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# REDUCTION AND EMERGENCE IN THE UNIFIED THEORIES OF PHYSICS

by

**Bernulf Kanitscheider**
Professor for the Philosophy of Science
Center for Philosophy
University of Giessen
West Germany

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# Reduction and Emergence in the Unified Theories of Physics

Bernulf Kanitscheider

## I. Methodological and Metaphysical Reductionsm.

In his postscript to the Logic of Scientific Discovery Karl Popper points out an important distinction: on the one side there is the assertion that adjoining sciences like physics and chemistry, chemistry and biology, biology and psychology, psychology and sociology can have common methodological traits in gaining their knowledge, in the evaluation of their hypotheses and in testing their conjectures. On the other side this community should not be interpreted in the sense, that ultimately this sciences have only one ontological domain, that means their reference class is a homogeneous set of objects of the same kind. This according to Karl Popper would be a metaphysical misuse of the methodological mutuality.

Common method in the Popperian sense does surely not mean, that there are no differences in the special *tactics* of the various disciplines - controlling a chemical assertion cannot be accomplished by the same procedures as the testing of a theorem in psychology. Methodological unity points only to very broad patterns which comprise the fallible states of all assertions, the preliminary way, in which science approaches its goal and the surely logically untrespassing fact that there can be no ultimate explanation, each proposed solution being open for criticisms forever.[1]

The conceptual difference between common *method* and differing *tactics* of the various sciences is a crucial one, because it mirrors the independence and ontological autonomy of the universes of discourse of the various disciplines.

It is Popper's sorrow that the autonomy of the various ontological domains would get lost if we trespass our knowledge-claim from methodology to metaphysics. In the following I would like to make a proposal how methodological talk about common procedures of different disciplines can be combined with ontological talk of different layers of reality without eliminating the crucial characteristics of the respective scientific domains. This should be managed by a balanced use of the concept of 'level' and 'hierarchy'. Examples from the unified theories of physics will document the fruitfulness of this explication.

## II. Reductionism in a strong and a weak sense.

There has been considerable quarrel in the foundations of biology and of the social sciences on the levels of organization, on the hierarchy of the structural layers of different complexity. In any case this dispute revealed that 'level' has many uses. This ambiguity can be reduced if we adopt a sharpening of the concept which has been introduced by Mario Bunge[2]

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1 K.R. Popper: Scientific Reduction and the Essential Invompleteness of all Science, in: The Open Universe. London 1981, p. 131

2 M. Bunge: The Metaphysics, Epistemology and Methodology of Levels, in: Model, Matter and Method, Dordrecht 1973, p.16o

He starts from the definition of a *level structure* L

D 1 L is a level structure iff L is an ordered pair $L = \langle S, E \rangle$ where S is a family of sets of individual systems and E is a binary relation in S such that the following conditions are fulfilled:

L1 Every member of S is a set of systems that are equivalent in some respect.

L2 E is a one-many, reflexive and transitive relation in S.

L3 E represents the emergence of qualitatively new systems in a process.

D 2 A set of individual systems is a *level* iff it is a member of the family S of a level structure L

D 3 A level is *newer* than another level of the same structure L iff the former has emerged from the latter.

This proposal for the use of 'level' characterizes the concept as a collection of systems with a typical set of properties and laws. The evolutionary line is indicated within the succession of levels only by means of the time-dependence, a biological mechanism for descent is not necessarily included. If one level grows out of the former, it is not in any sense superior, it only came into existence at later times. Therefor no *value concept* and no *domination relation* is involved in Bunge's reconstruction of level structure, although it could be included if it should be strengthened in the direction of the concept of a *'hierarchy'*. The same concerns the notion of *order*: The general concept of level structure is not bound to be partially or even totally ordered because the relation E of emergence is not in every case asymmetric. In customary analyses too much stress has been laid on totally ordered sets of theories[1] but it has been shown by H. Primas and W. Gans that in general theoretical levels are not so simply related.[2]

If we cast an eye on nature as it is mirrored by today's best corroborated theories, we can filter out some epistemologically abstract ontological theses which lie at the bottom of science.The universe does not seem to be a homogeneous block but obviously possesses a stratification, such that the different strata are ontologically and nomologically connected Within each sector a relative autonomy of the constituents and their mutual interaction can be observed.

A strong reductionism posed as a claim on the nature of reality in the sense that in the last end there exists only one monistic (physicalistic or spiritualistic) entity is not justified by current natural science. Whether this strong reductionist thesis can be upheld within one particular discipline like physics will be treated in a later chapter.

On the other side there is no vindication for an overstated emergentism in the sense that the above mentioned strata are totally isolated realms without interactions. Emergence is real but not lawless! The used metaphor of stratification originates in geology. Sedimentation, the process of the production of the different layers, occurs surely in a lawful way and can be described by theories which make the

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1 P. Oppenheim and H. Putnam: Unity of Science as a working hypothesis, in: Minn. Stud. Phil. Sci. II. Minneapolis 1958 p. 3-36

2 H. Primas and W. Gans: Quantenmechanik, Biologie und Theorienreduktion, in: B. Kanitscheider (ed.): Materie - Leben - Geist. Berlin 1979, p. 15-42

whole edifice comprehensible. In the same way as we can understand how the marvellous structural formation of the Grand Canyon came about from the Cambrian layer of the Colorado River till the mesozoic rock formations at the south and the north rim, we want to have an explanation how the multifarious structure of reality originated. Two possible mistakes lurk around the corner. Neglecting the level structure eliminates the explanandum, neglecting the lawful interaction between the different layers makes the understanding of the whole edifice of nature impossible, because it seems to be a miracle how the later level of higher complexity could have arisen at all.

