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何为希格斯玻色子的本体论地位？
——关于一个未了结方案（恩格勒—布绕特—希格斯机制）的评注

What is the Ontological Status of the Higgs Boson?
Notes on the Englert-Brout-Higgs Mechanism as an Unfinished Project

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摘　要: 恩格勒—布绕特—希格斯机制究竟在何种程度上被观察所确认了呢？在何种意义上，该机制有助于我们去理解质量的产生呢？要解答这些问题，关键取决于对“机制究竟意味了什么”的理解。本文通过对这一机制的起源历史进行考究，澄清了其所涉及的概念基础。基于此，带质量的玻色子和恩格勒-布绕特-希格斯机制自身的本体论地位（是实在论的，还是工具主义的）通过考究其基础的真正地位而得以分析和讨论。通过这种分析，恰当地获得了一个结论，即面对两个疑惑（戈德斯通模的动力学恒等变换和重组物理自由度上的不变性），恩格勒—布绕特—希格斯机制和希格斯玻色子的本体论地位仍然是不确定的。

关键词: 希格斯玻色子　恩格勒—布绕特—希格斯机制　本体论地位　不确定

Abstract: Pending the resolution of the coupling-transmutation mystery and the dissolution of the fixity in reorganizing the fields, the uncertain status of the Englert-Brout-Higgs(EBH) mechanism— a physical reality in the subatomic realm or an ad hoc fictitious mental device— has not been even slightly changed by the observation of the Higgs boson. Moreover, this uncertainty also has implications for the understanding of the origin of the mass of subatomic particles. In order to justify the claim that the EBH mechanism contributes to our understanding of the origin of mass, the mechanism itself has to be shown to be real. But this is yet to be done. For this reason, the EBH mechanism can only be taken as an unfinished project.

Key Words: Higgs Boson; Englert-Brout-Higgs(EBH) mechanism; Ontological status; Uncertainty

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1. Introduction

The recent observation of a massive scalar particle -- first explicitly suggested in a context of broken symmetry by Peter Higgs in 1964 and referred to as the Higgs boson ever since -- by the ATLAS and CMS experiments at CERN’s Large Hadron Collider is a significant development in particle physics . It has changed the perspective from which the electroweak theory and the future of fundamental physics are conceived. The very existence of a fundamental scalar boson has opened new vistas for, and set severe constraints on, further theoretical and experimental explorations about the true nature of the scalar sector as well as the naturalness of the hierarchy of

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fundamental scales, which involve many speculative notions, such as supersymmetry, technicolor, extra dimensions, inflaton, dark energy, and many more.

As a philosopher and conceptual historian of particle physics, what interests me the most is the change of perspective on this question as a result of understanding how this discovery was made and what its implications really are.

One popular assessment is that it confirms a mechanism -- first suggested by Francois Englert and Robert Brout in 1964 and then refined by Peter Higgs in 1966 , so let us call it the Englert-Brout-Higgs mechanism -- which is supposed to contribute to our understanding of the origin of mass of subatomic particles . To what extent the EBH mechanism is confirmed -- or what is supposed to have been and what is actually confirmed -- by the observation and in what sense the mechanism contributes to our understanding of the mass generation, however, critically hinges on the understanding of what is meant by the mechanism. In this lecture, the conceptual foundation of the mechanism will be clarified (section 3) through a historical examination of its genesis (section 2); then the ontological status of massive bosons and the EBH mechanism itself, realist or instrumental, will be discussed through an examination of the reality status of its foundation (section 4) , with a conclusion that the uncertainty in the ontological status of the EBH mechanism and thus of the Higgs boson remains before the two puzzles, the transmutation of the Goldstone modes' dynamic identity and the fixity in reorganizing the physical degrees of freedom, are properly addressed (section 5).

