IC/77/148

INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS

STRONG GRAVITY AND SUPERSYMMETRY

Ali H. Chamseddine

Abdus Salam

and

J. Strathdee

INTERNATIONAL ATOMIC ENERGY AGENCY

UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION

1977 MIRAMARE-TRIESTE

IC/77/148

International Atomic Energy Agency
and
United Nations Educational Scientific and Cultural Organization

INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS

STRONG GRAVITY AND SUPERSYMMETRY *

Ali H. Chamseddine
International Centre for Theoretical Physics, Trieste, Italy,

Abdus Salam
International Centre for Theoretical Physics, Trieste, Italy,
and
Imperial College, London, England,

and

J. Strathdee
International Centre for Theoretical Physics, Trieste, Italy.

MIRAMARE - TRIESTE
November 1977

* To be submitted for publication.

** Present address: Faculty of Science, Lebanese University, Hadath, Chouifat, Lebanon.

ABSTRACT

We construct a supersymmetric theory for a strong f plus a weak g graviton, together with their accompanying massive gravitinos, by gauging the graded OSp(2,2,1) × OSp(2,2,1) structure. The mixing term between f and g fields, which makes the strong graviton massive, can be introduced through a spontaneous symmetry-breaking mechanism implemented in this note by constructing a non-linear realization of the symmetry group.

I. INTRODUCTION

Much progress has been achieved recently in making general relativity supersymmetric [1]. It is hoped that this will lead to a more fundamental understanding of the nature of spacetime and perhaps even to a renormalizable theory of gravity. Here we propose to extend this programme to include the so-called two-tensor theories of gravity [2]. In this kind of theory the tensor field associated with gravity is accompanied by another tensor which obeys rather similar field equations but interacts strongly with hadrons. Now, in addition there will be spin-$\frac{3}{2}$ fermions along with each tensor.

There is a very simple way to embed gravity in a supersymmetric scheme. It is by extending the group of local Lorentz transformations, SL(2,$\mathbb{C}$), to a graded form, OSp(2,2,1), that this is achieved [3]. The orthosymplectic symmetry is necessarily broken spontaneously and a number of Higgs-like fields must be introduced for the purpose. In order to restrict the spectrum of states as much as possible, one imposes covariant constraints on the components of the Higgs system.

A virtue of the orthosymplectic formulation of strong gravity is that it incorporates a fairly unique mixing of the two tensors. The old formulations suffered from the arbitrariness of the mixing term. In fact, the bosonic subgroup, Sp(2,2), represents in itself a non-trivial extension of the local frame symmetry, SL(2,$\mathbb{C}$), and leads to the restricted form of the mixing term. However, it must be emphasised that the mixing is qualitatively different here in that kinetic as well as mass terms are involved. Since our main object is to extract this modified strong gravity system, we shall at many points suppress the spin-$\frac{3}{2}$ fields and the formal complications entailed by the full orthosymplectic symmetry.

II. ORTHOSYMPLECTIC SYMMETRY

As stated above, the main idea in the approach to relativistic supersymmetry followed here is the enlarging of the local gauge group from SL(2,$\mathbb{C}$) to OSp(2,2,1). The fundamental representation of the latter group is five-dimensional: four of these comprise a Majorana spinor and the fifth a real scalar. An infinitesimal transformation takes the form

$$\delta \begin{pmatrix} \psi_\alpha \\ \phi \end{pmatrix} = \begin{pmatrix} \frac{1}{2}\omega_\alpha{}^\beta & \epsilon_\alpha \\ \bar{\epsilon}^\beta & 0 \end{pmatrix} \begin{pmatrix} \psi_\beta \\ \phi \end{pmatrix} , \qquad (2.1)$$

where ε is a Majorana spinor and ω is a symplectic matrix,

$$\varepsilon = C\,\bar{\varepsilon}^T \quad , \qquad \omega = -C\,\omega^T C^{-1} = \gamma_0\,\omega^\dagger\,\gamma_0 . \tag{2.2}$$

One can easily verify that provided ε anticommutes with the fermionic co-ordinates, ψ, the bilinear form

$$-\bar{\psi}\psi + \phi^2 = \psi^T C^{-1}\psi + \phi^2 \tag{2.3}$$

is invariant. The symplectic matrix ω can be represented in the form

$$\omega = \omega^a\,\gamma_a + \frac{1}{2}\,\omega^{ab}\,\sigma_{ab} , \tag{2.4}$$

which shows how the subgroup SL(2,C) is contained in the ten-parameter symplectic group Sp(2,2).

