Chapter 22

Unity of Science as a Working Hypothesis

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1. *Introduction*

1.1. The expression "unity of science" is often encountered, but its precise content is difficult to specify in a satisfactory manner. It is the *aim of this paper* to formulate a precise concept of unity of science; and to examine to what extent that unity can be attained.

A concern with unity of science hardly needs justification. We are guided especially by the conviction that science of science, i.e., the metascientific study of major aspects of science, is the natural means for counterbalancing specialization by promoting the integration of scientific knowledge. The desirability of this goal is widely recognized; for example, many universities have programs with this end in view; but it is often pursued by means different from the one just mentioned, and the conception of the unity of science might be especially suited as an organizing principle for an enterprise of this kind.

1.2. As a preliminary, we will distinguish, in order of increasing strength, three broad concepts of unity of science:

First, unity of science in the weakest sense is attained to the extent to which all the terms of science[1] are reduced to the terms of some one discipline (e.g., physics, or psychology). This concept of *unity of language* (12) may be replaced by a number of subconcepts depending on the manner in which one specifies the notion of "reduction" involved. Certain authors, for example, construe reduction as the *definition* of the terms of science by means of those in the selected basic discipline (reduction by means of biconditionals (47)); and some of these require the definitions in question to be analytic, or "true in virtue of the meanings of the terms involved" (epistemological reduction); others impose no such restriction upon the biconditionals effecting reduction. The notion of reduction we shall employ is a wider one, and is designed to include reduction by means of biconditionals as a special case.

Second, unity of science in a stronger sense (because it implies unity of language, whereas the reverse is not the case) is represented by *unity of laws* (12). It is attained to the extent to which the laws of science become reduced to the laws of some one discipline. If the ideal of such an all-comprehensive explanatory system were realized, one could call it *unitary science* (18, 19, 20, 80). The exact meaning of 'unity of laws' depends, again, on the concept of "reduction" employed.

Third. unity of science in the strongest sense is realized if the laws of science are not only reduced to the laws of some one discipline, but the laws of that discipline are in some intuitive sense "unified" or "connected." It is difficult to see how this last

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requirement can be made precise; and it will not be imposed here. Nevertheless, trivial realizations of "unity of science" will be excluded, for example, the simple conjunction of several branches of science does not *reduce* the particular branches in the sense we shall specify.

1.3. In the present paper, the term 'unity of science' will be used in two senses, to refer, first, to an ideal state of science, and, second, to a pervasive *trend* within science, seeking the attainment of that ideal.

In the first sense, 'unity of science' means the state of unitary science. It involves the two constituents mentioned above: unity of vocabulary, or "unity of language"; and unity of explanatory principles, or "unity of laws." That unity of science, in this sense, can be fully realized constitutes an overarching metascientific hypothesis which enables one to see a unity in scientific activities that might otherwise appear disconnected or unrelated, and which encourages the construction of a unified body of knowledge.

In the second sense, unity of science exists as a trend within scientific inquiry, whether or not unitary science is ever attained, and notwithstanding the simultaneous existence, (and, of course, legitimacy) of other, even *incompatible*, trends.

1.4. The expression 'unity of science' is employed in various other senses, of which two will be briefly mentioned in order to distinguish them from the sense with which we are concerned. In the first place, what is sometimes referred to is something that we may call the *unity of method* in science. This might be represented by the thesis that all the empirical sciences employ the same standards of explanation, of significance, of evidence, etc.

In the second place, a radical reductionist thesis (of an alleged "logical," not an empirical kind) is sometimes referred to as the thesis of the unity of science. Sometimes the "reduction" asserted is the definability of all the terms of science in terms of *sensationalistic predicates* (10); sometimes the notion of "reduction" is wider (11) and predicates referring to *observable qualities of physical things* are taken as basic (12). These theses are epistemological ones, and ones which today appear doubtful. The epistemological uses of the terms 'reduction', 'physicalism', 'unity of science', etc., should be carefully distinguished from the use of these terms in the present paper.

2. *Unity of Science and Microreduction*

2.1. In this paper we shall employ a concept of reduction introduced by Kemeny and Oppenheim in their paper on the subject (47), to which the reader is referred for a more detailed exposition. The principal requirements may be summarized as follows: given two theories T_1 and T_2, T_2 is said to be *reduced* to T_1 if and only if:

(1) The vocabulary of T2 contains terms not in the vocabulary of T_1.
(2) Any observational data explainable by T_2 are explainable by T_1.
(3) T_1 is at least as well systematized as T_2. (T_1 is normally more complicated than T_2; but this is allowable, because the reducing theory normally explains more than the reduced theory. However, the "ratio," so to speak, of simplicity to explanatory power should be at least as great in the case of the reducing theory as in the case of the reduced theory.)[2]

Kemeny and Oppenheim also define the reduction of a branch of science B_2 by another branch B_1 (e.g., the reduction of chemistry to physics). Their procedure is as follows: take the accepted theories of B_2 at a given time t as T_2. Then *B_2 is reduced to B_1* at time t if and only if there is some theory T_1 in B_1 at t such that T_1 reduces T_2 (47). Analogously, if *some* of the theories of B_2 are reduced by some T_1 belonging to branch

B_1 at t, we shall speak of a *partial reduction* of B_2 to B_2 at t. This approach presupposes (1) the familiar assumption that some division of the total vocabulary of both branches into theoretical and observational terms is given, and (2) that the two branches have the same observational vocabulary.

2.2. The essential feature of a *micro*reduction is that the branch B_1 deals with the parts of the objects dealt with by B_2. We must suppose that corresponding to each branch we have a specific universe of discourse U_{Bi};[3] and that we have a part-whole relation, Pt (75; 76, especially p. 91). Under the following conditions we shall say that the reduction of B_2 to B_1[4] is a *micro*reduction: B_2 is reduced to B_1; and the objects in the universe of discourse of B_2 are wholes which possess a decomposition (75; 76, especially p. 91) into proper parts all of which belong to the universe of discourse of B_1. For example, let us suppose B_2 is a branch of science which has multicellular living things as its universe of discourse. Let B_1 be a branch with cells as its universe of discourse. Then the things in the universe of discourse of B_2 can be decomposed into proper parts belonging to the universe of discourse of B_1. If, in addition, it is the case that B_1 reduces B_2 at the time t, we shall say that *B_1 microreduces B_2 at time t*.

We shall also say that a branch B_1 is a *potential microreducer* of a branch B_2 if the objects in the universe of discourse of B_2 are wholes which possess a decomposition into proper parts all of which belong to the universe of discourse of B_1. The definition is the same as the definition of 'microreduces' except for the omission of the clause 'B_2 is reduced to B_1.'