2. The Genesis of the Englert-Brout-Higgs Mechanism

Historically, the EBH mechanism emerged as a result of three lines of development: (1) broken symmetry manifested in a degenerate vacuum, (2) scalar field theory with a broken symmetry solution, and (3) mechanism for gauge bosons to be massive.
With the developments since the mid-1950's, such as PCAC, Sakurai's and Glashow's gauge theory, SU(3) flavour symmetry and current algebra, particle physicists increasingly recognized the desirability of a proper understanding of broken symmetry. More pertinent to our concern, however, was an observation, made by Abraham Pais as early as 1953, about the existence of a hierarchy of (strong, electromagnetic, and weak) interactions with regressively less symmetry . This notion of a hierarchy of interactions and their associated symmetries was suggestive of Heisenberg's non-linear unified field theory proposed in 1958 : his unified theory would make no sense if he could not derive phenomena in various types of interaction possessing various symmetries from the equations of the underlying field that possess a higher symmetry than the phenomena themselves.

On November 21, 1958, Lev Landau wrote Heisenberg in support of his unified theory, with a novel idea which was perhaps derived from his early work on phase transitions: "the solutions of the equations will possess a lower symmetry than the equations themselves." In resonance with Laudau's suggestion, Heisenberg explored the notion of the vacuum, whose properties underlie the conceptual structure of a field theory. He first invoked the idea of a degenerate vacuum to account for internal quantum numbers in 1958, and then asserted in 1959 that "it is by no means certain a priori that the theory must give a vacuum state possessing all the symmetrical properties of the starting equation", and thus "it should be considered not really a vacuum but rather a world state, forming the substrate for the existence of elementary particles. This state must then be degenerate" and "is the basis for the symmetry breaking." Heisenberg's idea of a degenerate vacuum was influential. But he never reached a satisfactory understanding of the origin, mechanism and physical consequences of broken symmetry, nor did he give a convincing mathematical formulation of it.

The physical realization in field theory of Heisenberg's idea was first provided by Nambu, who applied the BCS-Bogoliubov formulation of superconductivity to a chiral invariant field theory, with the former's phonon-mediated interaction being replaced by a non-linear interaction among fermions. In Bogoliubov's formulation, the elementary excitations are pseudo-particles or doubly charged Cooper pairs, whose energy gap explains superconductivity. The states of the charged pairs are not eigenstates of the charge, and thus not gauge invariant. So the vacuum as the condensate of the pairs is also not gauge invariant and thus degenerate. An important result in Nambu's work is that one of the exact solutions of the vertex part equation, namely the collective mode of the quasi-particles, which leads to the Ward Identity and thus ensures the gauge invariance of the whole theory, is the bound state of a pair with zero spin and zero energy-momentum. So the existence of the massless spinless bound states appears to be the logical consequence of gauge invariance when the vacuum is degenerate. Nambu transplanted this reasoning to a chiral invariant field theory and interpreted, with some modifications, the symmetry restoring collective modes as pions, the bound nucleon-anti-nucleon pairs, which successfully explained the successes of PCAC

Nambu's work in fact has already disproved a widely adopted misnomer, spontaneous breakdown of symmetry. Symmetry is always broken by some physical mechanism (but never spontaneously), such as the Cooper pairing in superconductors, or his own non-linear fermion interactions. It is some dynamic mechanism that brings the system into energetically favourable asymmetrical states as compared to the symmetrical ones. This dynamic origin of symmetry breaking can also be seen clearly in Goldstone's work.

The theoretical context in which Goldstone explored Heisenberg's idea of broken symmetry manifested in a degenerate vacuum was quite different from Nambu's. While Nambu examined the consequences of a broken symmetry solution for the nature of the vacuum and for the inevitable appearance of massless spinless bound states in a non-renormalizable model of a self-interacting fermion field, Goldstone examined the conditions for a field theory to have a broken symmetry solution in a renormalizable model of a self-interacting boson field. Both Nambu and Goldstone observed the necessary appearance of the symmetry-restoring massless boson in a symmetry-breaking field theory. But Goldstone's boson, in contrast with Nambu's bound fernion-antifermion pair, arises from a primary scalar field. While the chiral symmetry in Nambu's case was broken by an unknown self-interaction of the fermion field, Goldstone found that, in addition to the self-coupling of the boson field, only when the boson mass squared is negative and the coupling constant satisfies a certain inequality, does the field model he examined have a broken symmetry solution, that is, the field would have a degenerate vacuum, consisting of an infinite number of lowest energy states separated by superselection rules.