The process of emergence which engenders new autonomous kinds of stable entities is an occurence which surely cannot be conceived as a simple cumulative progress, since within the class of complexer entities properties and lawful connections of the simpler level may be lost, but on the other side there is a dependence of the more complex levels on the earlier more simple constituents which deliver the building material of the former. In order to grasp the intra-level structure of one layer of reality and the genesis of the whole construction two kinds of laws must be taken into consideration, those laws which guarantee the morphology and *stability of one special level* and the *morphogenetic laws* which govern the transformation of the structures into more complex ones and the decay into their elements, if the physical boundary conditions change.

Remember, if today's cosmology should provide us with an approximately correct picture of the universe, than in each case, be it spatially closed or spatially infinite in extent, there is only a short interval of cosmic time during which structures can grow and be maintained for a while. In the case of closure all higher structures will be broken up by the high temperatures which prevail near the final singularity (big crunch), and in the case of an open universe all complex entities will decay at very late times until only a few stable elementary particles will make up the material constituents of a thinning and ever expanding cold space.

One of the decisive demands of a coherent philosophy of science consists in keeping a logically clear relation between the ontology, the epistemology, and the methodology of science. Although the fundamental nature of things cannot be grasped in an immediate theoryfree way and has to be reconstructed under the presupposition that a group of current theories is approximately true, we have to ponder Aristotle's rule that the ordo essendi is logically prior to the ordo cognoscendi. Thus, if ontology mirrors the general traits of 'the way things are', our epistemology should correspond, at most in a mediate way, to the nature of this reality.

Therefore the assertion gets plausible that the division of science in a plurality of different sciences is not a conceptual artifact but an indicator that also within our knowledge a level structure shows up that mirrors the diversity of peculiar natural kinds on the level of reality.

If we take it for granted that neither reality is a large monolithic block nor science can be a undivided whole, then a simple eliminative reductionism can be excluded. This in turn does not mean that research in one field of science should not care of the adjacent levels, particularly those levels in which the universe of discourse in question has its root. On the contrary, genetic questions which point to the origin of a class of systems are deeper and more difficult to answer than those which pertain to one given layer. The investigation of the form and structure of galaxies is a live object of current research. A lot of details are known how spirals, barren-spirals, and elliptic galaxies are constructed, but far more difficult to fathom is the question of the formation of galaxies, their development from primordial fluctuations of the matter and radiation content of the universe after the era of recombination.[1] In the physical domain, the agglomeration of matter to bulky objects represents a decisive step from homogeneity to heterogeneity in the state of the universe, and by this kind of phase transition an entirely new type of condensed matter is created. A theory that accounts for this transition or emergence of a new level of reality and that gives reasons why galaxies are stable enduring systems governed by a novel network of laws, can be called a morphogenetic theory.

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1 cf. J. Silk: The big bang. San Francisco 198o

Our example suggests that explanations of the origin of one level should at first be sought in the adjacent earlier existing level. If we are interested in the question, why there are biological systems at all, we are well advised not to delve into the problem of galaxy formation. In this respect we can introduce the concept of *ontological distance* and together with it the methodological rule that explanation of levels should be contrived with minimal ontological distance. Methodology in general must bear in mind the ontological and epistemological hypotheses about levels. Method should be the rule-directed guide in the search for knowledge; in that endeavour it has to respect the structure of the world and our intellectual power.

In this context *methodological reductionism* has its natural place. If a strange phenomenon suddenly appears within one level of reality, seemingly disconnected from every process known so far within this realm, one is well advised to try explanations as far as possible within this level; but should it be so recalcitrant as to withstand every reduction to the constituents of this level and their interactions one has to be aware that possibly an *emergent phenomenon* has been discovered. No general rule can be given when to start the keen hypothesis that the phenomenon in question cannot be integrated in a specific level. When all attempts fail to construct explanations within conceptually most parsimonious intralevel solutions it would be stubborn to stick to ontological reductionism; in this case one has to be open minded to *interlevel explanations* to catch the possible novelty of the emergent phonomenon.

In this way a methodological reductionism can be combined with the metaphysical background conviction that the world has an ontological stratification. It is, however, a recommendable strategy of scientific method not to be too lavish of the introduction of apparent new levels.

A thoroughgoing examination of the mechanism of emergence is needed in the case of an interlevel explanation. Little is gained if we formulate just the introduction of the new layer of reality in a black box manner: "If we take for granted the unknown substance X with the emergent properties Y governed by the laws Z, phenomenon Φ can be explained." The black box by which X was introduced has to be transformed in a translucid or glass box by giving an explicit mechanism how substance X hitherto unknown within the pertinent level of explanations is related to the well known intralevel properties. Levels cannot pop out of nothing, they have a history and therefore their genesis must be reconstructed by finding the laws of emergence. The postulate of lawless genesis of new levels is sheer obscurantism and furthers irrationalism. As we shall see in due time in connection with the mind body problem and the methodological weight of monistic and dualistic solutions, it is the crucial point of the dualistic view to specify the mechanics of emergence of the psychic substance out of the older biological matter and to make explicit the lawful interaction among the two kinds of ontological levels.