Any microreduction constitutes a step in the direction of *unity of language* in science. For, if B_1 reduces B_2, it explains everything that B_2 does (and normally, more besides). Then, even if we cannot define in B_1 analogues for some of the theoretical terms of B_2, we can *use B_1 in place of B_2*. Thus any reduction, in the sense explained, permits a "reduction" of the total vocabulary of science by making it possible to dispense with some terms.[5] Not every reduction moves in the direction of unity of science; for instance reductions *within* a branch lead to a simplification of the vocabulary of science, but they do not necessarily lead in the direction of unity of science as we have characterized it (although they may at times fit into that trend). However, *micro*reductions, and even partial microreductions, insofar as they permit us to replace some of the terms of one branch of science by terms of another, *do* move in this direction.

Likewise, the microreduction of B_2 to B_1 moves in the direction of *unity of laws*; for it "reduces" the total number of scientific laws by making it possible, in principle, to dispense with the laws of B_2 and explain the relevant observations by using B_1.

The relations 'microreduces' and 'potential microreducer' have very simple properties: (1) they are transitive (this follows from the transitivity of the relations 'reduces' and 'Pt'); (2) they are irreflexive (no branch can microreduce itself); (3) they are asymmetric (if B_1 microreduces B_2, B_2 never microreduces B_1). The two latter properties are not purely formal; however, they require for their derivation only the (certainly true) empirical assumption that there does not exist an infinite descending chain of proper parts, i.e., a series of things x_1, x_2, x_3 ... such that x_2 is a proper part of x_1, x_3 is a proper part of x_2, etc.

The just-mentioned *formal* property of the relation 'microreduces'—its transitivity—is of great importance for the program of unity of science. It means that microreductions have a *cumulative* character. That is, if a branch B_3 is microreduced to B_2, and B_2 is in turn microreduced to B_1, then B_3 is automatically microreduced to B_1. This simple fact is sometimes overlooked in objections[6] to the theoretical possibility of attaining unitary science by means of microreduction. Thus it has been contended that one manifestly cannot explain human behavior by reference to the laws of atomic physics. It would indeed be fantastic to suppose that the simplest regularity in the field of psychology could be explained directly—i.e., "skipping" intervening branches of science—by employing subatomic theories. But one may believe in the attainability of unitary science without thereby committing oneself to this absurdity. It is not absurd to suppose that psychological laws may eventually be explained in terms of the behavior of individual neurons in the brain; that the behavior of individual cells—including neurons—may eventually be explained in terms of their biochemical constitution; and that the behavior of molecules—including the macromolecules that make up living cells—may eventually be explained in terms of atomic physics. If this is achieved, then psychological laws will have, in *principle,* been reduced to laws of atomic physics, although it would nevertheless be hopelessly impractical to try to derive the behavior of a single human being directly from his constitution in terms of elementary particles.

2.3. *Unitary* science certainly does not exist today. But will it ever be attained? It is useful to divide this question into two subquestions: (1) If unitary science can be attained at all, *how* can it be attained? (2) *Can* it be attained at all?

First of all, there are various abstractly possible ways in which unitary science might be attained. Howvever, it seems very doubtful, to say the least, that a branch B_2 could be reduced to a branch B_1, if the things in the universe of discourse of B_2 are not themselves in the universe of discourse of B_1 and also do not possess a decomposition into parts in the universe of discourse of B_1. ("They don't speak about the same things.")

It does not follow that B_1 must be a potential *micro*reducer of B_2, i.e., that all reductions are microreductions.

There are many cases in which the reducing theory and the reduced theory belong to the same branch, or to branches with the same universe of discourse. When we come, however, to branches with different universes—say, physics and psychology—it seems clear that the possibility of reduction depends on the existence of a structural connection between the universes *via* the 'Pt' relation. Thus one cannot plausibly suppose—for the present at least—that the behavior of inorganic matter is explainable by reference to psychological laws; for inorganic materials do not consist of living parts. One supposes that psychology may be reducible to physics, but not that physics may be reducible to psychology!

Thus, the only method of attaining unitary science that appears to be seriously available at present is microreduction.

To turn now to our second question, can unitary science be attained? We certainly do not wish to maintain that it has been *established* that this is the case. But it does not follow, as some philosophers seem to think, that a tentative acceptance of the hypothesis that unitary science can be attained is therefore a mere "act of faith." We believe that this hypothesis is *credible;*[7] and we shall attempt to support this in the latter part of this paper, by providing empirical, methodological, and pragmatic reasons in its support. We therefore think the assumption that unitary science can be attained through cumulative microreduction recommends itself as a *working hypothesis.*[8] That is, we believe that it is in accord with the standards of reasonable scientific judgment to tentatively accept this hypothesis and to work on the assumption that further progress can be made in this direction, without claiming that its truth has been established, or denying that success may finally elude us.

3. *Reductive Levels*

3.1. As a basis for our further discussion, we wish to consider now the possibility of ordering branches in such a way as to indicate the major potential microreductions standing between the present situation and the state of unitary science. The most natural way to do this is by their universes of discourse. We offer, therefore, a system of *reductive levels* so chosen that a branch with the things of a given level as its universe of discourse will always be a potential microreducer of any branch with things of the next higher level (if there is one) as its universe of discourse.

Certain conditions of adequacy follow immediately from our aim. Thus:

(1) There must be several levels.
(2) The number of levels must be finite.
(3) There must be a unique lowest level (i.e., a unique "beginner" under the relation 'potential microreducer'); this means that success at transforming all the *potential* microreductions connecting these branches into *actual* microreductions must, *ipso facto*, mean reduction to a single branch.
(4) Any thing of any level except the lowest must possess a decomposition into things belonging to the next lower level. In this sense each level, will be as it were a "common denominator" for the level immediately above it.
(5) Nothing on any level should have a part on any higher level.
(6) The levels must be selected in a way which is "natural"[9] and justifiable from the standpoint of present-day empirical science. In particular, the step from any one of our reductive levels to the next lower level must correspond to what is, scientifically speaking, a crucial step in the trend toward over-all physicalistic reduction.

The accompanying list gives the levels we shall employ;[10] the reader may verify that the six conditions we have listed are all satisfied.

6 .... Social groups
5 .... (Multicellular) living things
4 .... Cells
3 .... Molecules
2 .... Atoms
1 .... Elementary particles

Any whole which possesses a decomposition into parts all of which are on a given level, will be counted as also belonging to that level. Thus each level includes all higher levels. However, the highest level to which a thing belongs will be considered the "proper" level of that thing.

This inclusion relation among our levels reflects the fact that scientific laws which apply to the things of a given level and to all combinations of those things also apply to all things of higher level. Thus a physicist, when he speaks about "all physical objects," is also speaking about living things—but not qua living things.

