METHODOLOGICAL ASPECTS OF UNIFIED THEORIES IN PHYSICS

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Discussion Paper

on

Bernulf Kanitscheider

REDUCTION AND EMERGENCE IN THE UNIFIED THEORIES OF PHYSICS

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Comments to Bernulf Kanitscheider's paper "Reduction and Emergence in the Unified Theories of Physics"

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It has become quite popular to view the history of science, and of physics in particular, as a recurrent sequence of alternating phases of "normal science" and "revolutions" (Kuhn). The history of physical sciences may perhaps equally well be viewed as a sequence of alternate periods of fractionations and unifications of science. These two points of view are not necessarily antithetic to each other. On the contrary, there are good reasons to maintain that all great "revolutions" in science were coupled with sweeping conceptual unifications and all phases of "normal science" with processes of diversifications. The Newtonian "revolution" originated from a fusion of terrestrial and planetary motions into a unified theory of mechanics, the Maxwellian "revolution", or more precisely, the emergence of field theories in the second half of the nineteenth century, involved a unified treatment of electricity, magnetism and light; special relativity produced the unified notion of spacetime, "the only kind of union (of space and time) which preserves an independent reality", as Hermann Minkowski phrased it in his famous lecture of 1908; the central idea of Einstein's general relativity unified inertial motion and gravitational acceleration (equivalence principle) and quantum mechanics may be viewed as a formalism of unifying the corpuscular and undulatory aspects of physical reality.

Many physicists believe that future historians of science will regard the present period as being again an important, if not the most important, phase of unification, and this because of its stunning - though for the time being only partial - success in the quest toward a complete, consistent and unified theory of all known physical interactions. Of course, one has to be cautious about making such a prediction ("especially about the future", as Niels Bohr once added). History offers numerous examples of similar prognostications which subsequently turned out to be false prophesies.[1] But the present research in unified theory differs, I believe, fundamentally from all preceding argumentations for the completeness and unification of physics, and this not only in its theoretical approach but also in its methodological aspects: the intimate interplay between ingenious mathematical constructs and sophisticated experimental techniques elevates the epistemological status of modern unified theory above that of all previous speculations about the unity of physics. And yet, the epistemological and methodological foundations of these unified theories are still an almost completely unexplored territory in the philosophy of science the reason being of course the complexity and uncompleteness of the subject.

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1. Cf.,e.g., L. Badash, "The completeness of nineteenth century science", <u>Isis 63</u> (1972), pp. 48-58.

2. Among the few exceptions we mention the papers written by J.T.Cushing, M.L.G.Redhead, M.A.Melvin and K. Shrader-Frechette.

It is therefore most meritorious that Prof. Kanitscheider, whose previous work on this theme is well know to all of us, has chosen this subject again, and this time in the context of his proposal of how to combine a methodological analysis of common procedures in different scientific branches with ~~[illegible]~~ an ontological study of different levels of reality without ignoring the specific characteristics of the respective disciplines.

I shall confine my comments,which are more explanatory than critical, to the early and final sections of his paper. It is not so much Kanitscheider's own deliberations but rather his point of departure, namely Bunge's allegedly rigorous definition of "level" or "level structure" which I would like to enlarge upon.

In 1950 L. von Bertalanffy[3] ~~wrote that~~, one of the pioneers in the development of General System Theory, wrote that "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."[3] Eight years later, Paul Oppenheim and Hilary Putnam, adopting this categorization of reality, presented their method of derivational reductionism by proposing

[3] L. von Bertalanffy, "An outline of general system theory", *The British Journal for the Philosophy of Science 1* (1950), pp. 134-165.

a system of reductive levels which were so chosen that a class of objects of a given level could serve as a potential reducer of any class of objects of the next higher level, if there is one, as e.g. in the categorization : Elementary particles, atoms, molecules, cells, multicellular organisms, social groups. To each class of objects of a given level, it was claimed, corresponds a scientific discipline which, with the exception of physics, should be derivable from the laws of science belonging to the next lower level, together with bridge principles which identify the nature of objects at the level to be reduced with particular structures of the objects of the reducing level, that is, the next lower level.

It soon became apparent that the Oppenheim-Putnam scheme of levels is not only greatly oversimplified but that also its linear, hierarchical order does not hold in concrete applications. Thus, to mention a more recently discussed example[4], any ecological system, such as that of bacteria, combines in its structure at least three levels : molecules, single cells, and multicellular organisms. Moreover, it became clear that the very notion of "level" was highly ambiguous.

