СООБЩЕНИЯ
ОБЪЕДИНЕННОГО
ИНСТИТУТА
ЯДЕРНЫХ
ИССЛЕДОВАНИЙ

Дубна

E2-95-342

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PHYSICAL ANALYSIS OF SOME FEATURES OF THE GAUGE THEORIES WITH HIGGS SECTORS

1995

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Физический анализ некоторых черт калибровочных теорий с хиггсами

Проводится физический анализ некоторых свойств калибровочных теорий с хиггсовскими секторами. Показано, что для того чтобы устранить противоречия, возникающие в калибровочных теориях с хиггсами, нужно предполагать, что калибровочные преобразования в фермионном и хиггсовском секторах различаются (т.е., имеют разные заряды). Тогда хиггсовский механизм можно интерпретировать как некоторый механизм экранировки калибровочного поля. В таком механизме фермионы остаются безмассовыми. Делается вывод, что в стандартном сценарии развития вселенной монополи не могут выживать при низких температурах.

Работа выполнена в Лаборатории сверхвысоких энергий ОИЯИ.

Сообщение Объединенного института ядерных исследований. Дубна, 1995

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Physical Analysis of Some Features of the Gauge Theories with Higgs Sectors

A physical analysis of some features of the gauge theories with Higgs sectors is made. It is shown that we should assume gauge transformations in the fermion and Higgs sectors to be different (i.e., to have different charges) in order to remove contradictions arising in gauge theories with Higgs sectors. Then, the Higgs mechanism can be interpreted as some mechanism of gauge field shielding. In such a mechanism fermions remain without masses. The conclusion is made that in the standard theory of the development of the Universe, monopoles cannot survive at low temperatures.

The investigation has been performed at the Laboratory of Particle Physics, JINR.

Communication of the Joint Institute for Nuclear Research. Dubna, 1995

I. Introduction

The Higgs mechanism [1] is usually used in order to obtain the masses of vector bosons in the gauge theories [2] without violation of the renormalization invariance of these theories [3]. But in the gauge theories with Higgs sectors other possibilities appear: for instance, the possibility to build up monopoles without peculiarities [4].

The aim of this work is to make some physical analysis of the guage theories with Higgs sectors issue by analogy with statistical physics and solid-state physics.

II. Possible physical interpretation of the Higgs mechanism and some of its consequences

In ref. [5] it was observed that when the Higgs mechanism is used in gauge theories with the fermionic sector (U(1), SU(N) theories), a contradiction arises. In U(1) (or SU(N)) theories, interactions of fermions and of Higgs particles occur through the exchange of the same vector bosons, i.e. the charges of fermions and Higgs particles coincide. It must be stressed that, when the Higgs mechanism is switched on, a Higgs particle becomes neutral (vector fields are shielded), and a part of the Higgs particle component is transferred to vector bosons. At the same time, the fermionic fields remain without changes, i.e. a charge in this sector remains without changes (though the vector fields are shielded). Evidently, in order to make the charge of fermions neutral, it is necessary to apply a mechanism analogous to the Higgs one (obviously, it is the simplest way to get an analogous effect to make the fermions neutral).

And, in order to get rid of this contradiction in ref. [5] it was suggested to assume the charges of the fermions and Higgs particles to differ. Then, the vector fields get their masses via the Higgs mechanism, and the fermion charge remains without changes, and the renormalization of the theory is preserved. In statistical physics and solid-state physics there is a profound analogy with the Higgs mechanism. This is the shielding of a charge in the plasma, a magnetic field in a superconductor [6], the theory of superconductivity [7], etc. Though shielding takes place in these examples, but the global charge is preserved. It is well seen in the example of the shielding of plasma (though shielding of a charge takes place in plasma, the charge itself is preserved, i.e. the system gets the charge). In elementary particle physics we can see an analogous example; the Π and K mesons can are created in weak interactions, then the masses of these mesons are generated in the strong interactions but not in the weak interactions.

It can assumed that the Higgs mechanism works by analogy with the above, i.e. the vector fields are shielded in the Higgs scalar fields, and gauge invariance is not violated, as the fermionic part remains without any change (i.e. the shielding of the charge is induced). But in principle, the other version is possible: the charges in fermionic and Higgs sectors coincide, but at the same time the Higgs sector works at another level (in order to clear up the point of this remark we should point to the Van-der-Wals forces which are the electromagnetic by origin, but they just work at another level).