We maintain that each of our levels is *necessary* in the sense that it would be utopian to suppose that one might reduce all of the major theories or a whole branch concerned with any one of our six levels to a theory concerned with a lower level, *skipping* entirely the *immediately* lower level; and we maintain that our levels are *sufficient* in the sense that it would *not* be utopian to suppose that a major theory on any one of our levels *might* be directly reduced to the next lower level. (Although this is *not* to deny that it may be convenient, in special cases, to introduce intervening steps.)

However, this contention is significant only if we suppose some set of *predicates* to be associated with each of these levels. Otherwise, as has been pointed out,[11] *trivial* microreductions would be possible; e.g., we might introduce the property "Tran" (namely, the property of being an atom of a transparent substance) and then "explain the transparency of water in terms of properties on the atomic level," namely, by the hypothesis that all atoms of water have the property Tran. More explicitly, the explanation would consist of the statements

(a) (x) (x is transparent ≡ (y) (y is an atom of x ⊃ Tran (y))

(b) (x) (x is water ⊃ (y) (y is an atom of x ⊃ Tran (y))

To exclude such trivial "microreductions," we shall suppose that with each level there is associated a list of the theoretical predicates normally employed to characterize things on that level at present (e.g., with level 1, there would be associated the predicates used to specify spatiotemporal coordinates, mass-energy, and electric charge). And when we speak of a theory concerning a given level, we will mean not only a theory whose universe of discourse is that level, but one whose predicates belong to the appropriate list. Unless the hypothesis that theories concerning level $n + 1$ can be reduced by a theory concerning level n is restricted in this way, it lacks any clear empirical significance.

3.2. If the "part-whole" ('Pt') relation is understood in the wide sense, that x Pt y holds if x is spatially or temporally contained in y, then everything, continuous or discontinuous, belongs to one or another reductive level; in particular to level 1 (at least), since it is a whole consisting of elementary particles. However, one may wish to understand 'whole' in a narrower sense (as "structured organization of elements"[12]). Such a specialization involves two essential steps: (1) the construction of a calculus with such a narrower notion as its primitive concept, and (2) the definition of a particular 'Pt' relation satisfying the axioms of the calculus.

Then the problem will arise that some things do not belong to *any* level. Hence a theory dealing with such things might not be microreduced even if all the microreductions indicated by our system of levels were accomplished; and for this reason, unitary science might not be attained.

For a trivial example, "a man in a phone booth" is an aggregate of things on different levels which we would not regard as a whole in such a narrower sense. Thus, such an "object" does not belong to any reductive level; although the "phone booth" belongs to level 3 and the man belongs to level 5.

The problem posed by such aggregates is not serious, however. We may safely make the assumption that the behavior of "man in phone booths" (to be carefully distinguished from "men in phone booths") could be completely explained given (a) a complete physicochemical theory (i.e., a theory of levels up to 3, including "phone booths"), and (b) a complete individual psychology (or more generally, a theory of levels up to 5). With this assumption in force, we are able to say: If we can construct a theory that explains the behavior of all the objects in our system of levels, then it will also handle the aggregates of such objects.

4. *The Credibility of Our Working Hypothesis*

4.1. John Stuart Mill asserts (55, Book VI, Chapter 7) that since (in our wording) human social groups are wholes whose parts are individual persons, the "laws of the phenomena of society" are "derived from and may be resolved into the laws of the nature of individual man." In our terminology, this is to suggest that it is a logical truth that theories concerning social groups (level 6) can be *microreduced* by theories concerning individual living things (level 5); and, *mutatis mutandis*, it would have to be a logical truth that theories concerning any other level can be microreduced by theories concerning the next lower level. As a consequence, what we have called the "working hypothesis" that unitary science can be attained would likewise be a logical truth.

Mill's contention is, however, not so much *wrong* as it is vague. What is one to count as "the nature of individual man"? As pointed out above (section 3.1) the question whether theories concerning a given reductive level can be reduced by a theory concerning the next lower level has empirical content only if the theoretical vocabularies are specified; that is, only if one associates with each level, as we have supposed to be done, a particular set of theoretical concepts. Given, e.g., a sociological theory T_2, the question whether there exists a true psychological theory T_1 *in a particular vocabulary* which reduces T_2 is an empirical question. Thus our "working hypothesis" is one that can only be justified on empirical grounds.

Among the factors on which the degree of credibility of any empirical hypothesis depends are (45, p. 307) the *simplicity* of the hypothesis, the *variety* of the evidence, its *reliability*, and, last but not least, the *factual support* afforded by the evidence. We proceed to discuss each of these factors.

4.2. As for the *simplicity*[13] of the hypothesis that unitary science can be attained, it suffices to consider the traditional alternatives mentioned by those who oppose it. "Hypotheses" such as psychism and neovitalism assert that the various objects studied by contemporary science have special parts or attributes, unknown to present-day science, in addition to those indicated in our system of reductive levels. For example, men are said to have not only cells as parts; there is also an immaterial "psyche"; living things are animated by "entelechies" or "vital forces"; social groups are moved by "group minds." But, in none of these cases are we provided *at present* with postulates or coordinating definitions which would permit the derivation of testable predictions. Hence, the claims made for the hypothetical entities just mentioned lack any clear scientific meaning; and as a consequence, the question of supporting evidence cannot even be raised.

On the other hand, if the effort at microreduction should seem to fail, we cannot preclude the introduction of theories postulating presently unknown relevant parts or presently unknown relevant attributes for some or all of the objects studied by science. Such theories are perfectly admissible, provided they have genuine explanatory value. For example, Dalton's chemical theory of molecules might not be reducible to the best available theory of atoms at a given time if the latter theory ignores the existence of the electrical properties of atoms. Thus the hypothesis of microreducibility,[14] as the meaning is specified at a particular time, may be false because of the insufficiency of the theoretical apparatus of the reducing branch.

Of course, a new working hypothesis of microreducibility, obtained by enlarging the list of attributes associated with the lowest level, might then be correct. However, if there are presently unknown attributes of a more radical kind (e.g., attributes which are relevant for explaining the behavior of living, but not of nonliving things), then no such simple "repair" would seem possible. In this sense, unity of science is an alternative to the view that it will eventually be necessary to *bifurcate* the conceptual system of science, by the postulation of new entities or new attributes unrelated to those needed for the study of inanimate phenomena.

4.3. The requirement that there be *variety* of evidence assumes a simple form in our present case. If all the past successes referred to a single pair of levels, then this would be poor evidence indeed that theories concerning each level can be reduced by theories concerning a lower level. For example, if all the past successes were on the atomic level, we should hardly regard as justified the inference that laws concerning social groups can be explained by reference to the "individual psychology" of the members of those groups. Thus, the first requirement is that one should be able to provide examples of successful micreductions between several pairs of levels, preferably between all pairs.