The gauge fields associated with this group are fourteen in number, ten bosonic plus four fermionic. They can be represented in the form of a 5 × 5 matrix,

$$\Phi_\mu = \begin{pmatrix} \frac{1}{2} W_\mu & \psi_\mu \\ \bar{\psi}_\mu & 0 \end{pmatrix} , \tag{2.5}$$

where $\psi_\mu = C\,\bar{\psi}_\mu{}^T$ is a Majorana-Rarita-Schwinger field and W_μ is a ten-component matrix of 4 vectors

$$W_\mu = L_\mu{}^a\,\gamma_a + \frac{1}{2}\,B_\mu{}^{[ab]}\,\sigma_{ab} . \tag{2.6}$$

The field strengths are constructed according to the familiar Yang-Mills prescription

$$\Phi_{\mu\nu} = \partial_\mu \Phi_\nu - \partial_\nu \Phi_\mu + [\Phi_\mu, \Phi_\nu]$$

$$= \begin{pmatrix} \frac{1}{2} W_{\mu\nu} + \psi_\mu\,\bar{\psi}_\nu - \psi_\nu\,\bar{\psi}_\mu & \psi_{\mu\nu} \\ \bar{\psi}_{\mu\nu} & 0 \end{pmatrix} , \tag{2.7}$$

where

$$W_{\mu\nu} = \partial_\nu W_\nu - \partial_\nu W_\mu + \frac{i}{2}[W_\mu , W_\nu] .$$

$$\psi_{\mu\nu} = \partial_\mu \psi_\nu - \partial_\nu \psi_\mu + \frac{i}{2}(W_\mu\,\psi_\nu - W_\nu\,\psi_\mu) . \tag{2.8}$$

We are interested in the direct product of two orthosymplectic groups and so require two sets of gauge fields, Φ_μ and Φ'_μ. These fields transform independently. One can indicate this by the formulae

$$\Phi_\mu \to \Omega\,\Phi_\mu\,\Omega^{-1} + \Omega\,\partial_\mu\,\Omega^{-1} ,$$

$$\Phi'_\mu \to \Omega'\,\Phi'_\mu\,\Omega'^{-1} + \Omega'\,\partial_\mu\,\Omega'^{-1} , \tag{2.9}$$

where Ω and Ω' denote independent orthosymplectic matrices. With respect to general co-ordinate transformations, the gauge fields are covariant vectors,

$$\Phi_\mu(x) \to \bar{\Phi}_\mu(\bar{x}) = \frac{\partial x^\nu}{\partial \bar{x}^\nu}\,\Phi_\nu(x) , \tag{2.10}$$

and similarly for Φ'_μ. The field strengths $\Phi_{\mu\nu}$ and $\Phi'_{\mu\nu}$ transform as antisymmetric covariant tensors.

In order to have some significant interaction between the two gauge systems it is necessary to introduce another kind of field, one which belongs to a mixed representation of the local symmetries and which therefore couples to both gauge systems. The simplest possible candidate for this role is the 5 × 5 matrix $G(x)$ which transforms according to

$$G \to \Omega\,G\,\Omega'^{-1} \tag{2.11}$$

under the local symmetry and as a scalar under co-ordinate transformations. The twenty-five components of G include eight fermions and seventeen bosons

$$G = \begin{pmatrix} H & \eta \\ \bar{\xi} & \varphi \end{pmatrix} , \tag{2.12}$$

where H denotes a 4 × 4 matrix and φ a scalar, ξ and η are Dirac spinors. The components of G may be subject to the reality condition

$$\varphi^* = \varphi , \qquad \xi = C\,\bar{\xi}^T ,$$

$$\gamma_0\,H^\dagger\,\gamma_0 = C\,H^T C^{-1} , \qquad \eta = C\,\bar{\eta}^T .$$