To remove this ambiguousness Mario Bunge proposed in 1960 a semantical classification of "levels" which in his view could clear the ground for ontological speculations. In his classification Bunge listed nine different meanings of "level", the first of which (Level_1) explicates "level" as synonymous with "degree" in a purely quantitative sense (like "height") and the last of which (Level_9), described by Bunge

[4] J. Dupré, "The disunity of science", Mind 92 (1983), pp. 321-346.

as being the "most important for the building up of scientifically oriented ontologies", is used if one speaks of levels of reality.[5] As it seems, Bunge himself was not satisfied with his analysis, for thirteen years later he proposed[6] what he regarded a more rigorous definition of "level", and which has been adopted by Kanitscheider in his present paper (p.3). Bunge also argued for the elimination of the order relation (which had been postulated by von Bertalanffy as well as by Oppenheim and Putnam) and in its stead introduced the emergence relation E to express the appearance of qualitative novelties. Thus, just as in differential geometry where the definition of a "differential structure" precedes that of a "differential manifold", Bunge defined first a <u>level structure</u> as an ordered pair $\langle S , E \rangle$ and then a <u>level</u> as "a set of individual systems iff it is a member of the family S of a level structure. The binary relation E is "a one-many, reflexive and transitive relation in S." Since the relation E plays an important role also in Kanitscheider's conception of "emergence", it is not out of place to look at it more closely. As just mentioned, this relation E is postulated to be "one-many" as well as "transitive". Now, the "many" in "one-many" is already implied by the transitivity and hence redundant; the requirement under discussion is therefore confined to only demanding that cases like $\sigma_1 E \sigma$ and $\sigma_2 E \sigma$ are not admitted, where σ_1, σ_2 and σ are elements of S.

[5] M. Bunge, "Levels : a semantical preliminary", <u>Review of Metaphysics 13</u> (1960), pp. 396-406.

[6] M.Bunge, "The metaphysics, epistemology and methodology of levels" in <u>Method, Model and Matter</u> (Reidel, Dordrecht, 1973), pp. 160-168.

7

True, E not being an asymmetric relation, a level structure is certainly not a partially or totally ordered set, although it is nevertheless a set of "chains" (in the sense as used in lattice theory). I am not sure whether the above-mentioned "one-many" restriction was really intended and whether it is essential. In any case, it seems to me that Bunge hinself did not adhere to it in some of his illustrations[7] and applications[8].

Let me now turn to the substance-matter of Kanitscheider's paper proper. The argumentation for the inadequacy of a simple eliminative reductionism, in contrast to his plea for a methodological reductionism, involving interlevel explanations, are quite convincing. The notion of "ontological distance", as introduced in his paper on p.8, seems to be very fruitful not only with respect to his insistence that "explanation of levels should be contrived with minimal ontological distance". But is this kind of "distance" accessible of metrization ?

Prof. Kanitscheider's historical remarks about the problem concerning the unity versus plurality of science, in its ontological, epistemological and methodological aspects (from Copernicus to Wheeler) are very instructive and I fully accept his conclusion concerning the need of of ontological and epistemological coherence as a precondition for the knowability of nature.

7. M.Bunge, op.cit. (Ref.6), p. 162.
8. M.Bunge, "Is chemistry a branch of physics ?", Zeitschrift für allgemeine Wissenschaftstheorie 13 (1982), pp. 209-223, where even the notion "hierarchy of sciences" precisely in the context of level structures is made use of (p. 210).

Let me now turn to the final sections of Prof. Kanitscheider's paper and comment on the problem raised there whether the recent development of unified theories in physics can be regarded as supporting the claim of the strong reductionist that physical reality will ultimately reveal itself as being only one ontological entity.

Reviewing the development of modern physics with the progressive and cumulative unification of its diverse branches, one gets the impression that the answer is positive. It is worthwhile to recall some of the critical steps in this development.

Classical physics and even the quatum theory as far as it was developed until 1928 were ontologically based on the dichotomy of physical reality into particles on the one hand, and fields (or waves) on the other. The conceptual breakthrough toward the unification of these two seemingly disparate categories was achieved in 1928 when Wigner and Jordan were able to show that "die Existenz materieller Teilchen [wird] in ähnlicher Weise [erklärt] , wir durch die Quantelung der elektromagnetischen Wellen die Existenz von Lichtquanten ... erklärt wird."[9] By showing that material particles can be regarded as quanta of fields Wigner and Jordan paved the way toward a unified field-theoretic conception in which the status of particles was reduced to that of merely an epiphenomenon. The emerging quantum field theory which so successfully accounted for the creation and annihilation of particles

[9] P. Jordan and E. Wigner, "Über das Paulische Äquivalenzverbot", *Zeitschrift für Physik 47* (1928), pp. 631-651.

was soon faced, however, with a serious difficulty. Only two years later when Robert Oppenheimer tried to calculate the energy shift produced by the interaction of an atomic electron with the quantum electromagnetic field, he found that the result diverges to an infinity. Soon similar infinities were found in other contexts such as electron scattering or the polarization of the vacuum by applied electric fields. To overcome these difficulties the renormalization method was developed (Weisskopf), a method which eliminates infinities simply by absorbing them into a redefinition of physical parameters such as mass or charge. Yet in spite of its brilliant predictions of the Lamb-Retherford shift (Bethe) and of the anomalous magnetic moment of the electron (Schwinger), quantum field theory lost much of its credibility after it was shown in 1949 (Dyson) that only a small class of quantum field theories were renormalizable. In particular, the phenomena of weak interaction, responsible for beta-decay or neutron-decay, could not be accounted for by a renormalizable field theory, nor was it possible - though for different reasons, as we know today - to construct for strong interactions a renormalizable field theory which yields quantitative predictions in agreement with experience.