Second, within a given level what is required is, preferably, examples of different kinds, rather than a repetition of essentially the same example many times. In short, one wants good evidence that *all* the phenomena of the given level can be microreduced.

We shall present below a survey of the past successes in each level. This survey is, of course, only a sketch; the successful microreductions and projected microreductions in biochemistry alone would fill a large book. But even from this sketch it will be apparent, we believe, how great the variety of these successful microreductions is in both the respects discussed.

4.4. Moreover, we shall, of course, present only evidence from authorities regarded as *reliable* in the particular area from which the theory or experiment involved is drawn.

4.5. The important factor *factual support* is discussed only briefly now, because we shall devote to it many of the following pages and would otherwise interrupt our presentation.

The first question raised in connection with any hypothesis is, of course, what *factual* support it possesses; that is, what confirmatory or disconfirmatory evidence is available. The evidence supporting a hypothesis is conveniently subdivided into that providing *direct* and that providing *indirect* factual support. By the direct factual support for a hypothesis we mean, roughly,[15] the proportion of confirmatory as opposed to disconfirmatory instances. By the indirect factual support, we mean the inductive support obtained from other well-confirmed hypotheses that lend credibility to the given hypothesis. While intuitively adequate quantitative measures of direct factual support have been worked out by Kemeny and Oppenheim,[16] no such measures exist for indirect factual support. The present paper will rely only on intuitive judgments of these magnitudes, and will not assume that quantitative explicata will be worked out.

As our hypothesis is that theories of each reductive level can be microreduced by theories of the next lower level, a "confirming instance" is simply any successful microreduction between any two of our levels. The *direct* factual support for our hypothesis is thus provided by the *past successes* at reducing laws about the things on each level by means of laws referring to the parts on lower (usually, the next lower) levels. In the sequel, we shall survey the past successes with respect to each pair of levels.

As *indirect* factual support, we shall cite evidence supporting the hypothesis that each reductive level is, in evolution and ontogenesis (in a wide sense presently to be specified) prior to the one above it. The hypothesis of *evolution* means here that (for n + 1 . . . 5) there was a time when there were things of level n, but no things of any higher level. This hypothesis is highly speculative on levels 1 and 2; fortunately the microreducibility of the molecular to the atomic level and of the atomic level to the elementary particle level is relatively well established on other grounds.

Similarly, the hypothesis of ontogenesis is that, in certain cases, for any *particular* object on level n, there was a time when it did not exist, but when some of its parts on the next lower level existed; and that it developed or was causally produced out of these parts.[17]

The reason for our regarding evolution and ontogenesis as providing indirect factual support for the unity of science hypothesis may be formulated as follows:

Let us, as is customary in science, assume causal determination as a guiding principle; i.e., let us assume that things that appear later in time can be accounted for in terms of things and processes at earlier times. Then, if we find that there was a time when a certain whole did not exist, and that things on a lower level came together to form that whole, it is very natural to suppose that the characteristics of the whole can be causally explained by reference to these earlier events and parts; and that the theory of these characteristics can be microreduced by a theory involving only characteristics of the parts.

For the same reason, we may cite as further indirect factual support for the hypothesis of empirical unity of science the various successes at *synthesizing* things of each level out of things on the next lower level. Synthesis strongly increases the evidence that the characteristics of the whole in question are causally determined by the characteristics, including spatio-temporal arrangement, of its parts by showing that the object is produced, under controlled laboratory conditions, whenever parts with those characteristics are arranged in that way.

The consideration just outlined seems to us to constitute an argument against the view that, as objects of a given level combine to form wholes belonging to a higher level, there appear certain new phenomena which are "emergent" (35, p. 151; 76, p. 93) in the sense of being forever irreducible to laws governing the phenomena on the level of the parts. What our argument opposes is not, of course, the obviously true statement that there are many phenomena which are not reducible by currently available theories pertaining to lower levels; our working hypothesis rejects merely the claim of absolute irreducibility, unless such a claim is supported by a theory which has a sufficiently high degree of credibility; thus far we are not aware of any such theory. It is not sufficient, for example, simply to advance the claim that certain phenomena considered to be specifically human, such as the use of verbal language, in an abstract and generalized way, can never be explained on the basis of neurophysiological theories, or to make the claim that this conceptual capacity distinguishes man in principle and not only in degree from nonhuman animals.

4.6. Let us mention in passing certain *pragmatic* and *methodological* points of view which speak in favor of our working hypothesis:

(1) It is of *practical* value, because it provides a good synopsis of scientific activity and of the relations among the several scientific disciplines.
(2) It is, as has often been remarked, *fruitful* in the sense of stimulating many different kinds of scientific research. By way of contrast, I belief in the *irreducibility* of various phenomena has yet to yield a single accepted scientific theory.
(3) It corresponds *methodologically* to what might be called the "Democritean tendency" in science; that is, the pervasive methodological tendency[18] to try, insofar as is possible, to explain apparently dissimilar phenomena in terms of qualitatively identical parts and their spatio-temporal relations.

5. *Past Successes at Each Level*

5.1 By comparison with what we shall find on lower levels, the microreduction of level 6 to lower ones has not yet advanced very far, especially in regard to human societies. This may have at least two reasons: First of all, the body of well-established theoretical knowledge on level 6 is still rather rudimentary, so that there is not much to *be* microreduced. Second, while various precise theories concerning certain special types of phenomena on level 5 have been developed, it seems as if a good deal of further theoretical knowledge concerning other areas on the same level will be needed before reductive success on a larger scale can be expected.[19] However, in the case of certain very primitive groups of organisms, astonishing successes have been achieved. For instance, the differentiation into social castes among certain kinds of insects has been tentatively explained in terms of the secretion of so-called social hormones (3).

Many writers[20] believe that there are some laws common to all forms of animal association, including that of humans. Of greater potential relevance to such laws are experiments dealing with "pecking order" among domestic fowl (29). In particular, experiments showing that the social structure can be influenced by the amount of male hormone in individual birds suggest possible parallels farther up the evolutionary scale.

With respect to the problems of human social organization, as will be seen presently, two things are striking: (1) the most developed body of theory is undoubtedly in the field of *economics*, and this is at present entirely microreductionistic in character; (2) the main approaches to *social* theory are *all* likewise of this character. (The technical term 'microreduction' is not, of course, employed by writers in these fields. However, many writers have discussed "the Principle of Methodological Individualism";[21] and this is nothing more than the special form our working hypothesis takes in application to human social groups.)