(Note that this means the S, P, A components of H are real, while the V, T components are imaginary.) A useful equivalent representation of this multiplet is the matrix

$$\tilde{G} = \begin{pmatrix} C H^T C^{-1} & -\xi \\ -\bar{\eta} & \varphi \end{pmatrix} , \tag{2.14}$$

which transforms according to

$$\tilde{G} \to \Omega' \tilde{G} \Omega^{-1} . \tag{2.15}$$

In setting up a Lagrangian in the next section there will be needed the covariant derivatives

$$\begin{aligned} \nabla_\mu G &= \partial_\mu G + \Phi_\mu G - G\Phi'_\mu \\ &= \begin{pmatrix} \partial_\mu H + \frac{i}{2} W_\mu H - \frac{i}{2} H W'_\mu + \psi_\mu \bar{\xi} - \eta \bar{\psi}'_\mu & \partial_\mu \eta + \frac{i}{2} W_\mu \eta + \psi_\mu \varphi - H \psi'_\mu \\ \partial_\mu \bar{\xi} - \frac{i}{2} \bar{\xi} W'_\mu + \bar{\psi}_\mu H - \varphi \bar{\psi}'_\mu & \partial_\mu \varphi + \bar{\psi}_\mu \eta - \bar{\xi} \psi'_\mu \end{pmatrix} \end{aligned} \tag{2.16}$$

and $\nabla_\mu \tilde{G}$ similarly defined.

III. LAGRANGIAN

In addition to the gauge fields Φ_μ and Φ'_μ, a pair of Higgs fields G_1 and G_2, both in the same representation, is used. For the Lagrangian density of this system we adopt the expression

$$\begin{aligned} \mathcal{L} = \varepsilon^{\kappa\lambda\mu\nu} \mathrm{Tr} \Big[& \alpha\, G_1 \tilde{G}_2 \Phi_{\kappa\lambda} \Phi_{\mu\nu} + \alpha' \tilde{G}_1 G_2 \Phi'_{\kappa\lambda} \Phi'_{\mu\nu} \\ & + \beta\, \nabla_\kappa G_1 \nabla_\lambda \tilde{G}_1 \nabla_\mu G_1 \nabla_\nu \tilde{G}_2 + \beta' \nabla_\kappa G_2 \nabla_\lambda \tilde{G}_2 \nabla_\mu G_2 \nabla_\nu \tilde{G}_1 \Big] + \text{h.c.} \end{aligned} \tag{3.1}$$

In order to have invariance under space reflections, one can assign normal parities to the components of G_1 and abnormal to G_2. There is one relation among the parameters α, α', β and β' which will emerge in the following.

In order that the theory should possess a stable, flat (Poincaré invariant) vacuum solution, it is required that G_1 and G_2 be non-vanishing in the vacuum

$$\langle G_1 \rangle = a \quad , \quad \langle G_2 \rangle = b\gamma_5 \quad .$$

In other words, the original symmetry $OSp(2,2,1) \times OSp(2,2,1)$ is broken spontaneously to $SL(2,\mathbb{C})$. To simplify the analysis we shall assume a number of constraints among the components of G_1 and G_2, which are sufficient to reduce the number of independent components to the minimum needed for parametrizing the homogeneous space

$$OSp(2,2,1) \times OSp(2,2,1)/SL(2,\mathbb{C}) \quad .$$

There must be $14 + 14 - 6 = 22$ independent components of which 8 are fermionic. This means that $25 + 25 - 22 = 28$ constraints *) are needed, of which $8 + 8 - 8 = 8$ must be fermionic.

Having reduced the number of independent components from 50 to 22, one can then eliminate these remaining ones by means of 22 gauge conditions. In such a <u>unitary gauge</u> the fields G_1 and G_2 reduce to constants,

$$G_1 = a \quad , \quad G_2 = b\,\gamma_5 \quad . \tag{3.2}$$

The remaining gauge freedom concerns the as yet unbroken local $SL(2,\mathbb{C})$ and can be dealt with in the usual way (by imposing symmetry on the vierbein matrix, for example).

The Lagrangian (3.1) simplifies a great deal in the unitary gauge. One finds

---

*) One may alternatively impose fewer constraints and keep the scalar and pseudoscalar components of G_1 and G_2 as live fields, obtaining an analogue of (3.2) by minimizing the quartic Higgs potential contained in (3.1). This would correspond to the more conventional scheme of symmetry breaking.

