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J. Lukierski

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L. Rytel

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GEOMETRIC ORIGIN OF CENTRAL CHARGES *

J. Lukierski[†] and L. Rytel[†]

International Centre for Theoretical Physics, Trieste, Italy

ABSTRACT

The complete set of $N(N-1)$ central charge generators for $D=4$ N -extended super-Poincaré algebra is obtained by suitable contraction of $OSp(2N; 4)$ superalgebra. The superspace realizations of the spinorial generators with central charges are derived. The conjugate set of $N(N-1)$ additional bosonic superspace coordinates is introduced in an unique and geometric way.

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1. The central charges were introduced originally in [1] as a mathematical possibility*, but recently they appeared to be an important enlargement of the fundamental super-Poincaré algebra. Already the study of $N=2$ extended supersymmetry shows (see e.g. [2]) that in some cases only the presence of central charges allows for the existence of nontrivial (i.e. describing interacting theory) field representations. It is also believed that the difficulties with the formulation of $N \geq 3$ extended supergravities are related with the lack of proper understanding of the role of degrees of freedom generated by central charges.

The aim of this paper is to show that the central charge generators have a clear meaning as the contracted generators from the internal symmetry sector. If we assume that the linearly realized group on extended super-Poincaré generators is $SL(2, C) \times U(N)$ the supergroup which provides such a contraction can be uniquely determined as $OSp(2N; 4)$. In our contraction scheme all the bosonic generators survive the contraction limit: the translation generators are obtained from the four noncompact generators describing $Sp(4)$ and $N(N-1)$ central charges are obtained from the compact generators $SL(2, C)$ in the coset $\frac{O(2N)}{U(N)}$. From such a construction it follows that the central charges transform under $SU(N)$ as antisymmetric second rank tensor $Z_{ab} = X_{ab} + i Y_{ab}$, denoted by $(2, 0)$.

We would like to mention here that central charges are scalars under the "exact" internal symmetry of the S -matrix, but can transform under spontaneously broken internal symmetry. One should assume therefore that the $U(N)$ symmetry of N -extended supersymmetry is spontaneously broken in the presence of central charges. The reduced "exact" symmetry group for different choices of central charge generators has been recently calculated by Ferrara, Savoy and Zumino [3].

2. Let us recall that the superalgebra $OSp(2N; 4)$ has the bosonic sector $\mathfrak{g} = \mathfrak{g}_1 \oplus \mathfrak{g}_2$ where

$$\mathfrak{g}_1 = Sp(4, R) \simeq O(3, 2) \quad (\text{space-time symmetries})$$

$$\mathfrak{g}_2 = O(2N) \quad (\text{internal symmetries})$$

and the fermionic sector is generated by $2N$ four-component Majorana charges[†].

* J. Łopuszański, private communication.

† An alternative equivalent formulation uses $2N$ 2-component complex Weyl spinors (see e.g. [4]).

We introduce five 4×4 real matrices, describing the Majorana representation of $O(3, 2)$ Clifford algebra

$$(\Gamma_A, \Gamma_B) = 2g_{AB} \quad g_{AB} = \text{diag}(-1, 1, 1, 1, -1)$$

The supercharges Q_a^i , extending the Lie algebra $Sp(4, R) \oplus O(2N)$ to the superalgebra $OSp(2N; 4)$ satisfy the following relations:

$$\{Q_a^i, Q_b^j\} = \delta^{ij} (\Gamma^{\mu} \Gamma_0)_{ab} P_\mu + m [\delta^{ij} (\sigma^{\mu\nu} \Gamma_0 \Gamma_5)_{ab} M_{\mu\nu} + g (\Gamma_0 \Gamma_5)_{ab} \Pi^{ij}] \quad (1)$$

where $i, j = 1 \dots 2N$, $a, b = 1 \dots 4$, $\mu, \nu = 0, 1, 2, 3$, $Q_{\mu\nu} = \frac{1}{2} [\Gamma_\mu, \Gamma_\nu]$ and $\Pi^{ij} = -\Pi^{ji} = \tau_{ij}^r$ describe $O(2N)$ generators expanded in the adjoint $2N \times 2N$ matrix basis, denoted by τ_{ij}^r ($r = 1 \dots N(2N-1)$); $\tau_{ij}^r = -\tau_{ji}^r$.