In economics, if very weak assumptions are satisfied, it is possible to represent the way in which an individual orders his choices by means of an individual preference function. In terms of these functions, the economist attempts to explain group phenomena, such as the market, to account for collective consumer behavior, to solve the problems of welfare economics, etc. As theories for which a microreductionistic derivation is accepted in economics we could cite all the standard macro-theories; e.g., the theories of the business cycle, theories of currency fluctuation (Gresham's law to the effect that bad money drives out good is a familiar example), the principle of marginal utility, the law of demand, laws connecting change in interest rate with changes in inventory, plans, equipment, etc. The relevant point is while the economist is no longer dependent on the oversimplified assumption of "economic man," the explanation of economic phenomena is still in terms of the preferences, choices, and actions available to *individuals.*

In the realm of *sociology*, one can hardly speak of any major theory as "accepted." But it is of interest to survey some of the major theoretical approaches from the standpoint of microreduction.

On the one hand, there is the *economic determinism* represented by Marx and Veblen. In the case of Marx the assumptions of classical economics are openly made: Individuals are supposed—at least on the average, and in the long run—to act in accordance with their material interests. From this assumption, together with a theory of the business cycle which, for all its undoubted originality, Marx based on the classical laws of the market, Marx derives his major laws and predictions. Thus Marxist sociology is microreductionistic in the same sense as classical economics, and shares the same basic weakness (the assumption of "economic man").

Veblen, although stressing class interests and class divisions as did Marx, introduces some noneconomic factors in his sociology. His account is ultimately in terms of individual psychology; his hypothesis of "conspicuous consumption" is a brilliant—and characteristic—example.

Max Weber produced a sociology strongly antithetical to Marx's. Yet each of his explanations of group phenomena is ultimately in terms of individual psychology; e.g., in his discussion of political parties, he argues that people *enjoy* working under a "charismatic" leader, etc.

Indeed the psychological (and hence microreductionistic) character of the major sociologies (including those of Mannheim, Simmel, etc., as well as the ones mentioned above (54, 86, 94, 103)) is often recognized. Thus one may safely say, that while there is no one accepted sociological theory, all of these theoretical approaches represent attempted microreductions.

5.2. Since Schleiden and Schwann (1838/9), it is known that all living things consist of cells. Consequently, explaining the laws valid on level 5 by those on the cell level means microreducing all phenomena of plants and animals to level 4.

As instances of past successes in connection with level 5 we have chosen to cite, in preference to other types of example, microreductions and projected microreductions dealing with *central nervous systems* as wholes and nerve cells as parts. Our selection of these examples has not been determined by anthropocentrism. First of all, substantially similar problems arise in the case of multicellular animals, as nearly all of them possess a nervous system; and, second, the question of microreducing those aspects of behavior that are controlled by the central nervous system in man and the higher animals is easily the most significative (85, p. 1) one at this level, and therefore most worth discussing.

Very great activity is, in fact, apparent in the direction of microreducing the phenomena of the central nervous system. Much of this activity is very recent; and most of it falls under two main headings: *neurology*, and the *logical design of nerve nets*. (Once again, the technical term 'microreduction' is not actually employed by workers in these fields. Instead, one finds widespread and lasting discussion concerning the advantages of "molecular" versus "molar"[22] explanations, and concerning "reductionism.[23]

Theories constructed by neurologists are the product of highly detailed experimental work in neuroanatomy, neurochemistry, and neurophysiology, including the study of electric activity of the nervous system, e.g., electroencephalography.[24]

As a result of these efforts, it has proved possible to advance more or less hypothetical explanations on the cellular level for such phenomena as association, memory, motivation, emotional disturbance, and some of the phenomena connected with learning, intelligence, and perception. For example, a theory of the brain has been advanced by Hebb (32) which accounts for all of the above-mentioned phenomena. A classical psychological law, the Weber-Fechner law (insofar as it seems to apply), has likewise been microreduced, as a result of the work of Hoagland (36).

We turn now to *the logical design* of nerve nets: The logician Turing[25] proposed (and solved) the problem of giving a characterization of *computing machines* in the widest sense—mechanisms for solving problems by effective series of logical operations. This naturally suggests the idea of seeing whether a "Turing machine" could consist of the elements used in neurological theories of the brain; that is, whether it could consist of a network of neurons. Such a nerve network could then serve as a hypothetical model for the brain.

Such a network was first constructed by McCulloch and Pitts.[26] The basic element is the neuron, which, at any instant, is either *firing* or *not firing* (quiescent). On account of the "all or none" character of the activity of this basic element, the *nerve* net designed by McCulloch and Pitts constitutes, as it were, a digital computer. The various relations of propositional logic can be represented by instituting suitable connections between neurons; and in this way the hypothetical net can be "programmed" to solve any problem that will yield to a predetermined sequence of logical or mathematical operations. McCulloch and Pitts employ approximately 10^4 elements in their net; in this respect they are well below the upper limit set by neurological investigation, since the number of neurons in the brain is estimated to be of the order of magnitude of 10^{10}. In other respects, their model was, however, unrealistic: no allowance is made for time delay, or for random error, both of which are important features of all biological processes.

Nerve nets incorporating both of these features have been designed by von Neumann. Von Neumann's model employs bundles of nerves rather than single nerves to form a network; this permits the simultaneous performance of each operation as many as 20,000 times as a check against error. This technique of constructing a computer is impractical at the level of present-day technology, von Neumann admits, "but quite practical for a perfectly conceivable, more advanced technology, and for the natural relay-organs (neurons). I.e., it merely calls for microcomponentry which is not at all unnatural as a concept on this level" (97, p. 87). Still further advances in the direction of adapting these models to neurological data are anticipated. In terms of such nerve nets it is possible to give hypothetical microreductions for *memory, exact thinking, distinguishing similarity or dissimilarity of stimulus patterns, abstracting* of "essential" components of a stimulus pattern, recognition of shape regardless of form and of chord regardless of pitch (phenomena of great importance in Gestalt psychology (5, pp. 128, 129, 152)), *purposeful behavior* as controlled by negative feedback, *adaptive behavior*, and *mental disorders*.

It is the task of the neurophysiologist to test these models by investigating the existence of such nets, scanning units, reverberating networks, and pathways of feedback, and to provide physiological evidence of their functioning. Promising studies have been made in this respect.

5.3. As past successes in connection with level 4 (i.e.,as cases in which phenomena involving whole cells[27] have been explained by theories concerning the molecular level) we shall cite microreductions dealing with three phenomena that have a fundamental character for all of biological science: the *decoding, duplication*, and *mutation* of the genetic information that is ultimately responsible for the development and maintenance of order in the cell. Our objective will be to show that at least one well-worked-out microreducing theory, has been advanced for each phenomenon.[28] (The special form taken by our working hypothesis on this level is "methodological mechanism.")