$$\mathcal{L} = \varepsilon^{\kappa\lambda\mu\nu}\,\varepsilon_{abcd}\Big[-\alpha_1\,(L_\kappa{}^a L_\lambda{}^b B_{\mu\nu}{}^{[cd]} + L_\kappa{}^a L_\lambda{}^b L_\mu{}^c L_\nu{}^d)$$

$$-\alpha_1\,(L'^a_\kappa L'^b_\lambda B'_{\mu\nu}{}^{[cd]} + L'^a_\kappa L'^b_\lambda L'^c_\mu L'^d_\nu)$$

$$+\beta_1 L_{\kappa-}{}^a L_{\lambda-}{}^b L_{\mu-}{}^c L_{\nu+}{}^d - \beta_2 L_{\kappa+}{}^a L_{\lambda+}{}^b L_{\mu+}{}^c L_{\nu-}{}^d$$

$$-(\beta_1-\beta_2)\,B_{\kappa-}{}^{[ae]} B_{\lambda-}{}^{[eb]} L_{\mu+}{}^c L_{\nu-}{}^d + \frac{1}{2}(\beta_1+\beta_2)\,(L_{\kappa+}{}^a L_{\mu-}{}^e - L_{\kappa-}{}^a L_{\mu+}{}^e)\,B_{\lambda-}{}^{[bc]} B_{\nu-}{}^{[de]}\Big]$$

$$+\mathcal{L}_{\text{fermion}} \qquad (3.3)$$

where

$$\mathcal{L}_{\text{fermion}} = \alpha_1\,\varepsilon^{\kappa\lambda\mu\nu}\Big[\Big\{2i\,\bar\psi_\kappa\gamma_5 L_\mu(\partial_\nu + \frac{i}{2}B_\nu)\psi_\lambda + \text{h.c.}\Big\}$$

$$-\frac{3}{2}\bar\psi_\kappa\gamma_5[L_\mu,L_\nu]\psi_\lambda + i\,\bar\psi_\kappa\gamma_5 B_{\mu\nu}\psi_\lambda\Big]$$

$$+\alpha_2\,\varepsilon^{\kappa\lambda\mu\nu}\Big[\Big\{2i\,\bar\psi'_\kappa\gamma_5 L'_\mu(\partial_\nu + \frac{i}{2}B'_\nu)\psi'_\lambda + \text{h.c.}\Big\}$$

$$-\frac{3}{2}\bar\psi'_\kappa\gamma_5[L'_\mu,L'_\nu]\psi'_\lambda + i\,\bar\psi'_\kappa\gamma_5 B'_{\mu\nu}\psi'_\lambda\Big]$$

$$+\frac{1}{4}\beta_1\,\varepsilon^{\kappa\lambda\mu\nu}\Big[\bar\psi_\kappa\Big((L_+ + B_-)_\mu(L_- + B_-)_\nu\gamma_5 + \gamma_5(L_+ + B_-)_\mu(L_- + B_-)_\nu\Big)\psi_\lambda$$

$$+\bar\psi'_\kappa\Big((L_- + B_-)_\mu(L_+ - B_-)_\nu\gamma_5 - \gamma_5(L_- + B_-)_\mu(L_- + B_-)_\nu\Big)\psi'_\lambda\Big]$$

$$+\frac{1}{4}\beta_2\,\varepsilon^{\kappa\lambda\mu\nu}\Big[-\bar\psi_\kappa\Big((L_+ + B_-)_\mu(L_+ - B_-)_\nu\gamma_5 + \gamma_5(L_- + B_-)_\mu(L_+ + B_-)_\nu\Big)\psi_\lambda$$

$$+\bar\psi'_\kappa\Big((L_+ + B_-)_\mu(L_+ + B_-)_\nu\gamma_5 - \gamma_5(L_+ - B_-)_\mu(L_- - B_-)_\nu\Big)\psi'_\lambda\Big] \qquad (3.4)$$

in which is used the notation

$$L_{\mu\pm} = (L_\mu{}^a \pm L'^a_\mu)\gamma_a, \quad B_{\mu\pm} = \frac{1}{2}(B_\mu{}^{[ab]} \pm B'^{[ab]}_\mu)\,\sigma_{ab} \quad . \qquad (3.5)$$

The four surviving parameters are defined by

$$\alpha_1 = 2ab\alpha \quad , \quad \alpha_2 = 2ab\alpha' \quad , \quad \beta_1 = \frac{1}{4}a^3b\beta \quad , \quad \beta_2 = \frac{1}{4}ab^3\beta' \, , \qquad (3.6)$$

but they are not independent - at least, not if one requires that the system possess a stable Poincaré-invariant vacuum.