To give just another example that belongs to physics proper: I'll remind the reader of the discussion of the 195o's in cosmology concerning the creation of matter.[1] Relativistic cosmology was at that time paralysed by the crisis of time scale. Steady State Theory (SST) offered a solution to the recalcitrant phenomenon by invoking the hitherto totally unknown process of spontaneous creation of matter. A stationary state of the universe can only be upheld if an ex nihilo process is postulated which generates the new matter replenishing that one driven away by the expansion. The SST of Fred Hoyle postulated such a creation process and gave a mathematical expression for the origin of matter, but said nothing about the kind of matter that was created, especially it was silent on the quantum details specifying the creation process.

This failure of the theory to give any hint on the nature or mode of origin of the arising matter triggered Wolfgang Pauli's famous critic: "If matter could be created, it would be very good, but you must tell me exactly how it happens."[2] Pauli laid his finger tip precisely on the weak point of the SST. If there would be a new level of physical reality which is characterized by creation processes it had to be linked with the well known levels of nature, in order to

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1 For a broader analysis cf: B. Kanitscheider: Kosmologie. Geschichte und Systematik in philosophischer Perspektive. Reclam, Stuttgart 1984

2 F. Hoyle: Steady-State Cosmology Re-visited. Cardiff 198o, p. 9

prevent gaps in the rational description of nature. The same is valid for the age old mind body problem. The protagonist of the dualist solution believing in mind as an immaterial entity wherein feelings, memories, and ideas occur, must urgently pay attention that he does not dissect the spiritual minding substance from the rest of nature, because the historical process of emergence and also the actual psycho-physical interaction become very difficult to understand then.[1] The level-hypothesis should not be misused in the sense of a new dissociation of nature in nomologically unconnected parts. As we'll see in later examples it was the great success of modern science to establish a narrow interconnexity between the different domains of reality, one of the preconditions of the intelligibility of the universe. If this proviso is kept in mind ontological pluralism can be fruitfully combined with methodological reductionism.

## III. Ontological Unity and Knowledge

The problem of the unity versus diversity of science in all three aspects of philosophical reasoning - the ontological, epistemological and methodological one - was a matter of debate since ancient times. Geometry and astronomy belonged to the preferred topics of investigation of the Greeks. Since early times, they tried to construct rational models of the planetary motions. A famous mathematical model was developped by Eudoxos of Knidos, improved by Kallippos and further enriched and furnished with a realistic physical semantics by Aristotle.[2] It was him, who gave the decisive ontological interpretation corresponding to which there are two entirely

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[1] M. Bunge: The Mind-Body Problem. Oxford 198o

[2] N.R. Hanson: Constellations and Conjectures. Dordrecht 1973.

different kinds of substances in nature, terrestrial matter (the four elements) and celestial matter (the quinta essentia). The bordering line between these two substances is the sphere of the moon. The sublunar realm is not only ontologically, it is also nomologically separated from the heavenly realm, namely in regard to its possible motions. The supralunar celestial "bodies" built out of the ether perform perfect circular motions in accordance with the incorruptible nature of their substance, whereas the sublunar terrestrial bodies of the four elements are by there intrinsic nature destined to perform vertical rectilinear motions. These two kinds of geometrical forms would not by themselves hamper an investigation of the heavens; the inhibitorical effect on the progress of knowledge results from the fact that no terrestrial physical law, which can be tested by earth-bound observers may be transferred to the heavenly spheres.

If we start with the preconceived opinion that beyond the orbit of the moon a realm begins, which is nomologically independent and totally different, then a genuine astrophysics is impossible. Without the minimal assumption, that the two ontological and nomological domains can lawfully interact, an empirically controlled investigation of these parts of the cosmos which cannot be inspected by direct contact is forever out of our reach. If the laws of nuclear physics, thermodynamics, and magnetohydrodynamics which we control in our terrestrial laboratories are not applicable to celestial matter we are at a loss in astrophysics.

The assumption of the ontological unity of the universe is however not beyond control. It could be possible e.g. that the riddle of the solar neutrinos has something to do with a premature transference of local laws of nuclear physics. If taken seriously, Aristotle's dissection of the universe in two incommensurable parts would make even common sense observation of the sky incomprehensible. Historically regarded, when an optical variation of a part of the sky was observed, a meteorological explanation within the terrestrial atmosphere had to be inserted, because the location of such a variable phenomenon within the sphere of the fixed stars was forbidden by the immutability of the etherical matter.

Even before the invention of the telescope, the observation of the sky with spectacles (which was quite customary since 13th century) must have been suspect to a genuine Aristotelian, because that would mean to apply terrestrial geometrical optics to stellar light rays. In modern terminology we would ask such an Aristotelian why at all does the etherical matter emit electromagnetical waves or photons that can affect the retina of an organism built up from terrestrial matter? Why are there not two kinds of photons, a sidereal photon beside our common terrestrial photon? If the Aristotelians would have taken their hypothesis seriously the sky must have been unfathomable, or a miracular cosmic coincidence of unknown origin is required to take care of *some* hidden interaction in spite of the different nature of both substances. If someone objects that indeed there has been an empirical astronomy based on Aristotelian cosmology and that an empirical refutation took place in history of science, we have to remind the reader that in this case the *unity of light* is used surreptitiously as underlying the process of observation.

