be formulated in a clear and precise way.[36] This doubt applies with equal force, of course, to the various rival doctrines of empiricism; for what analytic research in recent decades has made increasingly clear is precisely that the conflicting theses and programs at issue involve concepts and. assumptions which are found wanting upon closer logical scrutiny.

Carnap's ingenious and illuminating methods of logical analysis and reconstruction, and the example he has set in his own work of rigorous but open-minded and undogmatic philosophic inquiry, have provided a powerful stimulus for a precise analytic approach to philosophic problems; and if in the light of recent analytic studies the objective of clearly explicating the concepts of cognitive significance and of analyticity appears as elusive, the research that suggested this conclusion has yielded a rich harvest of insights into the logic and methodology of science. Thus, the quest for an ever more adequate statement and defense of some of the basic conceptions of empiricism has come to play the role of the treasure hunt in the tale of the old winegrower who on his death-bed enjoins his sons to dig for a treasure hidden in the family vineyard. In untiring search, his sons turn over the soil and thus stimulate the growth of the vines: the rich harvest they reap proves to be the true and only treasure in the vineyard.

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[35] In recent years. a number of authors have made contributions to the explication of various aspects of the notion of theoretical simplicity; among these, see especially Popper, LF, secs. 41-46; Reichenbach EP, sec. 42 and TP, 447; Goodman, SA, ch. 3 and RDS; Kemeny. US; and chapter 9 of Barker, IH.

[36] On this point, cf., in addition to the references given, in note 34, Carnap, MP and Hempel, CS.

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