Simplicity and Observability: When are Particles Elementary?[1]

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1. Introduction

Writing the history of elementary particle physics has all the problems common to writing the history of any other subject "in the making". There is, however, an additional characteristic, unique to this branch of physics. The development of particle physics, unlike the situation in other branches of physics, reveals a continuously changing picture of what its object of investigation is, of what, in other words, the things we call particles are and how elementary they should be considered. The history of elementary particle physics is, in a way, the history of the continuous reinterpretation of both the ontological and methodological status of the notion of elementarity. Hence, examining the history of elementary particle physics is also an attempt to explicate this changing collective consciousness of the scientific community about the elementarity of particles. In studying, therefore, (practically any aspect of) the history of elementary particle physics, one has to be sensitive about a number of philosophical, and primarily methodological issues which have acquired an added significance due to the relatively recent and mainly theoretical developments. And these issues are better examined if we attempt to answer the following two questions.

(1) Does the present situation in elementary particle physics justify us to claim that we have reached a level of explanation where the constituent particles used for the explanation of the various phenomena can be regarded as elementary?

(2) What are the methodological prerequisites that have to be clarified in order to be able to systematically investigate the previous question?

I am not going to examine the series of problems arising out of the relationship of the notion of elementarity with much of our (Western) metaphysical tradition (Wallace 1968). The implications of the problematic concerning "teleological" and "first cause" arguments to the concept of elementarity will interest us only indirectly, and we shall concentrate, not on the ontological status of the various entities considered to be elementary, but rather on the methodological role of these entities in the construction of theories.

What is, however, an elementary particle? What are the aims of elementary particle physics? There is no better place to look for an answer, than in the two

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thorough and detailed reports of the National Research Council (US) (Physics in Perspective, 1973; Physics through the 1990's, 1986), since, if anything, they reflect a view compatible with the consensus of the high energy physics community.

> "We call a piece of matter an elementary particle
> when it has no other kinds of particles inside of it and no subparts that can be identified–we think of it as a point particle" (Physics through the 1990's, 1986; p. 19).

And as for the subject itself it is stated that:

> "The nature and purposes of elementary particle physics concern both the discovery of new phenomena exhibited by matter (and other forms of energy) under extreme conditions and the understanding of known phenomena" (Physics in Perspective, 1973; p. 13).

It is, then, quite remarkable that given these "definitions", the survey of the literature on the whole (Brown, Hoddeson 1983, Buschor 1976, Chew 1964, Cinquant' Anni di Fisica delle Interazioni Deboli, 1984, Close 1978, Conversi 1980, Feinberg 1977, Fermi, Yang 1949, Heisenberg 1976, Neeman, Kirsh 1983, Weingard 1984), displays a truly paradoxical situation. Despite the fact that the accounts of the various developments conform absolutely with the definition of what an elementary particle is, nearly all the writers express reservations and doubts about whether the particles we would presently consider as elementary (leptons, quarks and intermediaries (the photon, the W's, the Z, the gluons)) should really be given the status of the ultimate constituents of matter.

Two reasons are usually projected to justify nearly all the reservations expressed about the elementary character of all the structureless particles we know today and especially of the quarks. It is, firstly, remarked that not all of them have been seen and that all attempts to find free quarks have failed. And, secondly, that there are too many of those particles to consider them as the ultimate building blocks. In other words, despite the fact that leptons, quarks and intermediaries would be absolutely compatible with the "accepted definition" of what an elementary particle is, *further methodological criteria such as those of observability and simplicity are invoked in order to doubt the elementary status of the very same particles.*

The common conclusion, then, of most people who pass judgement on the present status of high energy physics, can be summarized as follows: Granted that quarks, leptons and intermediaries are particles with no other kinds of particles inside them, and they are in that respect point particles, we can neither observe in an isolated manner all of them, nor are they few so as to make up a convincing simple schema. Based, in effect, on this syllogism Schrader-Frechette (1977, 1979, 1982) argues that the Kuhnian paradigm of the world being built up by elementary particles should be abandoned, and that atomism is in deep crisis. This particular claim has been convincingly rebutted by Cushing (1982).

It may be argued that using explicitly stated methodological criteria for a further appraisal of physical theories is something to be encouraged. One still wonders, however, the status and the degree of consensus reached for the criteria with respect to which various questions are to be appraised. Do the criteria for particles to be regarded as elementary express a consensus only good for the day-to-day activities of physicists? And yet when an overview of the developments is attempted there seems to be a shift to a new consensus this time about the *non*-elementarity of the very same entities which are regarded as elementary in the day-to-day activities!