The moral of this historical example is quite clear. Knowing is a kind of interaction, in one regard on a par with other kinds of interactions in physics, chemistry and biology: Epistemological interaction means that something must be exchanged, in the same way as in physics photons, W-bosons, gluons and gravitons mediate the interactions. To make this possible, knowing system and known system must possess some affinity, a similarity in the ground plan. So we can formulate a condition for the mutual relation between ontological unity and knowability: Ontological and nomological coherence is a precondition for the knowability of nature.

Even Karl Popper's threefold ontology can be regarded in accord with our demand of knowability, because the three layers of reality have been interacted in the past when they originated and in principle the process of emergence can be elucidated by rational and scientific inquiry: furthermore there is continuous exchange among the material, the psychic and the ideal world, so no part of this ontology is really isolated. Excluded by our condition are such types of ontologies where different universes like two $S^3 \times R^1$ spacetimes (cylinder universes) are postulated which do not possess a common embedding and which, because of their static character, never interacted in the past nor will interact in the future. Even the splitting up of the state-vector in the many worlds interpretation of quantum mechanics which generates causally distinct branches of the universe is not eliminated by our criterion because the splitting up is an interaction in the past ruled by the dynamical law of the quantum mechanics that is by the Schrödinger equation.

As a second historical example we'll cast a glance on renaissance astronomy. One of the splendid achievements of the Copernican model of the planetary motions was the kinematical *interconnexity* between the celestial bodies. His systematization of the members of the solar system in one concatenated whole paved the way for a dynamical treatment of astronomy and therewith prepared a decisive step for physical cosmology. In the Copernican model the crystalline sphere of the fixed stars is upheld, although there is no intrinsic necessity for this boundary of the universe. Thomas Digges and, about the same time, Giordano Bruno opened the universe towards an infinite and homogeneous space inhabited by innumerable worlds. Now the question showed up, whether this huge ensemble of star associations can be regarded in any sense as a « system ». What are the lawful connections within an infinite set of bodies (worlds in Bruno's own terms) without center or edge?

If the universe is not bound in any direction it might be that each of the individual celestial bodies "act" according to inner unphysical principles in an unpredictable way:

'il principio di moti intrinseco [roots in] la propria natura, la propria anima, la propria intelligenza'.[1] This was indeed Bruno's conclusion. Heavenly bodies are animated beings in personal free movements, therefore an encompassing picture of the universe allowing a geometrical description is impossible. The epistemological moral is quite clear: If the systematical coherence, the lawful unity of the universe is denied - in Bruno's case by his stellar animism which defies any mathematical account - a scientific approach becomes impossible.

Today we know that the progress of the natural sciences went its way without being much impressed by Bruno's « astrobiology». Isaac Newton laid the foundations with his law of *universal* gravitation and so he was able to treat even an actually infinite universe of stars as a lawful system. Thomas Wright of Durham, Kant and Lambert provide the following steps for the "systematical organization of the fixed stars."[2] Without doubt it is the merit of Kant's "Natural History and Theory of the Heavens" to regard the universe as a causally connected system - the lawful patterns are knotted up so tightly that

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1 G. Bruno: La cena de le ceneri (ed. by G. Aquilecchia) Torino 1955, p. 2o8

2 "Die systematische Verfassung der Fixsterne". Cf. I. Kant: Allgemeine Naturgeschichte und Theorie des Himmels oder Versuch von der Verfassung und dem mechanischen Ursprung des ganzen Weltgebäudes nach Newtonschen Grundsätzen abgehandelt. Akademie Ausgabe Band 1, Berlin 191o, p. 246

it is possible to dig out the plan of the « systematical organization ».[1]

As it showed up at the end of the 19th century, even classical cosmology, seemingly so well conceived, was burdened with conceptual paradoxes (the electromagnetical and the gravitational paradox), but here Karl Popper's thesis is validated: "even where we do not succeed as reductionists, the number of interesting and unexpected results we may acquire on the way to our failure can be of greatest value".[2]

Kant's and his follower's endeavour to reconstruct the hierarchy of the levels of reality from the planetary system to the galactic structure was without doubt reductionist in the sense that it was a mechanistic approach; only the laws of classical mechanics should be used for the emergence of the origin of the level structure. The strive for this reduction unveiled a bundle of new exiting problems. The solution of these problems pointed directly to the theory of relativity which in the beginning of the 2oth century delivered the first rational treatment of the universe which was not beset by physical paradoxes.

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1 "Wir sehen die ersten Glieder eines fortschreitenden Verhältnisses von Welten und Systemen und der erste Teil dieser unendlichen Progression gibt schon zu erkennen, was man von dem ganzen vermuten soll" (I. Kant: loc.cit. p. 256)

2 K.R. Popper: The Open Universe: a.a.O., p. 134

IV. Geometrization, Einstein and the Unity of Physics.

The greatest research program ever tried in physics was the attempt to construct a monistic world picture solely based on the notion of geometry. Precursors of this idea can be found in Platon's theory of matter using the key term χώρα [1] and in the Cartesian trial to reduce everything in the physical world to extension. It is interesting to note that these very early approaches of a geometrization of matter deeply influenced the theorists of the 2o$^{th}$ century, as the following quote of Einstein shows:

> "Descartes hatte demnach nicht so unrecht, wenn er die Existenz eines leeren Raumes ausschließen zu müssen glaubte. Die Meinung scheint zwar absurd, solange man das physikalisch Reale ausschließlich in den ponderablen Körpern sieht. Erst die Idee des Feldes als Darsteller des Realen ... zeigt den wahren Kern von Descartes' Idee: Es gibt keinen feldleeren 'Raum'."(2)

That means the Cartesian conception of the plenum got a realization within a consequent field physics, because the field is an entity continuously spread leaving no part of spacetime free. Descartes geometrization, his reduction of the properties of matter to a static, undynamical and unelastic space (not spacetime) was performed by a simple act of identification. It was a long way from Cartesian physical monism [3] to the modern field theories expressed in geometrical language.