Biologists have long had good evidence indicating that the genetic information in the cell's nucleus—acting as an "inherited message"—exerts its control over cell biochemistry, through the production of specific protein catalysts (enzymes) that mediate particular steps (reactions) in the chemical order that is the cell's life. The problem of *"decoding"* the control information in the nucleus thus reduces to how the specific molecules that comprise it serve to specify the construction of specific protein catalysts. The problem of *duplication* (one aspect of the overall problem of inheritance) reduces to how the molecules of genetic material can be copied—like so many "blueprints."

And the problem of *mutation* (elementary step in the evolution of new inheritable messages) reduces to how "new" forms of the genetic molecules can arise.

In the last twenty years evidence has accumulated implicating *desoxyribose nucleic acid* (DNA) as the principal "message-carrying" molecule and constituting the genetic material of the chromosomes. Crick and Watson's[29] brilliant analysis of DNA structure leads to powerful microreducing theories that explain the decoding and duplication of DNA. It is known that the giant molecules that make up the nucleic acids have, like proteins (49, 66, 67), the structure of a backbone with side groups attached. But, whereas the proteins are polypeptides, or chains of amino-acid residues (slightly over 20 kinds of amino acids are known); the nucleic acids have a phosphate-sugar backbone, and there are only 4 kinds of side groups all of which are nitrogen bases (purines and pyrimidines). Crick and Watson's model contains a pair of DNA chains wound around a common axis in the form of two interlocking helices. The two helices are held together (forming a helical "ladder") by hydrogen bonds between pairs of the nitrogen bases, one belonging to each helix. Although 4 bases occur as side groups only 2 of 16 conceivable pairings are possible, for steric reasons. These 2 pairs of bases recur along the length of the DNA molecule and thus invite a picturesque analogy with the dots and dashes of the Morse code. They can be arranged in any sequence: there is enough DNA in a single cell of the human body to encode in this way 1,000 large textbooks. The model can be said to imply that the genetic "language" of the inherited control message is a "language of surfaces": the information in DNA structure is decoded as a sequence of amino acids in the proteins which are synthesized under ultimate DNA control. The surface structure of the DNA helix, dictated by the sequence of base pairs, specifies like a template[30] the sequence of amino acids laid down end to end in the fabrication of polypeptides.

Watson and Crick's model immediately suggests how the DNA might produce an exact copy of itself—for transmission as an inherited message to the succeeding generation of cells. The DNA molecule, as noted above, consists of two interwoven helices, each of which is the complement of the other. Thus each chain may act as a mold on which a complementary chain can be synthesized. The two chains of a DNA molecule need only unwind and separate. Each begins to build a new complement onto itself, as loose units, floating in the cell, attach themselves to the bases in the single DNA chain. When the process is completed, there are two pairs of chains where before there was only one![31]

Mutation of the genetic information has been explained in a molecular (microreduction) theory advanced some years ago by Delbrück.[32] Delbrück's theory was conceived long before the newer knowledge of DNA was available; but it is a very general model in no way vitiated by Crick and Watson's model of the particular molecule constituting the genetic material. Delbrück, like many others, assumed that the gene is a single large "nucleo-protein" molecule. (This term is used for macromolecules, such as viruses and the hypothetical "genes," which consist of protein and nucleic acid. Some recent theories even assume that an entire chromosome is a single such molecule.) According to Delbruck's theory, different quantum levels within the atoms of the molecule correspond to different hereditary characteristics. A mutation is simply a quantum jump of a rare type (i.e., one with a high activation energy). The observed variation of the spontaneous mutation rate with temperature is in good quantitative agreement with the theory.

Such hypotheses and models as those of Crick and Watson, and of Delbruck, are at present far from sufficient for a complete microreduction of the major biological generalization, e.g., evolution and general genetic theory (including the problem of the control of development). But they constitute an encouraging start towards this ultimate goal and, to this extent, an indirect support for our working hypothesis.

5.4. Only in the twentieth century has it been possible to microreduce to the atomic and in some cases directly to the subatomic level most of the *macrophysical* aspects of matter (e.g., the high fluidity of water, the elasticity of rubber, and the hardness of diamond) as well as the *chemical* phenomena of the elements, i.e. those changes of the peripheral electrons which leave the nucleus unaffected. In particular, electronic theories explain, e.g., the laws governing valence, the various types of bonds, and the "resonance" of molecules between several equivalent electronic structures. A complete explanation of these phenomena and those of the periodic table is possible only with the help of Pauli's exclusion principle which states in one form that no two electrons of the same atom can be alike in all of 4 "quantum numbers." While some molecular laws are not yet micro-reduced, there is every hope that further successes will be obtained in these respects. Thus Pauling (63, 64) writes:

> There are still problems to be solved, and some of them are great problems—an example is the problem of the detailed nature of catalytic activity. We can feel sure, however, that this problem will in the course of time be solved in terms of quantum theory as it now exists: there seems little reason to believe that some fundamental new principle remains to be discovered in order that catalysis be explained. (64)

5.5. Micro-reduction of level 2 to level 1 has been mentioned in the preceding section because many molecular phenomena are at present (skipping the atomic level) explained with reference to laws of elementary particles.[33] Bohr's basic (and now somewhat outdated) model of the atom as a kind of "solar system" of elementary particles is today part of everyone's conceptual apparatus; while the mathematical development of theory in its present form is formidable indeed! Thus we shall not attempt to give any details of this success. But the high rate of progress in this field certainly gives reason to hope that the unsolved problems, especially as to the forces that hold the nucleus together, will likewise be explained in terms of an elementary particle theory.

6. *Evolution, Ontogenesis, and Synthesis*

6.1. As pointed out in section 4.5, evolution provides indirect factual support for the working hypothesis that unitary science is attainable. Evolution (in the present sense) is an over-all phenomenon involving all levels, from 1 through 6; the mechansims of chance variation and "selection" operate throughout in ways characteristic for the evolutionary level involved.[34] Time scales have, indeed, been worked out by various scientists showing the times when the first things of each level first appeared.[35] (These times are, of course, the less hypothetical the higher the level involved.) But even if the hypothesis of evolution should fail to hold in the case of certain levels, it is important to note that whenever it does hold—whenever it can be shown that things of a given level existed before things of the next higher level came into existence—some degree of indirect support is provided to the particular special case of our working hypothesis that concerns those two levels.