A novelty of Goldstone's model is the introduction of a primary scalar field that has nothing to do with a "more fundamental" fermion field. The step taken by Goldstone appeared to be arbitrary or at best an ad hoc way of exploring issues accompanying symmetry-breaking with no other reasons, and thus was regarded as "a serious flaw" by Leonard Susskind and by many others. Numerous efforts have been made to get rid of this fundamental scalar field, so far all of them have failed. In the five decades since its introduction, the notion of a fundamental scalar field has become a new organizing principle in the exploration of symmetry-breaking in field theoretical models.

The most consequential result of Goldstone's work was his observation that whenever the original Lagrangian has a continuous symmetry, any broken symmetry solution will be invalidated by the entailed but non-existent massless boson, the so-called Goldstone boson. This observation was the first revolutionary step crucial for all the subsequent developments in the exploration of broken symmetry. Goldstone's observation was generalized into a theorem and thus posed a great challenge to the exploration of a broken symmetry solution to gauge theory. This prompted the enthusiasts of broken symmetry to set an agenda for evading it. Although mathematically no evasion is possible, the theorem itself turned out to be almost irrelevant in the ensuing developments. Crucial to the proof of the theorem was the assumption of Lorentz invariance. But in the context of gauge theory, a Lorentz-invariant formulation contains nonphysical degrees of freedom, such as timelike gauge bosons with negative probability. For this reason, all discussions of the subject in this context used the Coulomb gauge, which makes manifest the menu of experimentally accessible particles of the theory, without explicit Lorentz invariance. This reasonable move was regarded as a departure from the assumptions of the theorem. Still, Goldstone's original observation about the symmetry-restoring massless scalar boson remained valid, and had to be properly addressed.

This pursuit was readily possible because another innovative scheme pertinent to the issue proposed by Schwinger was already available by then. One of the motivations for having a broken symmetry solution in gauge theory was to have massive gauge bosons to account for the short range nuclear forces. Schwinger explored the issue from a dynamic perspective without explicitly mentioning broken symmetry because he believed that "the general requirement of gauge invariance no longer seems to dispose of this essentially dynamic question." In a toy model of two dimensional massless QED, Schwinger demonstrated that, when the gauge field is strongly coupled with a symmetry current, it might not be massless if its vacuum polarization tensor possesses a pole at light-like momenta. The assumed field-current coupling indicates that the context in which the gauge boson was examined was an interacting theory rather than a pure gauge theory, involving another field in the current, whose interactions with the gauge field under certain conditions may contribute to the appearance of the pole. Although the notion was not invoked by Schwinger, both the pole itself, which is connected with the non-vanishing vacuum expectation value of a field interacting with the gauge field -- either a primary field or a composite -- and its consequence of giving the photon a mass, were closely related with broken symmetry. Schwinger did not specify the reason why a pole would appear in the vacuum polarization tensor; he only asserted that it was dynamically produced, most likely by a bound state of Nambu's type. But its scalar nature makes it open to the interpretation that it is produced by a primary scalar field. This interpretive flexibility was soon exploited fruitfully by Englert and Brout, resulted in a mechanism which is the major subject of this note.

Schwinger's model was trivial, but his insights set a grandiose framework for many to follow. The first was Philip Anderson, who used the case of the plasmon to vindicate Schwinger's insights: Nambu's massless collective mode or bound state is converted into a massive plasmon by interacting with the electromagnetic field. From this case, he suggested that "the only mechanism for giving the gauge field mass is the degenerate vacuum type of theory." He even claimed that "the Goldstone zero-mass difficulty is not a serious one, because we can probably cancel it off against an equal Yang-Mill zero mass problem."

In terms of ideas, Anderson was the first to associate Schwinger's mechanism with broken symmetry and the Goldstone boson. In terms of physics, however, the suggested association was quite tenuous. His non-relativistic example of the plasmon did established some connection between broken symmetry and Schwinger's strategy of gauge bosons acquiring mass through interacting with another field; but the physics for symmetry-breaking involved in his case came from Nambu's bound states rather than Goldstone's primary scalar field.