For dimensional reasons we introduced the mass parameter m and dimensionless coupling g characterizing respectively de Sitter radius and the Yang-Mills coupling in $O(2N)$ sector. The covariance relations look as follows (compare with [5]):

$$\frac{1}{i} [P_\mu, Q_a^i] = \frac{m}{2} (\Gamma_\mu \Gamma_5)_{ab} \beta Q_b^i \quad (2a)$$

$$\frac{1}{i} [M_{\mu\nu}, Q_a^i] = (\sigma_{\mu\nu})_{ab} \beta Q_b^i \quad (2b)$$

$$\frac{1}{i} [\tau_r, Q_a^i] = g \tau_r^{ik} Q_a^k \quad (2c)$$

The generator of "curved translations" P_μ satisfies Z_2 -graded de Sitter algebra

$$\frac{1}{i} [P_\mu, P_\nu] = -m^2 M_{\mu\nu} \quad (3)$$

3. Let us introduce the Z_2 -grading in the internal symmetry sector by the following split of the $O(2N)$ Lie algebra

$$\Pi^{ij} \in O(2N): \quad \left(\begin{array}{c|c} A & S \\ \hline -S & A \end{array} \right) \oplus \left(\begin{array}{c|c} X & Y \\ \hline Y & -X \end{array} \right) \quad \frac{O(2N)}{U(N)} \quad (4)$$

where the $N \times N$ real matrices satisfy the relations:

$$\begin{aligned} A &= -A^T & X &= -X^T \\ S &= S^T & Y &= -Y^T \end{aligned} \quad (5)$$

Further we introduce generalized Weyl-Majorana spinors

$$\begin{aligned} Q^\pm &= \frac{1}{\sqrt{2}} (1 \pm \Gamma_5 \Omega) Q & \Omega^{ij} &= -\Omega^{ji} \\ & & \Omega^2 &= -1 \end{aligned} \quad (6)$$

satisfying the condition $Q^\pm = \pm \Gamma_5 \Omega Q^\pm$. Choosing $\Omega = \begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix}$ one can write

$$Q^\pm = \frac{1}{\sqrt{2}} \begin{pmatrix} Q^a \pm \Gamma_5 Q^{a+N} \\ \mp \Gamma_5 (Q^a \pm \Gamma_5 Q^{a+N}) \end{pmatrix} \quad (7)$$

The unconstrained N -component Majorana spinor describing $Q^\pm$ we denote by $Q_a^{\pm} (a = 1 \dots N)$:

$$Q_a^{\pm} = \frac{1}{\sqrt{2}} (Q_a^a \pm \Gamma_5 Q_a^{a+N}) \quad (8)$$

The commutation relations (1) split as follows ($m' = gm$):

and satisfies the Z_h -grading relations*

$$\langle L_i, L_j \rangle \subset L_{i+j} \quad (i, j, i+j \bmod 4) \quad (13)$$

where L_0, L_2 are bosonic and L_1, L_3 fermionic sectors. The grading (13) implies that one can perform the rescaling

$$L_0 \rightarrow L_0 \quad L_1 \rightarrow \frac{1}{\sqrt{R}} L_1 \quad L_2 \rightarrow \frac{1}{R} L_2 \quad L_3 \rightarrow \frac{1}{\sqrt{R}} L_3 \quad (14)$$

and consider the contraction limit $R \rightarrow \infty$ in consistency with the Jacobi identities. The rescaled generators satisfy the relations (9a), (9c), but we obtain $(Q_a^{*+}, Q_b^{-}) \sim \frac{1}{R}$ and also $[X_K, Q_a^{*+}] \sim \frac{1}{R}$, $[Y_K, Q_a^{*+}] \sim \frac{1}{R}$. The $O(2N)$ superalgebra is split by the grading (13) into Z_2 -graded symmetric Riemannian pair $(U(N), \frac{O(2N)}{U(N)})$ with the generators from $\frac{O(2N)}{U(N)}$ transforming under $U(N)$ as antisymmetric 2-tensor (2, 0). One can also write the algebra of de Sitter type (see (3)) describing the internal symmetry sector. One gets