2. Successful methods, broken symmetries and the question of simplicity

It is undoubtedly the case that reading the developments of high energy physics is necessarily influenced by one's metaphysical views, ontological beliefs, and epistemological preferences. It should not however escape our attention, that more often than not, it is the impressive success of the methods employed to understand the phenomena and the ensuing confidence in the theory which becomes dominant in the evaluation of the developments rather than more sophisticated philosophical considerations. Therefore, a considerable amount of confusion can be dispelled, if, in such evaluations, the following are differentiated and kept separate:-

(1) The metaphysical beliefs and the ontological claims.

(2) The successful methods.

(3) The emerging picture of Nature.

It is *then* a different question altogether, if as a result of our studies, we would decide to modify (1) because of (3) or choose to elevate (2) to a principle which seems to be the best for contributing to philosophical argumentation and so on. Let us take an extreme, yet especially characteristic case. The investigation of the problem of elementarity motivated by the success of S-matrix theory, and an analogous investigation motivated by the success of quantum field theory, will necessarily oblige the adoption of two different ontologies. In the case of the former, for example, the elementarity of particles is to be searched "in a reality" similar to that which emerged from the study of molecules and atoms and where complexity is expressed in terms of "excited states". The continuous subdivision of matter as a means of finding *the* elementary particles will be doubted since the question, what does a particle consist of?, is meaningless for such an approach if the energies used to find the constituents are larger than the mass of the particle being searched into. Thus, the specification of elementarity becomes, in effect, synonymous to achieving a self-consistent derivation of any given particle by "everything else" (Heisenberg 1949, 1976, Cushing 1986). The study of the same problem, motivated by the success of quantum field theory leads to quite a different situation. Here, the belief that it is possible to have a detailed space-time description of particles under extreme relativistic conditions by their fields is paramount. The "reality" in which the elementary particles are to be sought is very similar to that which emerged from the study of electromagnetism with its "well defined" procedures of translating the "tangible" particles into fields. In these examples, one can then see how the success of a particular method, under the influence of the "emerging reality" forces the adoption of a particular ontology (Redhead 1980, Schweber 1988, Schwinger 1970, Weinberg 1977, 1985).

It is interesting to note that Heisenberg's insistence to develop a way of viewing "elementarity" by extending arguments primarily used in atomic spectroscopy leads to the proposal that "what we have to look for are not fundamental particles, but fundamental symmetires" (Heisenberg 1973, p. 273). Such a proposal, however, does not provide us with an alternative framework to answer the questions we posed in the beginning. What is being sought is not the kinds of possible ontologies within which one could accomodate a notion of elementarity and be able to "read" consistently the various theories of particle physics. The opposite, in fact, is the case: the questions we posed presuppose a particular ontology–that of "the ultimate building *blocks*". What is sought is the contextual (and historical) character of "the ultimate".

We would like to argue that some of the problems mentioned above can be partly dispelled and a satisfactory answer be given to the questions we posed, (1) if elementarity is examined within a framework where the particles are to be regarded as elementary to the extent that they can be used to achieve a *unified* accout of all phenomena, and (2) if it is realized that the development of elementary particle physics has brought about conceptual changes which have radically modified the admittedly controversial issues of *observability* and *simplicity*. And that, if anything, a case can be made that the criterion of observability cannot be identified with observing an entity in an isolated manner, nor that of simplicity with fewness.

The emphasis on relating the study of the problem of elementarity to the question of seeking a set of laws providing a unified description of nature is not merely an attempt to take into account what has been the outstanding aim (and success) of high energy physics during the past years. What has been neglected, however, in the various discussions about elementary particles is an appraisal of the methodological status of the concept of elementarity within a context created by the attempts to construct a theory which provides a unified account of what seem to be different interactions giving rise to a class of phenomena. Finding (and I would say deciding) that a set of particles are elementary is meaningful only to the extent that it can be shown that these particles are sufficient for a unified account of as many phenomena which--intuitively, at least--we consider as delineating a particular level in the descriptive framework of the physical phenomena and a specific stratum in the organization of nature (Anderson 1972, Schweber 1988). Each such level has a relatively autonomous status. It is this *relative* autonomy which is important here, since there is always something with respect to which autonomy is signified, and that no level is fully autonomous since some of the phenomena used to delineate each level do not unambiguously belong to a single level. Furthermore, it is the *relative* autonomy which allows reductionism from one level to the next, and yet the relative *autonomy* of each level is what confines the practice of constructionism to within each level.