The first serious effort to fit Goldstone's scalar system into Schwinger's grandiose framework, in concrete physical terms rather than vague ideas, was made by Englert and Brout. In their model of scalar QED (which was extended to nonabelian symmetries without substantial structural changes) in which the symmetry-breaking scalar system was coupled to the gauge field, they directly interpreted the symmetry-restoring massless boson, in lowest order perturbative calculation of the vacuum polarization loop for the gauge field, as the physical base for Schwinger's pole, which gives mass to the gauge boson. This interpretation can be viewed as a realization of Anderson's conjecture. But it should be taken as a real breakthrough in physics, in terms of understanding the symbiotic nature of Goldstone's scalar system and its coupled gauge system: Neither the scalar system with a broken symmetry solution nor the pure gauge system could exist separately without being invalidated by the entailed but non-existent massless (scalar or vector) bosons; only jointly as two inseparable moments of a symbiont could they have broken symmetry solutions. One defect in their understanding of the nature of the symbiont was their erroneous claim that "the symmetry is broken through the gauge fields themselves;" actually, it is broken through the self-interactions of its scalar moment.

3. The Conceptual Foundation of the Englert-Brout-Higgs Mechanism

The conceptual situation was greatly clarified once the novel notion of "induced symmetry breakdown" (ISB) was introduced, with great scientific creativity, by Higgs in 1966. When the scalar system with a broken symmetry is Yukawa-coupled to a spinor system that contains no additional mechanism for symmetry breaking, Higgs asserted, the symmetry breaking in the scalar system breaks the symmetry of the spinor system to an extent that depends on the Yukawa coupling constant, and thus allows the system to have non-symmetrical states of massive fermions, whose masses are accordingly in proportion to their

Yukawa coupling constants. What was suggested by Englert and Brout fits perfectly into Higgs's notion: The gauge coupling there played the same role as the Yukawa coupling in Higgs's case, namely, for inducing symmetry breaking in the vector system by the symmetry-breaking scalar system. Thus the symmetry breaking in the vector and spinor system, manifested in the massive vectors and fermions, is not related to their own degenerate vacua, but is induced by the primary symmetry-breaking of the scalar system through the gauge coupling and the Yukawa coupling respectively. The notion of ISB has revealed a deep truth of the physical world: What renders possible a broken symmetry solution for a multi-field complex system (such as the scalar-spinor-vector system in Weinberg's unified electroweak theory) may only be one degenerate vacuum constituted by the self-interaction of its scalar component rather than a set of separate vacua, each for a component field.

Once the notion of ISB, which grounds the scalar-field-based EBH mechanism, was absorbed, consciously or unconsciously, into the understanding of broken symmetry physics, a clear picture, as proposed in Weinberg's unified theory, emerged. At the most fundamental level, the scalar field's self-coupling is the mechanism for constituting a degenerate vacuum (the related non-vanishing vacuum expectation value of the scalar field is a universal parameter in the electroweak domain, the weak scale). Its gauge coupling to gauge fields underlies the constitution of the massive gauge bosons and is responsible for the symbiosis of the scalar-vector complex manifested, through a redefinition of the fields involved, in a set of massive gauge bosons and a massive Higgs boson. Its Yukawa coupling to the fermion system underlies the constitution of massive fermions and contributes to CKM matrix, CP violation, and flavour physics. The gauge field's gauge coupling dictates the electroweak interactions, but contributes nothing to the constitution of the degenerate vacuum. The fermion system builds up its broken symmetry solutions, not from its own degenerate vacuum -- there is no such vacuum -- but from its Yukawa coupling to the scalar system, and thus can be viewed as conceptually less fundamental in the electroweak domain, although it itself is a primary existence that cannot be derived from anything else.

Thus the EBH mechanism can be properly understood as simply a set of scalar field couplings: its self-coupling is responsible for the broken symmetry solution, its gauge coupling and Yukawa couplings are responsible for the broken symmetry solutions for the gauge and spinor fields manifested in massive gauge bosons and massive fermions. If the EBH mechanism is understood in this way, it seems that the claim that it "contributes to our understanding of the origin of mass of subatomic particles" is justified.