To conclude this section, therefore, we consider the linearized theory on a flat background. All fields are treated as small quantities except for L and L' which can possess finite c-number parts

$$L_{\mu a}(x) = c\eta_{\mu a} + \phi_{\mu a}(x) \quad , \quad L'_{\mu a}(x) = c'\eta_{\mu a} + \phi'_{\mu a}(x) \quad , \qquad (3.7)$$

where $\eta_{\mu a}$ denotes the Minkowski metric. The constants c and c' are determined, in part, by the requirement that the Euler-Lagrange equations should be of first order in small quantities. Equivalently, when (3.7) is used in (3.3) the first-order part of the Lagrangian should vanish. This yields the equations

$$\alpha_1 = \beta_1\left(1 - \frac{c'}{c}\right)^2\left(1 + \frac{c'}{2c}\right) - \beta_2\left(1 + \frac{c'}{c}\right)^2\left(1 - \frac{c'}{2c}\right) \, ,$$

$$\alpha_2 = -\beta_1\left(1 - \frac{c}{c'}\right)^2\left(1 + \frac{c}{2c'}\right) + \beta_2\left(1 + \frac{c}{c'}\right)^2\left(1 - \frac{c}{2c'}\right) \, . \qquad (3.8)$$

Only the ratio, c'/c, enters these conditions and hence the scale of c and c' is not fixed. One constraint among the four parameters α_1, α_2, β_1 and β_2 is implied *).

With (3.8) satisfied, the bosonic part of the bilinear terms takes the form

$$\mathcal{L}^b_{(2)} = \frac{1}{4}\Big\{B^T_{\mu[\mu\alpha]}\,K\,B_{\nu[\nu\alpha]} - B^T_{\mu[\nu\alpha]}\,K\,B_{\nu[\mu\alpha]}\Big\} + \frac{1}{2}B^T_{\mu[\nu\alpha]}\,N\Big(\phi_{\alpha\mu,\nu} - \eta_{\mu\nu}\,\phi_{\alpha\lambda,\lambda} +$$

$$\eta_{\mu\nu}\,\phi_{\lambda\lambda,\alpha}\Big) + \frac{1}{4}\phi^T_{\mu\mu}\,M\,\phi_{\nu\nu} - \frac{1}{4}\phi^T_{\mu\nu}\,M\,\phi_{\mu\nu} \quad , \qquad (3.9)$$

where matrix notation is used:

*) If this constraint is not satisfied then there is no Poincaré-invariant ground state for the system. In this case there is an effective cosmological term and one should presumably therefore search for a ground state with a de Sitter symmetry.

$$B = \begin{pmatrix} B \\ B' \end{pmatrix} \quad , \quad \boldsymbol{\phi} = \begin{pmatrix} \phi \\ \phi' \end{pmatrix} ,$$

$$K = 8 \begin{pmatrix} -2\alpha_1 c^2 + (\beta_1 - \beta_2)(c^2 - c'^2) & -(\beta_1 - \beta_2)(c^2 - c'^2) \\ -(\beta_1 - \beta_2)(c^2 - c'^2) & -2\alpha_2 c'^2 + (\beta_1 - \beta_2)(c^2 - c'^2) \end{pmatrix} ,$$

$$N = -16 \begin{pmatrix} \alpha_1 c & 0 \\ 0 & \alpha_2 c' \end{pmatrix} .$$

$$M = 24 \ (\beta_1 + \beta_2) \ \frac{c^2 - c'^2}{cc'} \begin{pmatrix} c' \\ -c \end{pmatrix} (c' - c) \quad . \tag{3.10}$$

Since B is algebraic it can be solved for and eliminated,

$$B_{\mu[\nu\lambda]} = - K^{-1} N \left(\phi_{(\mu\nu),\lambda} - \phi_{(\mu\lambda),\nu} + \phi_{[\nu\lambda],\mu} \right) , \tag{3.11}$$

where the symmetric and antisymmetric parts are defined,

$$\phi_{\mu\nu} = \phi_{(\mu\nu)} + \phi_{[\mu\nu]} \quad .$$

On elimination of B the bilinear terms reduce to

$$\mathcal{L}^b_{(2)} = \frac{1}{4} \left(\phi^T_{(\mu\nu),\alpha} NK^{-1}N \phi_{(\mu\nu),\alpha} - 2 \phi^T_{(\nu\mu),\mu} NK^{-1}N \phi_{(\nu\alpha),\alpha} + 2 \phi^T_{\mu\mu,\alpha} NK^{-1}N \phi_{(\alpha\nu),\nu} - \phi^T_{\mu\mu,\alpha} NK^{-1}N \phi_{\nu\nu,\alpha} \right) - \frac{1}{4} \left(\phi^T_{\mu\nu} M \phi_{\mu\nu} - \phi^T_{\mu\mu} M \phi_{\nu\nu} \right) , \tag{3.12}$$