An intermediate step in the evolution was Maxwell's unified theory of magnetism and electricity. The fusion of the two

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[1] Platon: Timaios 49a
For a more complete treatment cf. B. Kanitscheider: Vom absoluten Raum zur dynamischen Geometrie. Mannheim 1976

[2] A. Einstein: Über spezielle und allgemeine Relativitätstheorie Braunschweig 1969, 21$^{th}$ ed., p. 125

[3] In his entire ontology Descartes was of course a dualist, but the res cogitans is irrelevant in our physical context.

interacting fields $\mathcal{E}$ and $\mathcal{H}$ to an undivisible entity (relativistically described by the Faraday tensor $F_{\alpha\beta}$) played the role of a prototype of all later attempts to unify different fields of matter or radiation.

Einstein himself regarded Maxwell's theory as an archetype for his own aim, the unification of gravitation and electromagnetism. Classical electromagnetism has all typical traits of a strong unification, an explication of which will be given in due time. The unitary character shows up most explicitly if we write its fundamental equation in tensor notation using the above mentioned $F_{\alpha\beta}$ which is constructed from the components of the two vectors $E_x$, $E_y$, $E_z$ and $H_x$, $H_y$, $H_z$. $F_{\alpha\beta}$ is a covariant mathematical object that means that its components can be varied or transformed away, but the whole entity has meaning independent from coordinates. $F_{\alpha\beta}$ is the mathematical object that bears in this formulation the semantical reference.

This is not to say that $\mathcal{E}$ or $\mathcal{H}$ themselves have no physical meaning, but if we introduce another reference frame in which the electrical field disappears, a magnetical field pops up in a compensatory way, showing that $F_{\alpha\beta}$ points to a real entangled entity and that $\mathcal{E}$ and $\mathcal{H}$ are coupled together by a tight lawful connection. Using the Faraday tensor $F_{\alpha\beta}$, the fusion of magnetodynamics and magnetostatics can easily be verified; there exists only one Lorentz-covariant tensor law for both and the same is true for electrostatics and electrodynamics.[1]

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1 Ch. Misner et al.: Gravitation. San Francisco 1973, p. 8o

In any case the unified theory is *logically* and *semantically* stronger than each partial theory, that means the nomological patterns get more tight and a surplus meaning is generated which cannot be grasped if separation is upheld. One of the very important, entirely new deductive results of Maxwell's electromagnetism is the explanation of the nature of light as an electromagnetic wave phenomenon.

In Maxwell's original theory, as well as in the special relativistic 4-dimensional formulations, the two fields are treated as foreign entities immersed in an immovable and undynamical spacetime. Particles and fields have their own dynamics, but spacetime itself is not involved in the interaction of particles and fields in any way, it is the mute arena of the physical events. Bernhard Riemann formulated 1854 the heuristic idea according to which the structure of physical geometry might depend on the matter content of space. He could not formulate a quantitative theory expressing which matter constellation produces a certain kind of space curvature, but he had a presentiment of Einstein's geometrical theory of gravitation which in its cleanest qualitative one sentence formulation can be read:
"Space acts on matter, telling it how to move; and matter reacts back on space, telling it how to curve."[1]

That will say, space with its metric fixes what can be considered the path of force-free motion, the geodesic, trajectory of a free particle; mass-energy in turn provides the curvature which is a metrical property of spacetime. Without doubt general relativity is in a certain sense a reducing theory

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1 J.A. Wheeler: Physics as Geometry. Epistemologia III (198o)

in that the older Newtonian concept of a gravitating force that acts within spacetime is foreign to Einstein's theory. His central idea was that there is no such force as gravitation, but there is a natural state of a particle, namely free fall. This is the very kernel of the principle of equivalence. Note that not space but spacetime is at stake. This is the lesson of special relativity, space and time play symmetrical roles in the transformations which connect different inertial systems; therefore gravitation has to be a manifestation of the curvature of spacetime, and not of space alone.

Einstein's reduction of Newtonian gravitational force by geometrization had its origin in a new perspective on what is the *natural state* of *motion* a physical object. In distinguishing free fall as that natural state, he unified two lines of thought which had been hitherto unconnected, Riemann's inclusion of geometry in physics and Mach's idea that the natural state of motion here in terrestrial test situations depends upon the far- away masses. Here we see how reduction and unification work together. The merging of the two great currents of thought did not only reproduce in a new language what had been known since a long time, but the new theory furnished a solution to an outstanding problem of the older theory of gravitation, namely the propagation of this force through empty space from one body to another.

Newton was quite aware of the preliminary trait of this action at a distance theory:

"That gravity should be innate, inherent, and essential to matter, so that one body may act upon another at a distance through a vacuum, without the mediation of anything else, by and through which their action and force may be conveyed from one to another, is to me so great an absurdity that I believe no one who has in philosophical matters a competent faculty of thinking can ever fall into it."[1]

At this time nobody had the faintest idea, how the mechanism of spreading the gravity influence to far away parts of space could be thought of. Einstein's theory is a field theory but in the early time of relativity it was not clear, whether the wave-like solutions found so far really make physical sense. Mathematical analysis of the field equations revealed, that the gravitational effects of a change in the matter distributions propagate along null geodesics, that means that they have the same paths as light rays and run with the same velocity.