4. The Ontological Status of Massive Bosons and the EBH Mechanism: Realism Versus Instrumentalism.

But the above happy conclusion about the significance of the EBH mechanism is somewhat disturbed by a seemingly naive question about its foundation: Does the broken symmetry solution of a scalar field exist? Surely it exists, the common wisdom asserts: Its massless modes are combined with ("absorbed by") the massless gauge bosons, resulting in the desirable massive gauge bosons, whose consequences have all been confirmed without any trace of doubt. As to its massive mode, which has been elusive for a long time, now it has finally been observed by experiments at CERN's LHC. With all the consequences of its existence confirmed, one may feel that its existence is confirmed. And this also seems to suggest the confirmation of the EBH mechanism built on it. A pundit may argue that it is logically fallacious to claim the validity of the antecedent by affirming the consequent. Yet confirming the consequences at least has provided evidential support for the antecedent. In this case, however, there are more seriously disturbing problems coming from physics than from the incomplete validity of inductive logic.

The validity of the common wisdom is explicitly or implicitly based on two assumptions. First, both the broken symmetry solution of a scalar field and the symmetrical solution of gauge fields exist in reality, at least at a deep, experimentally inaccessible level. Secondly, at the experimental ("physical") level, some of them always appear in a redefined (combined) way as the massive vector bosons. That is, both the massless scalar modes and massless vector modes are real, but not observationally-empirically-experimentally-cognitively accessible in a separate way. However, if there is simply no way to have any access to their separate existence, especially to the effects derivable from the Goldstone modes, either directly through their derivative couplings or indirectly through separating the effects produced by the Goldstone modes from the massive gauge boson-mediated events, then what is the ground for believing in their separate existence? An instrumentalist may thereby deny the reality of the broken symmetry solution of the scalar field and the symmetrical solution of gauge fields, relegating them into the fictitious status of phlogiston and the ether, whose only function is to construct the observable particles 16whose ratios are the relevant couplings), which, according to the positivist-instrumentalist philosophy, are the only realities in the physical world. That is, an instrumentalist would take Weinberg's model as physically nothing more than Glashow's model, except for an additional Higgs boson.

4.1 A Realist's Response: a Scalar-vector Symbiont as a New primary Entity

But there could be a realist reading of the EBH mechanism based on assumptions that differ from those taken by the common wisdom. Perhaps, rather than a set of scalar and vector fields, what exists in reality is a scalar-vector symbiont possessing broken symmetry solutions for its scalar and vector moments. Perhaps the physical foundation for the EBH mechanism is this primary symbiont -- whose internal dynamics, as we shall see shortly, explains the EBH mechanism -- but not a primary scalar field and its set of couplings. Although the symbiont, a physically primary non-decomposable (even at the deep, experimentally inaccessible level of reality) single entity is mathematically describable by analytically separable structures, no mathematical separation and manipulations would have any ontological meaning. That is, there could be no massless excitations of its scalar or vector moments arising from the symbiont: they are only the artefacts of an illegitimate separation of the non-decomposable structure. Thus the holistic structure of the symbiont is very different from, e.g. the structure of a coupled electron-photon system, whose components (electron and photon) in the gauge-less limit can have separate existence, and there is no way for its components to be recombined in different ways to produce different field configurations. To such a symbiont, an old Christian maxim applies: What God has joined together, let no man put asunder.

The ontological assumption of an inseparable symbiont may not prevent us from assuming that its two moments are dynamically separable at the deep level of reality, or even at the experimentally accessible level. That is, each moment has its own dynamical identity, its characteristic ways of coupling to other systems without being affected by those of the other moment. Thus the scalar moment has its self-coupling and Yukawa coupling without being affected by the vector moment's gauge coupling; similarly, the vector moment has its characteristic way of gauge coupling to other systems without being affected by the scalar moment's ways of coupling. This assumption is crucial for a realist reading of the EBH mechanism because otherwise, at the deep experimentally inaccessible level of reality, no self-coupling and Yukawa coupling of the scalar moment (and the degenerate vacuum and massive fermions constituted thereby) would be definable; and at the experimentally accessible level of reality, no vector moment's gauge coupling (and thus their electroweak interactions) would be definable.