and this can be put into the standard Fierz-Pauli form by adopting new field combinations. Write

$$\phi(x) = S \, \Phi(x) = \begin{pmatrix} c\lambda & \nu \\ c'\lambda & \mu \end{pmatrix} \begin{pmatrix} h(x) \\ F(x) \end{pmatrix} , \tag{3.13}$$

where λ, μ, ν are constants and $h_{\mu\nu}$, $F_{\mu\nu}$ are the new fields. The parameters λ, μ, ν are to be chosen so as to normalize the kinetic terms, i.e.

$$S^T N K^{-1} N S = 1$$

or

$$S S^T = N^{-1} K N^{-1} \quad . \tag{3.14}$$

From this one extracts three equations for λ, μ and ν,

$$c^2\lambda^2 + \nu^2 = \frac{1}{32\alpha_1^2} \left(-2\alpha_1 + (\beta_1 - \beta_2) \left(1 - \frac{c'^2}{c^2} \right) \right) ,$$

$$c'^2\lambda^2 + \mu^2 = \frac{1}{32\alpha_2^2} \left(-2\alpha_2 + (\beta_1 - \beta_2) \left(1 - \frac{c^2}{c'^2} \right) \right) ,$$

$$cc'\lambda^2 + \mu\nu = \frac{1}{32\alpha_1\alpha_2} (\beta_1 - \beta_2) \left(\frac{c'}{c} - \frac{c}{c'} \right) . \tag{3.15}$$

The components of S have been chosen so as to diagonalize the mass matrix as well as normalize the kinetic energy. The mass terms in (3.12) now take the form

$$- \frac{1}{4} m^2 (F_{\mu\nu} F_{\mu\nu} - F_{\mu\mu} F_{\nu\nu}) \quad , \tag{3.16}$$

where m^2 is given by

$$m^2 = \mathrm{Tr}\, M S S^T = 24 (\beta_1 + \beta_2) \frac{c^2 - c'^2}{cc'} (\nu c' - \mu c)^2 \quad . \tag{3.17}$$

The parameters β_1 and β_2 are dimensionless (in natural units) and hence α_1, α_2, ν, μ, $c\lambda$, $c'\lambda$ are also dimensionless, while c and c' have the dimension of mass. Out of the three independent dimensionless variables, β_1, β_2 and c'/c, it is necessary to obtain the two coupling constants $\kappa_f m(\sim 1)$ and $\kappa_g m(\sim 10^{-19})$ associated with strong and weak gravity, respectively. The remaining dimensionless parameter must play some more obscure role related to the details of the mixing.

To illustrate the orders of magnitude involved in as simple a manner as possible we choose $\beta_1 = \beta_2$ and treat the ratio

$$\frac{c'}{c} = k \tag{3.18}$$

as a small quantity. One finds $m^2 \approx c^2$ and

$$c\lambda \approx \frac{1}{4}\sqrt{\frac{k}{\beta}} \quad , \quad \mu \approx \frac{1}{4}\sqrt{\frac{3}{\beta}k^5} \quad , \quad \nu \approx \frac{1}{5}\sqrt{\frac{1}{3\beta k}} \quad .$$

$$\alpha_1 \approx -3\beta k \quad , \quad \alpha_2 \approx -\frac{\beta}{k^3} \qquad (3.19)$$

to leading order in k . In order to identify the couplings, one must examine the trilinear terms. One finds

$$\kappa_g \sim k\,\kappa_f \sim \frac{1}{c}\sqrt{\frac{k}{\beta}}$$

on interpreting the massless field $h_{\mu\nu}$ as the graviton and the orthogonal combination $F_{\mu\nu}$ as its strong analogue

$$c \sim m \sim 1 \text{ GeV} ,$$

$$c' \sim mk \sim \frac{m\kappa_g}{\kappa_f} \sim 10^{-19} \text{ GeV} ,$$

$$\beta \sim \frac{k^{-1}}{\kappa_f^2 m^2} \sim 10^{19} .$$

That the spontaneous symmetry-breaking mechanism should give rise to a juxtaposition of numbers as disparate as c and c' is but a consequence of the somewhat unfamiliar uniting of the strongest of the known forces with the weakest within one formalism.*)

The fermion spectrum is obtained by substituting $B_{\pm} = 0$ and $L_{\mu\pm} = (c + c')\gamma_\mu$ in (3.4). There is no mixing between ψ_μ and ψ'_μ : their masses are easily shown to be $\sim m$ and $\sim km \sim 10^{-19}$ m, respectively. Hence the graviton appears to be associated with a very light spinor [4] if the strong gravitinos mass is ~ 1 GeV.