The hypothesis of "evolution" is most speculative insofar as it concerns levels 1 to 3. Various cosmological hypothesis are at present undergoing lively discussion.[36] According to one of these, strongly urged by Gamow (24, 25, 26), the first nuclei did not form out of elementary particles until five to thirty minutes after the start of the universe's expansion; molecules may not have been able to exist until considerably later. Most present-day cosmologists still subscribe to such evolutionary views of the universe; i.e., there was a "zero point" from which the evolution of matter began, with diminishing density through expansion. However, H. Bondi, T. Gold, and F. Hoyle have advanced a conflicting idea, the "steady state" theory, according to which there is no "zero point" from which the evolution of matter began; but matter is continuously created, so that its density remains constant in spite of expansion. There seems to be hope that these rival hypotheses will be submitted to specific empirical tests in the near future. But, fortunately, we do not have to depend on hypotheses that are still so highly controverisal: as we have seen, the mircoreducibility of molecular and atomic phenomena is today not open to serious doubt.

Less speculative are theories concerning the origin of life (transition from level 3 to level 4). Calvin (9; Fox, 22) points out that four mechanisms have been discovered which lead to the formation of amino acids and other organic materials in a mixture of gases duplicating the composition of the primitive terrestrial atmosphere.[37] These have, in fact, been tested experimentally with positive results. Many biologists today accept with Oparin (61) the view that the evolution of life as such was not a single chance event but a long process possibly requiring as many as two billion years, until precellular living organisms first appeared.

According to such views, "chemical evolution" gradually leads in an appropriate environment to evolution in the familiar Darwinian sense. In such a process, it hardly has meaning to speak of a point at which "life appeared." To this day controversies exist concerning the "dividing line" between living and non-living things. In particular, viruses are classified by some biologists as living, because they exhibit self-duplication and mutability; but most biologists refuse to apply the term to them, because viruses exhibit these characteristic phenomena of life only due to activities of a living cell with which they are in contact. But, wherever one draws the line,[38] non-living molecules preceded primordial living substance, and the latter evolved gradually into highly organized living units, the unicellular ancestors of all living things. The "first complex molecules endowed with the faculty of reproducing their own kind" must have been synthesized—and with them the beginning of evolution in the Darwinian sense—a few billion years ago, Goldschmidt (27, p. 84) asserts: "all the facts of biology, geology, paleontology, biochemistry, and radiology not only agree with this statement but actually prove it."

Evolution at the next two levels (from level 4 to level 5, and from 5 to 6) is not speculative at all, but forms part of the broad line of Darwinian evolution, so well marked out by the various kinds of evidence referred to in the statement just quoted. The line of development is again a continuous one;[39] and it is to some extent arbitary (as in the case of "living" versus "non-living") to give a "point" at which true multicellulars first appeared, or at which an animal is "social" rather than "solitary." But in spite of this arbitrariness, it is safe to say that:

(a) Multicellulars evolved from what were originally competing single cells; the "selection" by the environment was in this case determined by the superior survival value of the cooperative structure.[40]

(b) Social animals evolved from solitary ones for similar reasons; and, indeed, there were millions of years during which there were only solitary animals on earth, and not yet their organization into social structures.[41]

6.2. To illustrate ontogenesis, we must show that particular things of a particular level have arisen out of particular things of the next lower level. For example, it is a consequence of most contemporary cosmological theories—whether of the evolutionary or of the "steady state" type—that each existent atom must have originally been formed by a union of elementary particles. (Of course an atom of an element may subsequently undergo "transmutation.") However, such theories are extremely speculative. On the other hand, the chemical union of atoms to form molecules is commonplace in nature.

Coming to the higher levels of the reductive hierarchy, we have unfortunately a hiatus at the level of cells. Individual cells do not, as far as our observations go, ever develop out of individual molecules; on the contrary, "cells come only from cells," as

Virchow stated about one hundred years ago. However, a characteristic example of ontogenesis of things of one level out of things of the next level is afforded by the development of multicellular organisms through the process of mitosis and cell division. All the hereditary characteristics of the organism are specified in the "genetic information" carried in the chromosomes of each individual cell, and are transmitted to the resultant organism through cell division and mitosis.

A more startling example of ontogenesis at this level is provided by the slime molds studied by Bonner (3). These are isolated amoebae; but, at a certain stage, they "clump" together chemotactically and form a simple multicellular organism, a sausage-like "slug"! This "slug" crawls with comparative rapidity and good coordination. It even has sense of a sort, for it is attracted by light.

As to the level of social groups, we have some ontogenetic data, however slight; for children, according to the well-known studies of Piaget (70, 71) (and other authorities on child behavior), acquire the capacity to cooperate with one another, to be concerned with each other's welfare, and to form groups in which they treat one another as peers, only after a number of years (not before seven years of age, in Piaget's studies). Here one has in a rudimentary form what we are looking for: the ontogenetic development of progressively more social behavior (level 6) by what begin as relatively "egocentric" and unsocialized individuals (level 5).

6.3. Synthesis affords factual support for microreduction much as ontogenesis does; however, the evidence is better because synthesis usually takes place under controlled conditions. Thus it enable one to show that one can obtain an object of the kind under investigation invariably by instituting the appropriate causal relations among the parts that go to make it up. For this reason, we may say that success in synthesizing is as strong evidence as one can have for the possibility of microreduction, short of actually finding the microreducing theory.

To begin on the lowest level of the reductive hierarchy, that one can obtain an atom by bringing together the appropriate elementary particles is a basic consequence of elementary nuclear physics. A common examples from the operation of atomic piles is the synthesis of deuterium. This proceeds as one bombards protons (in, e.g., hydrogen gas) with neutrons.

The synthesis of a molecule by chemically uniting atoms is an elementary laboratory demonstration. One familiar example is the union of oxygen and hydrogen gas. Under the influence of an electric spark one obtains the appearance of H_2O molecules.

The next level is that of life. "On the borderline" are the viruses. Thus success at synthesizing a virus out of non-living macro-molecules would count as a first step to the synthesis of cells (which at present seems to be an achievement for the far distant future).

While success at synthesizing a virus out of atoms is not yet in sight, synthesis out of non-living highly complex macro-molecules has been accomplished. At the University of California Virus Laboratory (23), protein obtained from viruses has been mixed with nucleic acid to obtain active virus. The protein does not behave like a virus—it is completely non-infectious. However, the reconstituted virus has the same structure as "natural" virus, and will produce the tobacco mosaic disease when applied to plants. Also new "artificial" viruses have been produced by combining the nucleic acid from one kind of virus with the protein from a different kind. Impressive results in synthesizing proteins have been accomplished. e.g., R. B. Woodward C. H. Schramm (107; see also Nogushi and Hayakawa, 60; and Oparin, 61) have synthesized "protein analogues"—giant polymers containing at least 10,000 amino-acid residues.