Instead of, then, asking the question, what are the ultimate consituents of matter?, one should rather inquire about those (ultimate) constituents of matter which can be used to provide a unified description of phenomena and be, in turn, determined by this description. It is the latter that is historically meaningful, even though it was the first question that acquired a legitimacy on purely epistemological grounds. The (theoretical or experimental) search for the ultimate constituents of matter is then related with ways of "combining" them, proposing schemata by which we can build up the composite particles and the phenomena to which they give rise to, and understanding in a more fundamental manner those laws and regularities which have already provided an explanation for many phenomena and whose validity has been repeatedly tested. It is within such a framework that the status of the various constituents so far as elementarity is concerned, has to be appraised.

Simplicity as a criterion to be used for choosing among "competing" modes of explanation has been repeatedly invoked by physicists and philosophers alike, and it was usually the "more symmetric" mode that was eventually preferred. Its discussion is inherently difficult, especially if the aim is to reach a consensus on how the criterion of simplicity should be used in a consistent manner. Its only meaningful discussion seems to me is to argue about the relative merits of a particular criterion with respect to other such proposed criteria.

The notion of the "ultimate constituents" of matter and the ways devised to reach a consensus about their identity has been inextricably related to the notion of simplicity. And it is within such a problematic, that among the many modes whose explanatory power is roughly equivalent, the one with the fewer proposed (sub-)particles is favored as having a chance of being "more fundamental". And it is such a viewpoint which associates simplicity with fewness that is used to reject the quark model as providing a self-consistent account of phenomena in terms of *elementary* particles, because there are too many constituents which are particular to the quark model to be given the status of elementary.

Even though the adoption of such a particular criterion of simplicity cannot be comprehensively defended, there are some questions which can be posed independent of any specific criterion of simplicity. What happens, for example, if a particular criterion of simplicity appears to be violated in a systematic manner? How justified is one in using any such criterion, if one knows beforehand that it is bound to be violated? Can one talk of degrees of simplicity? Or, is there any meaning to the notion of approximate simplicity?

We will not attempt to answer these questions, but note that the developments in high energy physics seem to provide us the conceptual framework that allows their examination. Take, for example, the use of symmetires. It is no exaggeration to claim that symmetries have been regarded by physicists not only as principles of universal validity, but also as indications of the simplicity of nature at its deepest level. But most symmetries are demanded from the theories, with the certainty that they are violated either by interactions which have not been taken into consideration or dynamically. And various techniques have been devised to calculate the contributions of these violations. In the unified theories of particle physics, the approximate character of the symmetries of the strong, electromagnetic and weak interactions, is possible to be explained as being a consequence of gauge invariance and renormalization. There are, really, only exact symmetries which govern all interactions and their approximate character is dynamically explainable (Weinberg 1980). These new insights we have gained into the structure of theories allow us to inaugurate a totally different approach to the question of simplicity, rather than being entangled in the deadlock brought about by the process of deciding how many is too many, or how few is not too many!

3. The Notion of Observability

The developments in high energy physics, however, imply the possibility of a radical departure from a notion of observability so closely tied with the observation of *entities in an isolated manner. Details of the quark model, on which some of the* contents of this section are based, can be found in Lipkin (1973) and Greenberg and Nelson (1977).

The development of hadron physics has, until recently, consisted of a series of ad hoc rules, models and assumptions which were, at best, loosely connected to one another and even more tenuously related to an underlying dynamical theory. In the more recent past, however, one theory of hadrons has begun to emerge as something of a standard theory. This is the Yang-Mills theory of colored quark and gauge fields. Quantum chromodynamics (QCD) is a quantum field theory of the strong interactions with non-abelian gauge fields mediating the interactions between the quarks. The outstanding challenge posed by this theory is to learn to make reliable computations of hadron properties in a systematic fashion. Nothing comparable to the Feynman rules and the perturbation approximation series in quantum electrodynamics exist for the bound state physics of the QCD. And there is no proof for the existence of a single bound state in any relativistic four dimensional quantum field theory.

