AN APPROACH TO RELATE THE WEAK 
AND GRAVITATIONAL INTERACTIONS

Július Vanko¹ and Jozef Šima² and Miroslav Súkeník²

¹Comenius University, Mlynsk dolina F1, 842 48 Bratislava, Slovakia
²Slovak Technical University, FCHPT, Radlinského 9,
812 37 Bratislava, Slovakia
e-mail: vanko@fmph.uniba.sk,
jozef.sima@stuba.sk, sukenik.miroslav@stonline.sk

Abstract

Stemming from simple postulates of nondecelerative nature of the universe expansion and Vaidya metric application, the paper offers some dependences and relations between the gravity and weak interactions. It presents a mode of independent determination of the mass of vector bosons Z and W, and it derives the time of separation of electromagnetic and weak interactions. Comparisons of theoretically derived and experimentally obtained data indicate the relevancy of the used mode and provide a hint for further investigation. The W and Z bosons mass of about 100 GeV, together with the time and the Universe radius of electromagnetic and weak interactions separation approaching \( t_x = 10^{-10} \) s and \( a_x = 10^{-2} \) m, respectively, were obtained using our approach. The above values match well those commonly accepted.

Keywords: Weak interactions; Gravitational interactions; Boson mass;
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1 Introduction

The issue of unification of all four known physical forces is still one of the top-ten evergreens of theoretical physics. There are several approaches allowing to come to theoretical results which, in principle, do not contradict to the generally accepted physical principles and offer at least a partial solution of the matter. Among the approaches, the Standard Model [1–3] (which does not, however, provide a complete description of Nature since it does not address gravitational interactions), and the Superstring Theory [4–6], trying to become the Theory of Everything are to be mentioned. Within the elaboration of the mentioned and other theoretical approaches and their verification based on available experimental cosmological and particle physics data, several important achievements have been reached.
Frequently, the approaches involve the inflationary Universe [7] as a starting point. In this approach, the observable part of the Universe (its radius \(a\)) is emerging by the velocity of the light and, in turn, the Universe mass is gradually increasing. The same results may be obtained applying a hypothesis on nondecelerative expansion of the Universe (without the previous inflationary phase) with mass creation [8, 9]. The approaches differ mainly in metrics used since to describe the mass creation, the Vaidya metric [10, 11] or another metric implicitly involving such a creation must be involved. The Vaidya metric and the hypothesis on the matter creation has manifested its justification when explained both some macro world (cosmological) and micro world (particle physics) issues, such as rationalization and prediction of neutron star properties [8], questions concerning the entropy of the universe [9], estimation of lower and upper mass limits of black holes [12], explanation of Podkletnov’s phenomenon [13], clarification of the internal structure and parameters of the hydrogen atom [14], prediction of bands in far-infrared low-temperature spectra of chemical compounds [15].

A possibility of our approach to contribute to understanding the interactions of gravitational, electrostatic and electromagnetic fields [16] we have taken as a challenge to exploit the approach in an attempt to offer the applicability of Vaidya metric and the approach of nondecelerative expansion of the Universe in understanding of weak and gravitational forces unification. The results obtained are presented in this paper.

2 Energy of Z and W bosons

In the early stage of the Universe creation, i.e. in the leptons era an equilibrium of protons and neutrons formation existed at the temperature about \(10^9 - 10^{10}\) K. The amount of neutrons was stabilized due to weak interactions, which were responsible for processes such as

\[
\bar{\nu} + p^+ \rightarrow n + e^+ \tag{1}
\]

\[
e^- + p^+ \rightarrow n + \nu \tag{2}
\]

The cross section \(\sigma\) corresponding to the above processes may be expressed [17, 18] as

\[
\sigma \simeq \frac{g_F^2 E_w^2}{(\hbar c)^4} \tag{3}
\]

where \(g_F\) is the Fermi constant \((1.4 \times 10^{-62} \text{ J m}^3)\), \(E_w\) is the energy of weak interactions that, based on (3), can be formulated by relation

\[
E_w \simeq \frac{r \hbar^2 c^2}{g_F} \tag{4}
\]

where \(r\) represents the effective range of weak interactions. Stemming from relation (4) it holds that in a limiting case when

\[
r = \frac{\hbar}{m_W c} \tag{5}
\]
the maximum energy of weak interaction is given by
\[ E_w \approx m_W c^2 \] (6)

Relations (5) and (6) represent the Compton wavelength of the vector bosons Z and W, and their energy, respectively. Equations (4), (5) and (6) lead to the following expression for the mass of the bosons Z and W (indicated further on \( m_W \))
\[ m_{W}^2 \approx \frac{\hbar^3}{g_F c} \approx |100 \text{ GeV}|^2 \] (7)

providing the value that is in good agreement with the currently accepted value [19].