$$\begin{aligned} [X_K, X_L] &\sim \frac{1}{R^2} U(N) & [X_K, Y_L] &\sim \frac{1}{R^2} U(N) \\ [Y_K, Y_L] &\sim \frac{1}{R^2} U(N) \end{aligned} \quad (15)$$

where $U(N)$ denotes the element of $U(N)$ algebra.

* The Z_h -gradings were introduced in [6] for the description of supersymmetric generalization of a Riemannian symmetric pair $(H, \frac{G}{H})$: so-called super-Riemannian quadruple. The Z_h -gradings of physically interesting supergroups were discussed by the authors in [7], where also the grading (12) is given. Already in [7] the relation of internal symmetry generators from sector L_2 with central charges in the contraction limit $R \rightarrow \infty$ was pointed out.

$$\{Q_a^{*+}, Q_b^{*+}\} = \delta^{ab} (\Gamma^{\mu\nu})_{\alpha\beta} P_\mu + m^2 (\Gamma^{\mu\nu})_{\alpha\beta} X^{ab} + (\Gamma^{\mu\nu})_{\alpha\beta} Y^{ab} \quad (9a)$$

$$\{Q_a^{*+}, Q_b^{*-}\} = m \delta^{ab} (\Sigma^{\mu\nu} \Gamma^{\mu\nu})_{\alpha\beta} M_{\mu\nu} + m^2 (\Gamma^{\mu\nu})_{\alpha\beta} A^{ab} + (\Gamma^{\mu\nu})_{\alpha\beta} S^{ab} \quad (9b)$$

$$\{Q_a^{*-}, Q_b^{*-}\} = \delta^{ab} (\Gamma^{\mu\nu})_{\alpha\beta} P_\mu + m^2 (\Gamma^{\mu\nu})_{\alpha\beta} X^{ab} - (\Gamma^{\mu\nu})_{\alpha\beta} Y^{ab} \quad (9c)$$

The relations (2a-2b) are valid also for Q_a^{*+} , but the relation (2c) remains only valid for the generators belonging to $U(N)$ subgroup of $O(2N)$ (see (4)).

Let us observe that

$$\begin{aligned} [\tau_\tau, \Omega] &= 0 & \text{iff} & \tau_\tau \in U(N) \\ \{\tau_\tau, \Omega\} &= 0 & \text{iff} & \tau_\tau \in \frac{O(2N)}{U(N)} \end{aligned} \quad (10)$$

Writing $X^{ab} + \Gamma_5 Y^{ab} = \tau_K^{ab} (X_K + \Gamma_5 Y_K)$ ($K = 1 \dots \frac{N(N-1)}{2}$) one gets

$$\begin{aligned} \frac{1}{i} [X_K, Q_a^{*+}] &= g \tau_K^{ab} Q_b^{*+} \\ \frac{1}{i} [Y_K, Q_a^{*+}] &= \pm g \tau_K^{ab} (\Gamma_5 Q_b^{*+})_a \end{aligned} \quad (11)$$

It is easy to check that the whole superalgebra $OSp(2N; 4)$ can be decomposed into the following four sectors

$$\begin{array}{cccc} L_0 & L_1 & L_2 & L_3 \\ M_{\mu\nu} & Q_d^{*+} & P_\mu & Q_d^{*-} \\ A^{ab}, S^{ab} & X^{ab}, Y^{ab} & & \end{array} \quad (12)$$

It is easy to see therefore that in the contraction limit $R \rightarrow \infty$ the $N(N-1)$ generators X_K, Y_K become Abelian ones, and in the extended super-Poincaré algebra they appear as the central charges. Because if $R \rightarrow \infty$ the sectors Q_a^+ and Q_a^- decouple, one can restrict the fermionic sector to L_1 (or L_3). If we denote $Q_a^{\pm} \equiv Q_a^{\pm}$, one gets in the limit $R \rightarrow \infty$ from the sectors (L_0, L_1, L_2) the $D=4$ extended super Poincaré algebra with $N(N-1)$ real central charges.