The physical nature of gravitational waves was shown by Bondi, Metzner, van den Burg and Sachs in 1962, in that they could prove that gravitational waves carried energy away from a bounded system in asymptotically flat space.[2] In the meantime, there is strong indirect empirical evidence for the existence

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1 I. Newton: Third letter to Richard Bentley, in: M.K. Munitz (ed.) Theories of the universe, New York 1957, p. 217

2 H. Bondi, F.R. Sachs, M.G.I. Van den Burg, A.W.K. Metzner: Gravitational waves in general relativity. Proc. Roy.Soc. London Ser. A 269 (1962) p. 21-48

of gravitational waves.[1] The existence of physical wave solutions as well as the possibility of new geometrical objects like black holes of different types revealed the intrinsic dynamic degrees of freedom within physical geometry.

In regard to physical surplus meaning there were plenty of cases to demonstrate, that geometrization provides a strong unity, not just a linguistic reformulation. But there is a different aspect of the inclusion of geometry into the world of physics which seems to point more towards an *isolation* of gravitation from the rest of physics. If it should reveal that only gravitation can be included in the structure of spacetime, but not the other matter fields and interactions, a gap would break up within physics and the unity would be greatly jeopardized. Therefore after the advent of general relativity the strategies of investigation divided. Quantum field theorists were inclined to regard gravitation as a symmetrical tensor field in flat space, namely a Lorentz covariant massless field of spin 2, relativistic physicists tried to follow Einstein's vision of extending the approach of geometrization. The last program contains a clear cut reductionist position:

"There is nothing in the world except empty curved space. Matter, charge, electromagnetism, and other fields are only manifestations of the bending of space. « Physics is geometry »" (2)

This is ontological monism with a vengeance.

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[1] The most natural explanation of the loss of energy of two compact stars, whose orbit about each other is shrinking, seems to be the emission of gravitational waves. (I.H.Taylor, L.A.Fowler and P.M.Mc Culloch: Measurements of general relativity effects in the binary pulsar PSR 1913 + 1916, Nature 277 (1979) p. 437-44o)

[2] J.A. Wheeler: loc.cit. p. 89

The pathway leading to the inclusion of all classical fields into physical geometry and pursued by the defenders of Einstein's research program followed a result first discovered by Rainich (1924) and rediscovered by Ch. Misner (1957), namely the so called "Already Unified Field Theory."[1] Here sourcefree electromagnetism can be expressed by pure geometry without raising the number of dimensions of spacetime nor leaving its Riemannian character. Sources, electric charge and mass can be included by taking an open degree of freedom of geometry into consideration, the connectivity of space in the large. Einstein's field equations as well as the equations of the Already Unified Field Theory are local relations of infinitesimally neighbouring points, they do not decide anything concerning the global properties of space. Here the possibility shows up to introduce a domain of multiply connected topology instead of points in which apparently the lines of force converge. Electricity as an autonomous substance is thereby eliminated if it is reconstructed as the phenomenon that occurs if lines of force are trapped in the topology of a multiply connected space.

Here we see at work an almost universal tendency of all unification procedures, the ontological parsimony of the stronger theory has to be payed for. Unification is only possible if we retire more and more from the common sense notions of the empirical world with its anthropomorphic

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1 Ch. W. Misner in J.A. Wheeler: Classical physics as geometry. Gravitation, electromagnetism, unquantized charge and mass as properties of curved empty space. Reprinted in: Geometrodynamics. New York/London 1962, p. 225

elements and introduce more epistemologically abstract concepts. Multiply connected Riemannian space allows a very simple description of charge, but which is beyond any intuitive imagination. So unification leads us in a natural way from a narrow empiristical and instrumental interpretation of physical theories to a liberal use of theoretical concepts and their ontological import. May be some critics watch this resurrection of metaphysics with a frown. Lawrence Sklar has expressed this metaphysical consequence of the unitary theories very succinctly:

"After several decades of retreat to meta-language, linguistic mode, talk about theory rather than talk about the world etc. the question of unity of science has now dragged us, willy-nilly, back to the foggy realms of metaphysics. If the unity of science is to be found in the unity of theory, apparently the unity of theory must be discerned as a lingustistic reflection of the unity 'in the world'".(1)

Sklars remark points toward the right end, unified theories suggest a realistic epistemology, an ontological interpretation of theoretical terms without scruples, without all these empiristical constraints hampering an unabashed interpretation of the language of science.