3 Localization of gravitational energy

The following part deals with a mode of expressing the localization of gravitational energy based on ideas of nondecelerative expansion of the Universe and application of Vaidya metric. Divergence of Einstein relation
\[ R_{ik} - \frac{1}{2} g_{ik} R = \frac{8 \pi G}{c^4} T_{ik} \] (8)

leads, in case of weak fields, to
\[ \varepsilon = -\frac{R c^4}{8 \pi G} \] (9)

Inside the body, the scalar curvature \( R \) can be obtained by calculation. It follows that
\[ \varepsilon = \varepsilon_s \] (10)

where \( \varepsilon_s \) is the energy density of source.

For the region outside the body,
\[ \varepsilon = \varepsilon_g \] (11)

where \( \varepsilon_g \) is the energy density of gravitational field.

Scalar curvature is calculable only in the case of Vaidya metric [10, 11] application. The necessity of the Vaidya metric introduction deserves some words of justification. Suppose, the Universe horizon is expanding by the velocity of light \( c \), i.e.
\[ da = c dt \] (12)

and
\[ a = c t_U \] (13)

where \( a \) is the radius of the visible part of the Universe, \( t_U \) is the cosmological time. At the same time, new mass is emerging at the horizon, i.e. the mass of the visible part of the Universe \( m_U \) is increasing obeying the relation
\[ \frac{dm_U}{dt} = \frac{m_U}{t_U} \] (14)
Applying Vaidya metric and using relations (12), (13) and (14), the scalar curvature $R$ outside the body is obtained in the form

$$R = \frac{3R_g}{a r^2}$$  \hspace{1cm} (15)$$

where $R_g$ is the gravitational radius of a body with the mass $m$, $r$ is the distance. Inserting (15) into (9), a formula for gravitational energy density $\varepsilon_g$ is obtained

$$\varepsilon_g = -\frac{R c^4}{8 \pi G} = -\frac{3 m c^2}{4 \pi a r^2}$$  \hspace{1cm} (16)$$

4 Relation between the weak and gravitational interactions

The Universe radius $a$ reaches at present

$$a \approx 1.3 \times 10^{26} \text{ m}$$  \hspace{1cm} (17)$$

As a starting point for unifying the gravitational and weak interactions, the conditions in which the weak interaction energy $E_w$ and the gravitational energy $E_g$ of a hypothetic body with a limit mass $m_{\text{lim}}$  

$$E_w = |E_g|$$  \hspace{1cm} (18)$$

can be chosen. Based on relations (4) and (16) in such a case it holds

$$\frac{r \hbar^2 c^2}{gF} = \left| \int \varepsilon_g dV \right| = \frac{m_{\text{lim}} c^2 r}{a}$$  \hspace{1cm} (19)$$

where $r$ is the effective range of weak interaction. It follows from (19) that

$$m_{\text{lim}} \approx \frac{a \hbar^2}{gF}$$  \hspace{1cm} (20)$$

The above relation manifests that the limit mass depends on the Universe radius, i.e. it is increasing with time.

Let us see what happens if the limit mass equals the Planck mass $m_{\text{Pl}}$ ($2.1767 \times 10^{-8}$ kg)

$$m_{\text{lim}} = m_{\text{Pl}}$$  \hspace{1cm} (21)$$

It stems from (20) and (21) that

$$a_x \approx \frac{m_{\text{Pl}} gF}{\hbar^2} \approx 10^{-2} \text{ m}$$  \hspace{1cm} (22)$$

and

$$t_x \approx 10^{-10} \text{ s}$$  \hspace{1cm} (23)$$
This is actually the time when, in accordance with the current knowledge, electromagnetic and weak interactions separated. In the time $t_x$ it had to hold

$$\frac{m_{Pc}}{m_W} = \left( \frac{a_x}{l_{Pc}} \right)^{1/2}$$

Substitution of (22) into (24) leads to (7) which means that the mass of the vector bosons $Z$ and $W$ as well as the time of separation of the electromagnetic and weak interactions are directly obtained, based on the used approach, in an independent way.

If Planck length $l_{Pc}$ is substituted for $a$ in equation (20), the limit mass will approach to $10^{-41}$ kg corresponding to the rest energy of $10^{-5}$ eV. It might represent a rest energy of some of the neutrinos.

5 Conclusions

1. The Vaidya metric allowing to localize the gravitational energy exhibits its capability to manifest some common features of the gravitational and weak interactions.

2. The paper presents an independent mode of determination of the mass of vector bosons $Z$ and $W$, as well as the time of separation of the electromagnetic and weak interactions. The mode follows directly from the ability to localize gravitational energy density outside a body.

3. The paper follows up our previous contributions showing the unity of the fundamental physical interactions. It might suggest the existence of a deeper relation of the weak and gravitational interactions and a common nature of the both interactions before their separation. The paper can be considered as a hint for verification and justification of the chosen procedure, introduction of Vaidya metric in particular.

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