Now we can put the question: what limitations on the Higgs sector are required to realize the indicated picture? If we have the fields of the Higgs and vector particles, ϕ, A_i^μ, satisfying the equations of ref. [8] (see Supplement),

$$
\begin{aligned}
(\Box^2 + 2g^2 v^2)\, A_i^\mu &= 0 , \\
(\Box^2 + 4\lambda v^2)\, \Phi &= 0 ,
\end{aligned}
\qquad (1)
$$

(where i=1,2,3 for SU(2) and i=1 for U(1)), then the fields Φ ,A_i^μ are massive ($m_\Phi = g\sqrt{2}\, v$, $m_A = 2\sqrt{\lambda}\, v$).Since the origin of the mass of A_i^μ is determined by the Higgs' mechanism, these massive fields A_i^μ must, accordingly, be created in the region of action of the Higgs mechanism. Hence we can get the limitation on the masses and parameters of A_i^μ. The regions of action of the Higgs particle of mass m_Φ and of vector particles of mass m_A will be determined by $R_\Phi \simeq \frac{1}{m_\Phi}$ and $R_A \simeq \frac{1}{m_A}$, and, if vector particles are created in the region of action of the Higgs field, we can get the following limits:

$$R_A \le R_\Phi \quad \text{or} \quad m_A \ge m_\Phi . \qquad (2)$$

From (2) and (1) we can impose a limit on λ

$$g^2 \ge 2\lambda , \qquad (3)$$

i.e. if we assume that W,Z^o bosons get their masses through the Higgs machanism and take advantage of the relation (2),we can get the upper limitation on a mass of the Higgs particle

$$m_\Phi \le m_W , m_Z .$$

The lower limit of the mass of the Higgs particle can be obtained using the effective-potential method [9], and it is

$$m_\Phi > \frac{\sqrt{3}\ \alpha\ v}{4 \sin^2\theta_W} (2 + \sec^4\theta_W)^{1/2} , \qquad (4)$$

where $\theta_W$is the Weinberg angle. If the masses A_i^μ are not connected with the Higgs mechanism, no limitation will take place in this case.

Fermions (quarks and leptons) and the Higgs particle in a standard model have the charge g_2 [2]. The charge in the Lagrangian

$$L_{int} = g\,(\bar{L}\chi l_R + \chi^+ \bar{l}_R L) \qquad (5)$$

(where L, l_R are the left doublet and the right singlets of the fermions) ,from which the masses of fermions arise ($\chi = (v + \phi)/\sqrt{2}$),is considered to be g [10], and this charge is usually taken to differ essentially from the fermion and the Higgs particle charge - g_2. If we take into account that the Lagrangian (5) represents a generalization of the Yukawa interaction [11], and if we proceed from the experience that we have in strong interactions, these charges will have to coincide: $g = g_2$. In such case we come to the conclusion that the fermions in the Higgs mechanism obtain masses which are near to the masses of vector bosons. This conclusion is in accordance with the intuitive conclusion that the masses of particles due to one and the same machanism must be approximately equal. But this conclusion sharply contradicts the experimental data on the masses of W,Z^o bosons and fermions.

Just to solve this problem we must come back to the previous conclusion [5] that the gauge charge of the fermions and scalar Higgs particles must be different. Then the Lagrangian (5) does not arise, and the fermions do not obtain their masses through the Higgs' mechanism. Such a conclusion is quite remarkable, as the fermion remains light, i.e. within the above approach, the result which many authers have tried to obtain in different ways [3,12], arises automatically. The small masses, that the fermions have in this case, may be explained by contribution of the electromagnetic and strong interactions. In this connection, we shall point to refs. [13], where it is shown that the weak interaction cannot contribute to the fermionic masses because of their left character.

III. Place of a monopole in the gauge theories in the standard development scenario of the Universe

One of the most interesting recent achievements of theoretical physics was the discovery of the existence of the so-called monopole solutions in non-Abelian theories with Higgs sectors [4]. Monopoles found a natural place in unified theories [14] and are a constituent part of the current development scenario of the Universe [15]. For example, in the standard SU(5) theory the monopoles have a mass of the order of

$$m_M \sim 4\pi M_X/g^2 ,$$

where $M_X \simeq 10^{14}$ GeV is the mass of the X boson, so $m_M \sim 10^{16}$ GeV, and the charge of the monopole M is $g_M \simeq 2\pi/g$.