At the next level, no one has of course synthesized a whole multicellular organism out of individual cells; but here too there is an impressive partial success to report. Recent experiments have provided detailed descriptions of the manner in which cells organize themselves into whole multicellular tissues. These studies show that even isolated whole cells, when brought together in random groups, could effectuate the characteristic construction of such tissues.[42] Similar phenomena are well known in the case of sponges and fresh-water polyps.

Lastly, the "synthesis" of a new social group by bringing together previously separated individuals is extremely familiar; e.g., the organization of new clubs, trade unions, professional associations, etc. One has even the deliberate formation of whole new societies, e.g., the formation of the Oneida community of utopians, in the nineteenth century, or of the state of Israel by Zionists in the twentieth.

There have been experimental studies in this field; among them, the pioneer work of Kurt Lewin and his school is especially well known.[43]

7. *Concluding Remarks*

The possibility that all science may one day be reduced to microphysics (in the sense in which chemistry seems today to be reduced to it), and the presence of a unifying trend toward micro-reduction running through much of scientific activity, have often been noticed both by specialists in the various sciences and by metascientists. But these opinions have, in general, been expressed in a more or less vague manner and without very deep-going justification. It has been our aim, first, to provide precise definitions for the crucial concepts involved, and, second, to reply to the frequently made accusations that belief in the attainability of unitary science is "a mere act of faith." We hope to have shown that, on the contrary, a tentative acceptance of this belief, an acceptance of it as a working hypothesis, *justified*, and that the hypothesis is *credible*, partly on methodological grounds (e.g., the simplicity of the hypothesis, as opposed to the bifurcation that rival suppositions create in the conceptual system of science), and partly because there is really a large mass of direct and indirect evidence in its favor.

The idea of reductive levels employed in our discussion suggests what may plausibly be regarded as a *natural order of sciences*. For this purpose, it suffices to take as "fundamental disciplines" the branches corresponding to our levels. It is understandable that many of the well-known orderings of things[44] have a rough similarity to our reductive levels, and that corresponding orderings of sciences are more or less similar to our order of 6 "fundamental disciplines." Again, several successive levels may be grouped together (e.g., physics today conventionally deals at least with levels 1, 2, and 3; just as biology deals with at least levels 4 and 5). Thus we often encounter a division into simply physics, biology, and social sciences. But these other efforts to solve a problem which goes back to ancient times[45] have apparently been made on more or less intuitive grounds; it does not seem to have been realized that these orderings are "natural" in a deeper sense, of being based on the relation of *potential microreducer* obtaining between the branches of science.

It should be emphasized that these six "fundamental disciplines" are, largely, fictitious ones (e.g., there is no actual branch whose universe of discourse is *strictly* molecules and combinations thereof). If one wishes a less idealized approach, one may utilize a concept in semantical information theory which has been defined by one of us (3). This is the semantical functor: 'the amount of information the statement S contains about the class C' (or, in symbols: *inf* (S, C)). Then one can characterize any theory

S (or any branch, if we are willing to identify a branch with a conjunction of theories) by a sextuple: namely, inf(S, level 1), inf(S, level 2) . . . inf(S, level 6). This sextuple can be regarded as the "locus" of the branch S in a six-dimensional space. The axes are the loci of the imaginary "fundamental disciplines" just referred to; any real branch (e.g., present-day biology) will probably have a position not quite on any axis, but nearer to one than to the others.

Whereas the orderings to which we referred above generally begin with the historically given branches, the procedure just described reverses this tendency. *First* a continuous order is defined in which any imaginable branch can be located; *then* one investigates the relations among the actually existing branches. These positions may be expected to change with time; e.g., as microreduction proceeds, "biology" will occupy a position closer to the "level 1" axis, and so will all the other branches. The continuous order may be described as "Darwinian" rather than "Linnean"; it derives its naturalness, not from agreement with intuitive or customary classifications, but from its high systematic import in the light of the hypothesis that unity of science is attainable.

Notes

1. Science, in the wider sense, may be understood as including the formal disciplines, mathematics, and logic, as well as the empirical ones. In this paper, we shall be concerned with science only in the sense of empirical disciplines, including the sociohumanistic ones.
2. By a "theory" (in the widest sense) we mean any hypothesis, generalization, or law (whether deterministic or statistical), or any conjunction of these; likewise by "phenomena" (in the widest sense) we shall mean either particular occurrences or theoretically formulated general patterns. Throughout this paper, "explanation" ("explainable" etc.) is used as defined in Hempel and Oppenheim (35). As to "explanatory power," there is a definite connection with "systematic power." See Kemeny and Oppenheim (46, 47).
3. If we are willing to adopt a "taxonomic system" for classifying all the things dealt with by science, then the various classes and subclasses in such a system could represent the possible "universes of discourse." In this case, the U_{Bi} of any branch would be associated with the extension of a taxonomic term in the sense of Oppenheim (62).
4. Henceforth, we shall as a rule omit the clause 'at time t'.
5. Oppenheim (62, section 3) has a method for measuring such a reduction.
6. Of course, in some cases, such "skipping" does occur in the process of microreduction, as shall be illustrated later on.
7. As to degree of *credibility*, see Kemeny and Oppenheim (45, especially p. 307).
8. The "acceptance, as an overall fundamental working hypothesis, of the reduction theory, with physical science as most general, to which all others are reducible; with biological science less general; and with social science least general of all," has been emphasized by Hockett (37, especially p. 571).
9. As to *natural*, see Hempel (33, p. 52), and Hempel and Oppenheim (34, pp. 107, 110).
10. Many well-known hierarchical orders of the same kind (including some compatible with ours) can be found in modern writings. It suffices to give the following quotation from an article by L. von Bertalanffy (95, p. 164): "Reality, in the modern conception, appears as a tremendous hierarchical order of organized entities, leading, in a superposition of many levels, from physical and chemical to biological and sociological systems. Unity of Science is granted, not by an utopian reduction of all sciences to physics and chemistry, but by the structural uniformities of the different levels of reality." As to the last sentence, we refer in the last paragraph of section 2.2 to the problem noted. Von Bertalanffy has done pioneer work in developing a General System Theory which, in spite of some differences of emphasis, is an interesting contribution to our problem.
11. The following example is a slight modification of the one given in Hempel and Oppenheim (35, p. 148). See also Rescher and Oppenheim (76, pp. 93, 94).
12. See Rescher and Oppenheim (76, p. 100), and Rescher (75). Of course, nothing is intrinsically a "true" whole; the characterization of certain things as "wholes" is always a function of the point of view, i.e. of the particular 'Pt' relation selected. For instance, if a taxonomic system is given, it is very natural to define 'Pt' so that the "wholes" will correspond to the things of the system. Similarly for *aggregate* see Rescher and Oppenheim (76, p. 90, n. 1).