These difficulties notwithstanding, QCD has certain attractive features. It does not seem to be in conflict with any existing phenomenology of the strong interactions, and the symmetries that can be extracted from QCD are precisely the symmetries of the strong interactions and no more. Local gauge invariance of the color SU(3) and the formal existence of quarks transforming as the fundamental representation of this group are the only requirements and they seem to be sufficient to specify the theory.

Even though QCD has been constructed in close analogy with QED (Quantum Electrodynamics), the intermediaries of the strong force or the color charge quark, the gluons, have non-zero interactions (and self-interactions) among themselves. Exactly because gluons carry the strong color charge, it is possible for the color charge of a quark to be shared with the gluon cloud in addition to a color polarization phenomenon much like the charge screening of quantum electrodynamics. Because the color charge is spread out rather than localized, the effective color charge will tend to appear larger at long distances and smaller at short distances. The outcome of the competition between these two opposing tendencies depends on the number of gluon species that can share the color charge and on the number of quark types that can screen the color charge. If the color gauge group is SU(3), the net effect is one of antiscreening, that is, of a smaller effective charge at short distances. Extremely close to the quark, the effective color charge becomes vanishingly small, so that nearby quarks behave as if they are non-interacting free particles. This is the origin of the term asymptotic freedom.

Interestingly, asymptotic freedom does provide a partial, at least, justification of the parton model put forth to describe violent scattering processes: the measurable quantities are reproduced by assuming that the constituents of a proton are a swarm of non-interacting point entities.

Asymptotic freedom offers a qualitative explanation to the paradox of quasi free quarks that are permanently confined. At the short distances probed in deep inelastic scattering, the effective color charge is weak, so the strong interactions between quarks can largely be neglected. As quarks are separated the effective color charge grows, so the strong interaction becomes more formidable. This is the property of confinement (Bander 1981, Mandelstam 1980, Marciano, Pagels 1978).

What confinement means in QCD is that all physical states are color SU(3) singlets. Confinement implies that the color degrees of freedom are in principle not observable in an isolated manner although they mediate the strong force. The quarks and gluons since they are not color singlets have no corresponding physical states.

The prediction of a new particle (and usually its discovery) is followed by a process of "elementarizing" it. There is firstly the assignment of quantum numbers (mass, charge, spin, strangeness etc.) and its assignment to one of the particle families (leptons, quarks, intermediaries). Particles are, thus, first labelled and classified. The process, however, of "elementarization" is not completed unless the procedures of observability are also specified. One of the reasons that quarks are not regarded as elementary is because these procedures of observability are taken to imply observing an entity in an isolated manner. This is, however, totally unwarranted since the procedures of observability can be specified in such a manner so as to dispel any reservations about the possibility of not recognizing in a unique manner what it is that is being observed. In case a newly discovered particle is not observed in an isolated manner, it can be claimed that fulfilling the following conditions specifies the particle uniquely:-

a. Account for already observed particles.

b. Account for already observed interactions/decays.

c. Account for already observed properties (eg. magnetic moment).

d. Account for any observed unexpected phenomenon.

e. Predict particles/events *and* absence of events.

f. Predict events unique to particular mode *because* of constraints involved.

This process of "elementarizing" a particle is just another way of utilizing the polymorphous role of the symmetry considerations in elementary particle physics.

These are procedures that do not allow for the possibility of either manipulating or intervening (Hacking 1983). If, however, the impossibility to manipulate and intervene is stipulated by the theory itself, one is by no means justified in demanding that the only way a theory would be acceptable is if it responds positively to what *then* amounts to an externally brought-in criterion. If isolating a single quark is to be considered as the ultimate convincing evidence for the reality of the quarks and for accepting them as constituting elementary entities, is that not a way of negating, at least, the methodological implication's of confinement which seems to be a *dynamical* property of gauge theories? Alternatively, the totality of the proposed steps that make up the procedures of observation seem to be consistent with these implications. A parallelism can be made with the quantum theory of atoms. *So far as quantum theory is concerned it is meaningless* to pose the question as to where an electron is after it "leaves" an outer orbit and before it "appears" at a lower one. If one wants to make a claim about the discreteness of space-time, this meaninglessness cannot be taken as an indication for any claim favoring the discreteness of space-time. And it is "doubly wrong", after taking the interpretation of the electron jump as giving indications of discreteness in the structure of space-time, to *then* criticize the theory because it uses continuous space-time parameters. The same circular argumentation seems to me is being used in the case of the quarks, when it is demanded, on the one hand, that they be freely observed, when, on the other hand, their role has been articulated through a theory where confinement is a property *derived* from those structural characteristics (gauge invariance and renormalization) which are at least a necessary (and for some a sufficient as well) condition for achieving a unified description of all interactions.