4.2 A Spacetime Analogy: Reorganisable Moments of A Symbiont

There is a well-known predecessor of such a holistic symbiont. In 1908, Hermann Minkowski declared: "Henceforth space by itself, and time by itself, are doomed to fade away into mere shadows, and only a kind of union of the two will preserve an independent reality." Similarly, we may say that Goldstone's scalar system and Glashow's gauge system are doomed to fade away into mere shadows, and only a symbiont of the two (scalar and vector) moments exists as a holistic entity in the electroweak domain of the world, aside from the fermion system.

Just as the distinction between spatial and temporal aspects of the world remains, even though only spacetime is an independent reality, we can still meaningfully talk about the scalar moment and the vector moment of the symbiont -- and their experimentally accessible manifestations: massive scalar and vector bosons – characterized by their dynamical identity, with an understanding that they are just different moments (manifestations) of a single physical entity, having no separable existence. They are different from the scalar field and the vector field separately or joined in a coupled system because the symbiotic nature of the two moments allows the reorganization of their degrees of freedom within the symbiont. The role the reorganization plays is similar to the role the Lorentz transformation plays in the case of spacetime.

4.3 Realism of Symbiont Differs From Realism of Fields

Twenty one years ago I asked Peter Higgs at a SLAC conference: "What is the ontological status of the Higgs boson?" The question had two levels of meaning: (i) a choice between a real particle and a fictitious one (a phenomenological indicator of something complicate situation); and, assuming it is real, (ii) a choice, at that time, between a composite of Nambu's type, which underlay the pursuit of dynamical breakdown of symmetry, and a fundamental scalar boson of Goldstone's type. The LHC confirmation seems to have delivered the verdict in favour of the latter, within the EW domain, of course. Beyond that domain, the space for speculative ideas is virtually infinite, but the space for real physics is almost point-like.

But if the symbiont is a primary entity in the electroweak world, then the observation of the Higgs boson (or the W and Z bosons) cannot be taken as a vindication of the excitation of the scalar field (or gauge fields), as the old realist ontology would suggest. Rather, it can only be taken as a vindication of the excitation of the scalar (or vector) moment of the symbiont. The difference between the two ontological assumptions is scientifically significant. The old view takes the recent observation of the Higgs boson as a vindication of the reality of the scalar field, which has a package of physical implications. This may tempt people to use this new observation to address open questions in fundamental physics, such as inflation or dark energy. The symbiont view, however, would take the observation of the Higgs boson as a vindication of the reality of the scalar moment of the symbiont. That is, we take the massive boson as the quantum excitation of the scalar moment of the scalar-vector symbiont, which can be observationally registered when it is in interactions with other field quanta in the EW part of the physical world, but is physically tightly connected with the other excitations of the whole complex, including the gauge bosons.

Thus wherever the implications of the Higgs boson lead, the whole package of implications of the existence of the symbiont, including but not restricted to the effects of the W-bosns and the Z-boson, should also be taken into serious consideration. "What God has joined together, let no man put asunder." This will put severe constraints on the pursuit of these implications. But it will also give great predictive power to the pursuit.

4.4 Two Puzzles

The reorganizability of the degrees of freedom (from the inseparable moments of a symbiont) for a redefinition of fields is the characteristic feature of the symbiont, and is also crucial for grounding the EBH mechanism. In his classic 1967 paper, Weinberg indicated that the redefinition of the field (through the recombination of the degrees of freedom from two moments of the symbiont, as happened in the redefinition of gauge bosons) implied the reordering of the perturbation theory. The details of how the two are connected may be an effective technical means for addressing the subtle conceptual issues explored here. Unfortunately, Weinberg did not spell them out. But it seems reasonable to assume that what is to be recombined for redefinition of the fields, and reordered in the perturbation theory, should have their identities maintained before and after; otherwise an uncontrollable conceptual mess would ensue.