Before contraction in the $OSP(2N; 4)$ superalgebra the generators X_K, Y_K describe nonabelian or curved "precentral" charges; in order to obtain the conventional description of central charges one has to perform two steps:

a) the contraction limit. The generators become Abelian, but still do not commute with internal symmetry sector $U(N)$ (they can be called abelian "precentral" charges);

b) reduction of internal symmetry group $U(N)$ to its subgroup commuting with Z_1^1 . Such a reduction for different choices of the representations with nontrivially represented X_{ab}, Y_{ab} was discussed recently in [3]; see also [8].

4. It is already known (see e.g. [9]) that the superspace realization of supersymmetries with central charges require additional bosonic coordinates of superspace. In particular one can obtain central charges from the translations in extra bosonic dimensions [10,11] but in such a case one introduces "big" Lorentz group $O(D-1,1)$ ($D > 3$) and the breaking mechanism into physical space-time and internal sector is not justified. In the derivation of central charges presented here the additional bosonic variables acquire a clear geometric meaning: they describe complex "curved" translations on the coset $\frac{O(2N)}{U(N)}$, and in the limit $R \rightarrow \infty$ one obtains $N(N-1)$ additional bosonic variables U_{ab}, V_{ab} ($U_{ab} = -U_{ba}, V_{ab} = -V_{ba}$), with their translations generated by the central charge generators.

The N -extended superspace variables before the contraction parametrize the following coset

$$K = \frac{OSP(2N; 4)}{SL(2; C) \times U(N)} \quad (15)$$

Using the exponential parametrization of the coset variables

$$K = \exp(X_{\mu} P^{\mu} + Q_{\alpha}^{+} \bar{\theta}_{\alpha}^{+} + Q_{\alpha}^{-} \bar{\theta}_{\alpha}^{-}) \cdot \exp(X_{ab} U^{ab} + Y_{ab} V^{ab}) \quad (17)$$

Applying well-known techniques of nonlinear realizations on coset spaces (see e.g. [5,12]) one gets the transformation formulae of the super-space coordinates $(x_{\mu}, \theta_{\alpha}^{+}, \theta_{\alpha}^{-}, u^{ab}, v^{ab})$ e.g. under the supertranslation $\exp(Q_{\alpha}^{+} \bar{\epsilon}_{\alpha}^{+})$. Using the rescaled superalgebra, one can calculate the transformations up to order $\frac{1}{R}$. Describing the change of superfield coordinates as the result of the action of the superspace generator $\epsilon^{+} Q^{+}$, one gets

$$Q_{\alpha}^{+} = \frac{\partial}{\partial \theta_{\alpha}^{+}} - \frac{1}{2} (\bar{\theta}^{\mu} \Gamma_{\mu})_{\alpha} \frac{\partial}{\partial x_{\mu}} + m' (\bar{\theta}_{\alpha}^b \frac{\partial}{\partial u_{ba}} + (\bar{\theta}^b \Gamma_5)_{\alpha} \frac{\partial}{\partial v_{ba}}) + O(\frac{1}{R}) \quad (18)$$

where we did put $\theta_{\alpha}^{\pm} \equiv \theta_{\alpha}^{\pm}$. Calculating the anticommutator of the generators (19) one gets

$$\{Q_{\alpha}^{+}, Q_{\beta}^{+}\} = \delta^{\alpha\beta} (\Gamma_{\mu} \Gamma_0) \frac{\partial}{\partial x_{\mu}} + 2m' (\Gamma_0)_{\alpha\beta} \frac{\partial}{\partial u_{ab}} + (\Gamma_0 \Gamma_5)_{\alpha\beta} \frac{\partial}{\partial v_{ab}} + O(\frac{1}{R}) \quad (19)$$

The formula (20) in the limit $R \rightarrow \infty$ coincides with the extension of Salam-Strathdee superspace realization of N -extended super-Poincaré algebra with $N(N-1)$ central charges.