*) In the late Fifties when the proposal was first made, one felt the same unease at uniting weak and electromagnetic interactions.

REFERENCES

1) D.Z. Freedman, P.van Nieuwenhuizen and S. Ferrara, Phys. Rev. D13, 3214 (1976);
S. Deser and B. Zumino, Phys. Letters B62, 335 (1976).

2) C.J. Isham, Abdus Salam and J. Strathdee, Phys. Rev. D3, 867 (1971);
J. Wess and B. Zumino, Brandeis Lectures (1971).

3) S.W. McDowell and F. Mansouri, Phys. Rev. Letters 38, 739 (1977);
A.H. Chamseddine and P.C. West. Imperial College, London, preprint ICTP/76/22;
A.H. Chamseddine, ICTP, Trieste, preprint IC/77/13.

4) B. Zumino, CERN preprint TH.2293 (1977).

IC/77/51 P. GARBACZEWSKI: The method of boson expansions in quantum theory.

IC/77/53 V.K. SAMARANAYAKE: Determination of the pion-nucleon coupling constant.

IC/77/56* INT.REP. C.T.J. DODSON: Spacetime edge geometry (Chapter III.3: Friedmann spacetimes).

IC/77/57* INT.REP. A. AURILIA and D. CHRISTODOULOU: String dynamics in an external field: A family of exact solutions.

IC/77/58* INT.REP. N.S. BAAKLINI, S. FERRARA and P. van NIEUWENHUIZEN: Classical solutions in supergravity.

IC/77/59 N. KUMAR and J. HEINRICHS: Renormalization group-theoretic approach to electron localization in disordered systems.

IC/77/60* INT.REP. C.T.J. DODSON: A new bundle-completion for parallelizable spacetimes.

IC/77/61* INT.REP. C.T.J. DODSON: Bundle separation of singularities in parallelizable spacetimes.

IC/77/62 A.H. CHAMSEDDINE: Massive supergravity from non-linear realization of orthosymplectic gauge symmetry and coupling to spin-$\frac{1}{2}$, spin-1 multiplet.

IC/77/63 P. DI VECCHIA and S. FERRARA: Classical solutions in two-dimensional supersymmetric field theories.

IC/77/64 P. BUDINI and P. FURLAN: Genesis of unified models from Majorana-Weyl fields.

IC/77/65 J.C. PATI and ABDUS SALAM: Design of future experiments - I: To distinguish between the alternatives of physical and hidden colour; II: To test if the neutral gauge boson lies in the vicinity of PETRA-PEP region. (A note for experimental colleagues.)

IC/77/66 A. OSMAN: Perturbation of the Faddeev equations with tensor forces.

IC/77/67* INT.REP. C.T.J. DODSON: On the completion of manifolds with connection.

IC/77/68* INT.REP. R.E. AMRITKAR and N. KUMAR: Coherence factors in excitonic insulators.

IC/77/70 M.A. RASHID: The intelligent states - I. (Group-theoretic study and the computation of matrix elements.)

IC/77/71 W. KRÓLIKOWSKI and J. RZEWUSKI: Relativistic radial equations for two spin-$\frac{1}{2}$ particles.

IC/77/72* INT.REP. H. INAGAKI: Anomaly in the conformal spinor current.

IC/77/73 M.A. RASHID: The intelligent states - II. (The computation of the Clebsch-Gordan coefficients.)

* Internal Reports: Limited distribution.
THESE PREPRINTS ARE AVAILABLE FROM THE PUBLICATIONS OFFICE, ICTP, P.O. BOX 586, I-34100 TRIESTE, ITALY. IT IS NOT NECESSARY TO WRITE TO THE AUTHORS.

IC/77/74 S. PRAKASH and J. BONNET: Proton movement in fcc, bcc and hcp metals.