In the standard development scenario of the Universe, monopoles are created at a temperature T_M

$$T_M \geq m_M \simeq T_M$$

and their equilibrium is violated at temperatures $T < T_M$, so, evidently, the main channel of their disappearance is monopole-antimonopole annihilation, since in this model the monopoles are considered to be stable formations. Further it is assumed that when the distance between the monopoles becomes large, they can no longer annihilate. This means the monopoles that survive in the Universe must exhibit a certain concentration. At present, searches for these monopoles are under way.

We would like to point out a scheme for the disappearance of the monopoles at temperatures $T < M_X$. We shall disscus it within

the frame of purely physical reasoning. In unified theories the monopole solutions are obtained as solutions of the equations derived from a Lagrangian involving non-Abelian gauge fields X ($M_X \simeq 10^{14}$ GeV) and Higgs fields H (with $M_H \sim M_X$). These monopoles are non-local objects having non-trivial topological indices. These topological numbers are conserved. Evidently, the existence of such topological solutions is a consequence of non-Abelian gauge theories being non-linear. Then, in the standard development scenario of the Universe the monopoles (or monopole solutions) can exist only up to the end of the existence of X,H particles, i.e. up to the temperature $T \geq M_X$. At temperatures $T < M_X$ the X,H particles decay and this phase stops existing. After this phase gluons and W, Z^o, γ remain, and, accordingly, the monopole solutions in this subsequent phase can exist no longer. For the monopoles to survive it is necessary to provide stabilization with respect to decays of the X,H particles. It is clear, that within the framework of the standard theory there is no such mechanism preventing X,H particles from decaying (we can give an analogous example: no abstract soliton can exist out of touch with the surface (with the appropriate boundaries) where solitons can be created).

In the example with the monopoles we can be sure that no monopoles exist outside the region where the X,H particles exist. Because of this evident reason we do not consider mathematical issues relevant to this problem.

IV. Conclusion

It is shown that the gauge transformations in the fermion and Higgs sectors must be considered different (i.e., they have different charges) in order to remove the contradictions in gauge theories with Higgs sectors. Then, the Higgs mechanism can be interpreted as some mechanism of gauge field shielding. In such a mechanism fermions remain without masses.

The conclusion is made that in the standard development theory of the Universe monopoles cannot survive at low temperatures.

Supplement

The Lagrangian in U(1) theory with the Higgs sector is usually chosen in the form

$$L = | D_\mu \chi |^2 - \frac{1}{2} \lambda (|\chi|^2 - \frac{1}{2} v^2)^2 - \frac{1}{4} F_{\mu\nu}F^{\mu\nu}, \quad (s.1)$$

where χ is the scalar field, $D_\mu = \partial_\mu - ie A_\mu$; $F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu$, A_μ are vector fields.

Further, we can write $\chi = \chi' e^{i\theta(x)}$, and introducing the notation

$$\chi' = \frac{1}{\sqrt{2}} (v + \Phi(x)) \quad (s.2)$$

and performing the standard procedure [1,9] we obtain equation (1) for the fields A^μ, Φ .

For the SU(2) theory with the Higgs sector the corresponding Lagrangian has the form

$$L = | D_\mu \chi |^2 - \frac{1}{2} \lambda (|\chi|^2 - \frac{1}{2} v^2)^2 - \frac{1}{4} G_{\mu\nu}G^{\mu\nu}, \quad (s.3)$$

where $\chi = \begin{vmatrix} \chi_+ \\ \chi_o \end{vmatrix}$ is an isospinor, $D_\mu = \partial_\mu - \frac{i}{2} g \tau^i A^\mu_i$;

$$G_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu - ig [A_\mu A_\nu - A_\nu A_\mu]$$

Further, choosing χ in the form

$$\chi = \frac{1}{\sqrt{2}} \begin{vmatrix} 0 \\ v + \Phi(x) \end{vmatrix}, \quad (s.4)$$

and, also, applying the standard procedure we obtain equation (1) for Φ and A^i_μ.

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Received by Publishing Department
on July 25, 1995.