5. We would like to add the following remarks:

(a) We learned when our work was finished that Howe, Lindström [13] and Kalosh [14] introduced additional 56 bosonic coordinates for $N=8$ supergravity in order to incorporate into the curved superspace formalism the E_7

* The formula (19) in the limit $R \rightarrow \infty$ was also presented by J.G. Taylor during the supergravity workshop at ICTP, Trieste (4-6 May 1981).

"hidden symmetry" group. In our framework these additional variables are determined uniquely, and one can show that they carry the linear realizations of earlier discovered hidden symmetry E_7 (see e.g. [15]). At present we are not able to determine which "hidden symmetries" occur at given N using purely geometric arguments, however a look on the additional variables and linear realizations of hidden symmetries at any given N leads to the conclusion that they are "well fitted" to each other.

- (b) The additional bosonic coordinates can be used for the definition of mass operator which depends on the Casimirs of internal and hidden symmetry groups. These coordinates transform only under internal symmetries, and represent a new version of "old" isotopic space concept.
- (c) We discuss in this note only rigid extended supersymmetries. Our way of introducing central charges if applied to supergravity requires local gauging of $OSP(2N; 4)$ symmetry. The methods developed by McDowell (see e.g. [16]) and by supergroup approach (see e.g. [17]) should be useful in deriving the supergravity actions with central charges.
- (d) Because the number of new bosonic coordinates increases quadratically with N , it makes reasonable to look for composite superspaces, by supersymmetric extension of Penrose framework with "elementary" twistors and "composite" space-time coordinates. The outline of such a generalization, with more details provided for $N = 1$, has been presented recently by one of the authors [18].

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REFERENCES

- [1] R. Haag, J. Łopuszanski and M. Sohnius, Nucl. Phys. B88, 257 (1975).
- [2] M. Sohnius, K.S. Stelle and P.C. West, Proc. of Europhysics Conference "Unification of the Fundamental Interactions", Erice, March 1980, ed. Plenum Press.
- [3] S. Ferrara, C.A. Savoy and B. Zumino, CERN preprint TH 3010, December 1980.
- [4] S. Ferrara, Phys. Letters 69B, 481 (1977).
- [5] B. Zumino, Nucl. Phys. 127, 189 (1977).
- [6] J. Lukierski, Proceedings of IX-th Colloquium on Group-Theoretic Methods, Cocoyoc (Mexico), June 1980, publ. Lecture Notes in Physics, Vol. 135, p. 580.
- [7] J. Lukierski, and L. Rytel, University of Leuven preprint KUL-TP-80/11 April 1980, unpublished.
- [8] J. Łopuszanski and M. Wolf, in preparation.
- [9] M. Sohnius, Nucl. Phys. B138, 109 (1978).
- [10] D. Olive, Nucl. Phys. B153, 1 (1979).
- [11] H. Osborn, Univ. Cambridge preprint DAMP 79/4, 1979.
- [12] F. Gürsey and L. Marchildon, Phys. Rev. D17, 2038 (1978).
- [13] P. Howe and U. Lindström, Nucl. Phys. B181.
- [14] R. Kallosh, talk at Supergravity Workshop 4-6 May, ICTP, Trieste.
- [15] B. Julia, in "Superspace and Supergravity", Proc. of Nuffield Workshop Cambridge, June 16 - July 12 1980, ed. Cambridge Univ. Press, p. 331.
- [16] S.W. McDowell, ibid, p. 257.
- [17] R. d'Auria, P. Fré and T. Regge, Rivista del Nuovo Cimento, Vol. 3, No. 12 (1980).
- [18] J. Lukierski, Lecture at Winter School in Karpacz, February 1981; Wrocław Univ. preprint No. 534, April 1981.

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