IC/77/75* INT.REP. A. AMUSA: Normalization factors for (t,p) and (α,d) reactions with Tang-Herndon potential

IC/77/76 C.E. LACIANA, A.J. PEDRAZA and E.J. SAVINO: Lattice distortion due to oxygen and nitrogen di-interstitial clusters in niobium and vanadium.

IC/77/77 J.T. LOPUSZANSKI: Relations between the classical Yang-Mills and the massless φ^4 theories.

IC/77/78* INT.REP. N.H. MARCH and M.P. TOSI: Metal-electrolyte interface.

IC/77/79* INT.REP. V. SA-YAKANIT: The density of states in highly impure semiconductors: Path-integral approach.

IC/77/80* INT.REP. H.S. MANI, J.C. PATI and ABDUS SALAM: "Naturalness" of atomic parity conservation within left-right symmetric unified theories.

IC/77/81 M.O. TAHA: Causal basis of the Drell-Yan-West relation.

IC/77/82* INT.REP. P.V. GIAQUINTA, M. PARRINELLO and M.P. TOSI: Dynamics of charge fluctuations in ionic conductors.

IC/77/86* INT.REP. T.J. FAIRCLOUGH: A calculation of the effects of an externally applied stress on the equilibrium configurations of a cubic antiferromagnet.

IC/77/87 A.R. HASSAN: Exciton molecule in semiconductors by phonon-assisted two-photon absorption.

IC/77/88 H.S. MANI, J.C. PATI, S. RAJPOOT and ABDUS SALAM: Dilepton production in PP and $\bar{P}P$ collisions as a probe to the nature of the neutral current interaction

IC/77/89 A. OSMAN: Three-body correlations and tensor forces.

IC/77/90 E. TOSATTI: Surface charge-density wave phase transitions on MO and W(001)?

IC/77/91 M.A. SEMARY, H.F. MOSTAFA and M.A. AHMED: Magnetic susceptibility of $(CH_3NH_3)_2\,FeCl_3Br$. An example of a canted spin system.

IC/77/92 S.A. MAHMOUD, M.A. SEMARY and F. MOHSEN: Reduction of the magnetization curves for Ni 5% Mn alloy.

IC/77/93* INT.REP. V.K. AGARWAL: Present status and future potential of mono- and multi-molecular built-up films.

IC/77/94 L. MASPERI, V. ROBERTO and A. UNGKITCHANUKIT: Renormalization of the pomeron intercept in reggeon field theory on a transverse lattice.

IC/77/95 D. ADU-GYAMFI, M.K. BUSHEV, J. CHELA-FLORES and H.B. GHASSIB: Hydrodynamics of He II: An application to atomic structure.

IC/77/96* INT.REP. Y. YOKOO: Symmetric $SU(2) \times U(1) \times U(1)'$ model with natural flavour conservation in neutral weak currents.

IC/77/98* INT. T.J. FAIRCLOUGH: A calculation of the effects of an externally applied stress on the AFMR and other spin-wave frequencies of a cubic antiferromagnet.

IC/77/99 G. FELDMAN and P.T. MATTHEWS: Mass splitting in SU(4).

IC/77/100 A. OSMAN: Three-body problems with separable two-body interactions.

IC/77/101* INT.REP. S.A. EL WAKIL, E.A. SAAD and H.M. MACHALI: Neutron slowing down with inelastic scattering.

IC/77/102* INT.REP. DIPANKAR RAY: Exact solutions to non-linear chiral field equations.

IC/77/103 T. BARNES: Coloured quark and gluon constituents in the MIT bag model.

IC/77/104* INT.REP. A. AURILIA, D. CHRISTODOULOU and F. LEGOVINI: A classical interpretation of the bag model for hadrons.

IC/77/105 J. MAHANTY: Interaction of a charged particle with a metal surface.

IC/77/107* INT.REP. H.B. GHASSIB: Bound state for ^3He quasiparticles in dilute ^3He-He II mixtures.

IC/77/108* INT.REP. M.K. EL MOUSLY and F.A. GANI: Electrical conductivity and crystallization in supercooled liquid SSe samples.

IC/77/110* INT.REP. G. CHADDHA: Isotropic ferromagnets with biquadratic interactions.

IC/77/111 K.K. SINGH: Microscopic approach to tricritical behaviour in ^3He-^4He mixtures.

IC/77/113* INT.REP. M.Y.M. HASSAN and S. MOHARRAM: On the structure of ^{12}C.