Let us consider some characteristic cases from the history of elementary particle physics which have forced us to rethink the whole question of observability.

At first sight, the law of energy conservation (and of linear and angular momentum) did not seem to hold in the weak-decay with an initial state composed of only a neutron and a final one composed of the two observable particles, the proton and the electron (Gavroglu 1985, Wu, Moszkowski 1966). This situation prompted some physicists to question the validity of the law of conservation of energy when applied to individual microscopic processes. W. Pauli's suggestion first in 1930 and then in 1933 appeared at the time equally, if not more, preposterous. He proposed that a massless particle with zero charge and 1/2 spin and which because of its feeble interactions with surrounding matter escapes observation, is the carrier of the missing energy. This was something extremely bothersome since it was not like the other "unseen" particle, the photon, which could be accounted for as the quantum of the electromagnetic field by the then newly developed techniques of the second quantization. And, especially, after the demonstration of the particle like behaviour of the photon, the latter's status among the elementary particles of the period was hardly doubted. That was not, however, the case with the neutrino when it was first proposed. The change came after the proposal of a successful theory of weak interactions by E. Fermi in 1933-34, in analogy with quantum electrodynamics. The subsequent corroborating evidence in favor of such a theory left no doubt about the "existence" of the neutrino long before its first observation in an isolated form in 1953.

The second example is somewhat more intriguing. Heisenberg's uncertainty principle allows for the law of energy conservation to be "violated" provided this violation occurs in processes whose duration and the extent of the violation are related by Planck's constant. One of the simplest implications of such a state of affairs is for an electron to emit a photon and in a little while to absorb the same photon. Since the details of the electron-photon interaction were among the best known quantities, the effects of this phenomenon should have been quite straightforward to calculate. The calculation was, indeed, quite straightforward, its results, however, turned out to be infinite: the charge of the electron, as a result of such an effect had to be modified by an infinite amount. This difficulty was resolved in the late forties by the work of S. Tomonaga, J. Schwinger, R. Feynman and F. Dyson, where the mathematical techniques used were followed by a new interpretation of the physical meaning of the parameters expressing mass, and charge. The terms which were infinite expressed the various interactions of the "bare mass" m^1 and "bare charge" e^1, and which eventually gave the electron mass and charge their measured values. m^1 and e^1 would be the values of the electron mass and charge if all interactions were to be turned off–something impossible anyway and also devoid of any physical meaning and practical use. The way out of this difficulty was to put the physical mass and charge m' and e' plus the correction terms, whenever in the expressions there appeared the m and e. One now had two sources of infinities which "cancelled" each other: the one coming from the calculations of the various quantities when m^1 and e^1 are substituted by m and e, and the other by the corrections (Schweber 1986, 1988).

The third example is related to the possibility provided by the "coloring" of the quarks to construct a fairly satisfactory schema for the strong interaction (Marciano, Pagels 1978). Quantum chromodynamics, constructed in analogy with quantum electrodynamics, and after a considerable amount of insight was gained about the gauge theories, possesses the quite remarkable property of asymptotic freedom. The closer the quarks are to each other inside the hadrons, the weaker the interaction among them is and they behave like "free" particles. If the potential between the quarks is of the form $^{a(r)}/_{r}$, then asymptotic freedom follows from the structure of the theory. Because of quantum corrections the effective coupling constant of a quantum field theory depends on the distance scale r at which the coupling constant is measured. Thus since a(r) goes to zero as r goes to zero it is, then, possible to use perturbation theory for small r. It should be strongly emphasized that the corresponding quantum mechanical effect in electromagnetism is vacuum polarization and what amounts to asymptotic freedom is achieved in large distances–a state of affairs which has influenced the formation of our "traditionally" held view about observing isolated entities. The confinement of quarks whose only proofs are model dependent, seems to be quite indispensable for the only promising way of incorporating gravity into a unified description of all forces.