We cannot work out here all the details of the unification and reductionist program which is latter covered by the catchword « Physics is Geometry »[2], but it has to be mentioned that in the last, the program in its original aim failed, because it revealed to be impossible to include the quantum principle into the classical mathematical machinery. There

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1 L. Sklar: The evolution of the problem of the unity of science, in: R.J. Seeger, R.s. Cohen: Philosophical Foundations of Science. Dordrecht 1974, p. 541/42

2 Cf. B. Kanitscheider: Vom absoluten Raum zur dynamischen Geometrie. Mannheim 1976

was not even a natural place for pure spin 1/2-fields like the neutrino. Even restricting to the narrow aim to encompass all classical physics an intrinsic limit stood up because the final states of gravitational collapse could not be handled within the concept of a continuous Riemannian manifold with its Hausdorff topology. The crucial point was topology change and the growing up of singularities. The singularity theorems discovered by Hawking, Penrose, Geroch et al. suggest strongly, that a method of theory construction has been pushed to its uppermost limits. Under very reasonable and physically very weak constraints almost all general relativistic spacetimes develop singularities in which the principles of the theory itself break down. These mathematical theorems are especially important, because they do not depend on the full Einstein equations, but only on the property that gravitation remains always *attractive*; thus they would apply to any geometrical theory in which gravity is not strongly repulsive. Here we encounter the circumstantial evidence that the manifold structure presupposed by the spacetime picture has reached its limits. The breakdown presumably occurs, when the radius of curvature attains the order of the Planck length ($10^{-33}$cm). In this domain very strange things are likely to occur. If we construct a surface around a region in which the curvature becomes extremely high, we must reckon that inside this surface a quantum description of space time would be necessary. The singularity itself might be a inexhaustible source of matter or, in the words of Hawking and Ellis:

> "Matter crossing the surface could be thought of as entering or leaving the universe, and there would be no reason why that entering should balance that leaving."(1)

Unexpected events are bound to occur in the quantum domain of spacetime, on this point everyone of the great physicists agrees; but at the moment no fully developped theory of quantum gravity exists. The crisis of the spacetime description engendered by the initial singularity of the big bang and the final singularities of collapse indicates that the borderline of a natural *level* has been reached. Common sense experience teaches similar situations. An elastic solid seems to be a continuum, on a closer look it is built out of electrons and nulei, a selvage seems to be smooth from a distance, if we inspect it nearer it reveals to be woven out of thread. With this analogies in mind, J.A. Wheeler asks after the 'pregeometry' behind the geometry of spacetime.[2] How can we grasp the hidden structure beneath the manifold spacetime picture which gives us the impression that approximately, and that means to an accuracy of $1o^{-15}$cm, our world behaves like a spacetime continuum woven out of an underlying thread. Methodologically, we can draw an intriguing conclusion from other physical situations, where deeper levels are showing up. Think of elasticity. An elastic solid looking like a continuous substance is really built out of electrons and nuclei; its internal structure shows up on a crack, here we see that continuity is an approximation. In this superficial

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1 S.W. Hawking, J.F.R. Ellis: Large Scale Structure of Spacetime. Cambridge 1973, p. 363

2 J.A. Wheeler: Physics as Geometry. a.a.O. p. 87

tackling with elasticity a homogeneous isotropic elastic material is described by two elastic constants. But to understand these two constants we have to move to the forces between electrons and nuclei. Methodologically it is clear that no deductive way leads from the solid state property « elasticity » to the interaction between the constituent particles. The direction of explanation always goes from the small to the large but not the other way round.

Therefore a pregeometric structure has to be *postulated* which covers in turn the phenomena of the molar level with its spacetime properties. From this new layer perhaps it will be possible to give answers to old questions which have always been withstanding the hardest efforts of explanation within the spacetime realm itself, e.g. the problem of the dimensionality of space and of spacetime. Perhaps the deeper reason for the 3 + 1 dimension of spacetime can only be understood from the deeper level of pregeometry.[1] In this domain surely the quantum feature will play a leading rôle.

As philosophers, we can learn a decisive epistemological lesson from Einstein's research program of geometrization: even if in the narrow sense this heuristic direction is now out of date and perhaps spacetime description is not the deepest level of decription, an understanding of spacetime

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1 J.A. Wheeler: « Pregeometry: motivation and prospects » in: Quantum Theory and Gravitation (A.R. Marlow (ed.) New York 198o, p. 1-12

features does not mean explaining them away. As David Armstrong put it, we should always draw the distinction "between denying that a certain entity exists and giving an account of that entity in terms of other entities"..."what is not ultimate may yet be real".[1]

## V. From Quantum Electrodynamics to Supergravity

Einstein's dream of a unitary description of all physical fields revealed as *methodologically* sound, but it could only be regained with new and extended mathematical tools. It is interesting to note, that the novel approach started from a principle already discovered by Hermann Weyl, when he tried to extend the Einsteinian line of reasoning to the electromagnetic field, namely the gauge invariance.

Classical fields like the electromagnetic field bare the intrinsic symmetry that their potentials are not altered if the gradient of a function is added. This extra degreee of freedom Weyl tried to link with a geometric description of electromagnetism. Although, as Einstein remarked, this geometrical theory revealed itself as incompatible with the observations (the existence of sharp spectra ). The gauge symmetry, rediscovered for the quantum fields of particle physics by C.N. Yang and R. Mills, gained its importance, when Gerard t'Hooft in 1971 showed that even the non-Abelian

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1 D.M. Armstrong: Naturalism, Materialism and First Philosophy, in: D. Henrich (ed.): Ist systematische Philosophy möglich? Stuttgarter Hegelkongress 1975, Hegel-Studien Beiheft 17, Bonn 1977, p. 412

fields of the unified model of electroweak interaction, proposed by Salam and Weinberg, are renormalizable, that is, they are not any longer troubled by the infinities caused by the zero point fluctuations.