One important aspect of the identity of a degree of freedom is its dynamical identity mentioned above; namely, its characteristic ways of coupling to other systems. Thus, a scalar degree of freedom has its characteristic way of coupling to itself (self-coupling) and to fermions (Yukawa coupling). Through the redefinition, Weinberg noticed, "the Goldstone bosons (the massless mode of the scalar moment) have no physical coupling." By "physical coupling," surely he meant only experimentally accessible coupling, not all its dynamical interactions with other physical entities. The massless modes of the scalar moment do not disappear through the redefinition of the fields; they are only to be reorganized into vector fields, being their longitudinal components. Thus, their dynamical capability (manifested in their couplings to other physical entities) does not disappear, only gets to reappear in different incarnations. In fact, the dynamical interactions of the massless modes of the scalar moment with other physical entities can easily be understood as being realized through the dynamical interactions of the gauge bosons with other entities, acting as their longitudinal components. So it seems that nothing gets to disappear mysteriously through redefinition.

But there is indeed a mystery, a mystery of different kind: the mystery of the transmutation of the nature of the couplings of the massless modes of the scalar moment. In their interactions with another mode of the scalar moment (the Higgs mode) and with fermions, their original self-coupling and Yukawa coupling have been transmuted into the gauge coupling through the reorganization.

This mystery has not been addressed or even noticed by physicists. The closest approach to pondering on the subject, though not directly addressing it, was offered by Weinberg almost 20 years after his classic paper. In the section 21.1 of his book The Quantum Theory of Fields (volume II: modern applications), Weinberg was able to show that in the gaugeless limit, “the gauge boson exchange matrix element is the same as the Goldstone boson exchange matrix element” for a generic physical process. The same mathematical result coming from different couplings may have indicated an intimate connection between the two, but is not an adequate explanation of the transmutation from one to the other through the relocation of the same degree of freedom. It is not clear from his mathematical manipulations what the physical mechanism for such a transmutation is.

If we want to take the EBH mechanism realistically, rather than merely as a fictitious instrument for obtaining the empirical parameters that the Glashow model needed; or, more generally, if we want to take all the terms used in a theoretical discourse as having some physically real meaning, then this mystery has to be dispelled. Yet this task remains to be done.

A closely related or even deeper issue is: What are the physical processes through which various degrees of freedom coming from two moments of the scalar-vector symbiont can be reorganized, resulting in the redefinition of the field involved? In the analogous symbiont of spacetime, the reorganization of its spatial and temporal aspects is driven by a relative velocity between two reference frames, and thus the reorganization is flexible and variable, depending on the variable velocity involved, and can result in various different configurations of spatial and temporal aspects. Is there a similar flexibility and variability in the reorganization of our scalar-vector symbiont? If so, then what is the physical ground for such flexibility? So far no such ground has been explored, and in fact no trace of flexibility and variability has been displayed in the literature, aside from the unique reorganization of the degrees of freedom from the original Lagrangian into the massive gauge and Higgs bosons. If this fixity cannot be dissolved, the EBH mechanism threatens to be an ad hoc device for obtaining the observable particles and measurable parameters, and thus cannot be taken realistically.

5. Conclusion: Uncertainty remains

Pending the resolution of the coupling-ttransmutation mystery and the dissolution of the fixity in reorganizing the fields, the uncertain status of the EBH mechanism -- a physical reality in the subatomic realm or an ad hoc fictitious mental device -- has not been even slightly changed by the observation of the Higgs boson. Moreover, this uncertainty also has implications for the understanding of the origin of the mass of subatomic particles. Since all the masses of subatomic particles are expressed in terms of a product of the weak scale (which is constituted by scalar moment’s self-coupling) and these particles’ couplings to the scalar moment, if the scalar moment and its couplings are real, then the EBH mechanism does contribute to our understanding of the dynamic origin of the mass of subatomic particles. But if the EBH mechanism itself is merely an ad hoc fictitious conceptual device, if the scalar moment involved in the mechanism is only a fiction, and thus the weak scale and coupling constants are merely measurable parameters; then the mechanism contributes nothing to our understanding of the origin of mass.

In order to justify the claim that the EBH mechanism contributes to our understanding of the origin of mass, the mechanism itself has to be shown to be real. But this is yet to be done. For this reason, the EBH mechanism can only be taken as an unfinished project.

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