Recent developments introduce a different kind of "confinement" as well. The future success of the superstring theories is quite strongly dependent on devising a convincing method to show that the ten dimensions which are necessary to construct the theory can, in fact, be "compactified" to the four that make our space-time continuum (Schwarz, Green 1986). The rest are there, but unobservable, all curled up, not having had a chance to unfold during the first instants of the big bang–allowing, in a variant of the inflationary universe, for the "existence" of (many) universes with different dimensionality (Linde 1987).

The examples we mentioned display a move from (1) a situation where the unseen is *accounted* by a new theory and the procedures for its observation in an isolated form are explicitly and unambiguously stated, to (2) a situation where the proposed theory shows how to *tame* the catastrophes brought about by the unseen, proposing at the same time procedures for observing manifestations of the unseen, to (3) a situation where remaining unseen is *guaranteed* by the theory itself modifying analogously the procedures of observation.

It may be remarked that there is no rigorous proof of confinement which is (relatively) model independent, and that such a situation cannot justify our placing so much emphasis on this concept.* Such an argument, however, is quite irrelevant for what we attempt to do in this note which is to answer the two questions we posed in the beginning. And one of the ways for providing an answer is to show that the developments in high energy physics seem to be establishing a framework which *legitimizes* the use of a set of concepts which should, at least, motivate us to question our beliefs about the observability of the ultimate building blocks. This is, obviously, not a claim for the correctness of the dominant theories in particle physics, but rather an appeal to realize that on a conceptual level, we are in a position to have theories, which allow for quite radical departures from a set of accepted procedures of observability.

Might not all these be a series of mathematical tricks to ensure that what is not observed stays unobserved, because basically it is not there to start with? After all, there is such a historical precedent. It is the ether, whose ever enriching "physical" attributes were postulated "as excuses for hiding evidence of it from experiment" (Drell 1977, p. 30). The parallelism, however, cannot be sustained for one very crucial difference between the two. We now know that the main reason ether was introduced, was because of the prevailing prejudices in favor of the mechanistic outlook. It was impossible to imagine and accept the propagation of waves independent of a medium. And one of the truly remarkable aspects of Einstein's 1905 paper, is that it shows that the ether was not a *necessary* notion for a consistent reading of both electromagnetism and mechanics (Holton 1973, Miller 1981). His arguments convinced us that showing that something is unnecessary may have as tangible and measurable results as proving that something is right or wrong. For the case of the ether every time there was a failure to observe an expected property, there was an enrichment of its physical attributes. The situation with the quark model is totally different. Every predicted property of the quark model has been corroborated, and further refinements were able to account for the observed deviations. In the case of the ether the additional physical attributes guaranteed that what was "expected" and looked for and not found, stays unseen. In the case of the quarks what was expected was found and the development of the theory gave rise to confinement. In the case of the ether, one had from the start an unsuccessful mode, whereas in the case of the quarks one had, right from the beginning, a successful model.

4. Conclusion

What I have attempted to do was to argue that appraising the developments in high energy physics within a context founded on an ontology of "a few, freely observable ultimate building blocks" as being *the* elementary particles is quite misleading, and does not really conform with the implications of the emerging conceptual framework of these recent developments. The insight we seem to have been gaining for the features of the "subnuclear level" is that a consistent and unified account of all phenomena of this realm can be satisfactorily built with "quite a few particles taking part in gauge invariant and renormalizable interactions which necessarily confine some of the constituents". And it is only in this sense that leptons, quarks and intermediaries can be regarded as elementary, and that the paradigm of elementary particle physics is in no crisis.

Does all that mean that there is no possibility for a further underlying structure to be discovered? Does that mean that leptons, quarks and the intermediaries will forever remain structureless however much we try to find their structure? Nothing justifies to deny any such developments and if past experience is to have any guiding value new structures will almost certainly appear. One of my aims was to show that reaching the "smallest" and "structureless" constituents may in fact be a necessary condition in order to consider them as elementary, but it is by no means a sufficient condition. This latter requirement can only be fulfilled if these structureless constituents can actually provide a unified explanation of all the phenomena characteristic of a particular "realm", thus bringing forth the methodological significance of "elementarity" during each historical period. Concerning the developments of the last twenty-five years, nowhere is this significance more pronounced than in the changes brought to the process followed for elementarizing the particles, and especially in specifying their procedures of observability. These procedures are not merely a convenient means for constructing theories, they also seem to be continually modifying the conceptual framework within which a series of philosophical and methodological issues of elementary particle physics are discussed.

Note

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