The unification tool in this line of reasoning is based on local symmetries. The conceptual difference between local and global symmetry is decisive. This is easily to visualize, if we regard two equal spheres whose surface are covered with an arbitrary net of coordinates. Global symmetry shows up, if the first sphere is rotated about some axis. All points on the surface exhibit the same angular displacement. Local symmetry,in turn,is given if a part of the spere is streched while keeping its spherical shape. In this second case a force has to be introduced for moving some points of the sphere independently of the others. It is important to note Einstein's general theory of relativity and Maxwell's theory of electromagnetism are based on local symmetries. The transition from global to local symmetry is connected with the origin of the pertinent forces. As far as this local symmetry is concerned, both classical theories may be called gauge theories.[1] Here we see the common trait of the new unification movement towards a unitary theory of all interactions. Any theory unifying all the four forces in nature should have this local symmetry as a fundamental requirement.

It should be possible to generate each of the four known forces from the demand that the Lagrangian remains invariant under a local symmetry transformation. It is to be remembered

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1 Special relativity is however a theory with the global space time symmetry of the Poincaré invariance.

that in this approach general relativity has to be translated into the language of quantum field theory where the gravitational force originates from the exchange of a massless spin 2 particle (the graviton).

The encompassing theoretical framework within which theorists try to unify all physical forces, bares the grandiloquent name of supergravity. It results from the so-called supersymmetry which connects the two hitherto disparate broad classes of elementary particles, the fermions, and the bosons. In a supersymmetrical theory a fermion and a boson with adjacent spin can be regarded as a special manifestation of a single underlying particle. Again we see how the unification procedure delivers not only the old assertions of the former isolated theories, but something more: local supersymmetry engenders two new fields, the field of the spin 2 graviton which expresses the long-range gravitational force of general relativity and a new spin $\frac{3}{2}$ field in which spin $\frac{3}{2}$ gravitinos are exhcanged exhibiting a quantum gravity correction on microscopic scale. Needless to say, that today neither the classical graviton nor the gravitino of microscopic gravity have been experimentally discovered, but it is of decisive importance for judging this approach that a surplus meaning of this kind is included in this unified theory. The most speculative content of supersymmetric theories consists in that they give a hint to the new layer of elemental particles beneath the level of quarks and leptons. As Bruno Zumino expressed it: "In this picture leptons and quarks would be composite objects, the elementary constituents (preons) being the fields of the basic supergravity supermultiplet." [1]

Here we are possibbly provided with an argument, which stems from unification, that the proliferation of elementary particles may have an end at a deepest level of description.

## VI. Unification as a road to higher insights in the level structure of the universe

After this sketch of physical unificationary activity it is necessary to stress once more the epistemological upshot of this scientific task. What is gained, if scientists try to move towards a strong unity of science not only in the weak *methodological* sense of a commom strategy of control, nor in the stronger, but still weak *epistemological* sense of a common objectively existing, nomologically structured universe of discourse, but in the strongest sense of an ontological unity according to which reality is an interacting whole, where a strict separation of its subsystems and partial forces can only have approximate validity? The core feature of unification in physics can be formulated in the following way:

i) Unification is concerned with a kind of mild *reductionism*. As represented in the case of the spacetime picture, a deeper understanding of a level, of its origin and genesis, does not eliminate the validity and fruitfulness of one special mode of description. A structure can be real, even if it is not basic.

ii) Unification is concerned with *coherence*.

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1 B. Zumino: Supersymmetry - a way to the unitary field theory, in: H. Nelkowski et al.(ed.): Einstein Symposium Berlin Lectrres Notes in Physics, Vol. 1oo, Berlin 1979, p. 123

In a separatistical approach physical reality is split up in disconnected layers whose mutual relations must remain in the dark. The microworld of elementary particles (strong and weak interactions), the molar world of bulk matter (electromagnetic interaction) and the world of megaphysics (ruled by gravity) would be divided without interconnexity. The connexity of the level structure of the world is what renders nature intelligible

iii) Unification is concerned with *surplus meaning*.
The physical examples show that there is a host of phenomena that would be entirely unknowable, if we renounce with the stronger unified theories. The collective effort of a unified theory will be more productive than the sum of what the individual theories could accomplish working separately.

iv) Unification is concerned with *simplicity*.
In physics, unification also means to go up to a domain of higher energy. The gauge theory description reveals that the world becomes much more simple at extreme energies, when symmetries which are broken within our cold universe are restored. Six fundamental puzzles of classical cosmology are provided with a fresh answer, if analyzed in the domain of the grand unified theories: baryon synthesis, monopole problem, flatness problem, homogeneity problem, smallness of the cosmological term, and the isotropy problem. The unifying item is of course the hot big bang, it makes the explanation of this different puzzles possible.

v) Unification is concerned with *evolution*.

At late times the initially very simple and symmetric universe has evolved in a hierarchy of systems with growing complexity. This chain of evolutionary steps, each link of which is ruled by very different mechanisms (e.g. galaxy formation and Darwinian evolution of bio-systems), should be grasped by a particular theory which makes it especially clear why and how these different levels emerged. This is the place, where morphogenetic theories lik synergetics, non linear thermo-dynamics and catastrophe theory are urgently needed.

These five reasons make up without doubt no exhaustive roll, but they suggest, that against all sceptical voices unification is a progressive research program. Methodological unity is not enough. It was Einstein's conviction and it is today's theorists' too, that nature itself bears a deeper unity which to decover does not lie beyond man's possibilities and, moreover, is a necessity, if our understanding of nature should not remain incomplete in a crucial way. In Einstein's own words:

"In my opion, there is <u>the</u> correct path and ... it is in our power to find it".[1]

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[1] A. Einstein: On the method of theoretical physics. New York 1933