The resolution of this difficulty was found only after an idea was revived that had been proposed already in 1919 by Hermann Weyl in his abortive attempt to unify Einstein's general relativistic theory of gravitation with Maxwell's theory of the electromagnetic field : the idea of gauge invariance (a classic example of how good ideas are often discovered long before their time). Because of the paramount importance of this notion - all modern physical theories are gauge field theories - I shall discuss it in more detail. Instead of explaining how Weyl introduced this idea by enriching the affine connection of Riemannian geometry through an additional rule which determines whether two vectors at neighboring points are of equal length and interpreting this extra affine structure as the electromagnetic potential, I shall give an example which is simpler and also more congenial with its revival ofr field theory by C.N.Yang and Robert Mills in 1954.

As is well known from classical particle physics, any invariance or symmetry of the Lagrangian entails the existence of a conserved quantity. This theorem (Noether 1918), or its generalization for Lagrangian densities, remains valid also in quantum field theory. For example, the Lagragian which via the Euler-Lagrange variational process leads to the non-relativistic Schrödinger equation is invariant under a phase transformation of the wave function $\psi(x)$:

$$\psi(x) \longrightarrow \psi'(x) = e^{ia} \psi(x)$$

If a is a constant, this transformation is called a <u>global</u> gauge transformation (for the phase is being fixed "globally", that is, at every spacetime point to the same extent); if however a is itself a function of x, the transformation is a <u>local</u> gauge transformation. We speak of a local gauge invariance if the Lagrangian remains invariant under a local gauge transformation - which in our example happens if the electromagnetic four-potential is subjected to the classical (electromagnetic) gauge transformation. It should be clear that although the term "local" has the connotation of something more restricted than that suggested by the term "global", the requirement of a local symmetry imposes far more stringent constraints upon the construction of a theory than the requirement of a global symmetry. In fact, to preserve the invariance under a local transformation a new factor has to be added, a force (or equivalently a particle which transmits this force) so as to compensate for the variations at different spacetime localities. Any direct or indirect experimental demonstration of the existence of such a force (or particle) would of course constitute a corroboration of the theory. This also explains why Prof. Kanitscheider could justifiably declare (p. 33) that "there is a host of phenomena that would be entirely unknowable, if we renounce ... unified theories" and that "unification is concerned with surplus meaning" (p. 33).

This brings me back to the introductory considerations of the paper, namely Bunge's conception of level structure etc. For I claim that "would be entirely unknowable", or more precisely, the emerging knowability does not necessarily imply an innovation *de facto* and in a temporal sense. According to Bunge, any innovation, even in an epistemological sense, is always chronologically later - "just 'later' in the game", as he put it [10]. But consider a static distribution of electric charges. Charge conjugation (i.e. exchanging every positive charge by an equal negative charge and *vice versa*), or increasing the potential of the whole distribution system by a constant amount, are clearly global gauge transformations : no change of the electric field will be observed. If however some of the charges are in motion, producing

[10] M. Bunge, *op.cit.* (Ref.6), p. 161.

thereby a magnetic field, the global symmetry is broken. It is precisely the effect of the (emerging) magnetic field that reinstitutes local symmetry. But, as is well known, man's knowledge of magnetism (loadstone) is older than his knowledge of electricity, although in this example the level of magnetism "emerged" from that of electricity. However, with "electricity" or rather "electric charges" the situation is not much different. When Steve Weinberg (1967) and Abdus Salam (1968) proposed their unified gauge theory of the electromagnetic and weak interactions - ignoring the renormalizability problem which eventually was soved only in 1971 (G. t'Hooft) - it transpired that (due to the W boson gauge field) the classical electric charge e of the electron, measured by Robert A. Millikan in 1906 on the assumption of being described by Coulomb's law, actually contains contributions from the new weak interaction.

Such consequences of the Weinberg-Salam unified gauge theory are essentiall reinterpretations of well established results and as such can hardly be regarded as verifications of the theory, in contrast, say, to the recent discoveries of the $W^{\pm}$ bosons and the Z^{0} neutral currents.

But let us point out that there are a number of other predictions of the unified theories the methodological status of which with respect to their verificational power remains even more problematic. To provide the spontaneous symmetry-breaking mechanism in the Weinberg-Salam model Higgs bosons had to be introduced whose existence is subject to verification but not to falsification since their masses can be given arbitrarily high values. In the "grand unified theory" (GUT) which tries to unify the weak, electromagnetic and strong interactions, the respective coupling constants merge only at energies of the order of 10^{15} GeV, an amount which may be well unattainable. The most promising model of the supergravity theory, which attempts to unify these three interactions with that of gravitation, is based on the assumption of N = 8 particles or preons (Zumino) whose experimental detection seems likewise to be beyond human possibilities. From the methodological as well as epistemological point of view these facts raise problems rarely, if at all, encountered in the past. It seems as if knowledge progresses not only at the expense of intuitive understanding but also by a mortgage on the future.