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DISTRIBUTION OF MASSES AND CHARGE DENSITIES OF SPIN 5/2 AND 7/2, FIRST ORDER WAVE EQUATIONS BASED ON THE GROUP SO(4,1)

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Abstract: *The distribution of masses and charge densities of spin 5/2 and 7/2 first order wave equations based on the group SO(4,1) is studied and is shown that the charge associated with these fields is indefinite.*

1. INTRODUCTION

In this paper we are concerned with wave equations of the form[1-2]:

$$L_0 \frac{\partial \Psi}{\partial \chi_0} + L_1 \frac{\partial \Psi}{\partial \chi_1} + L_2 \frac{\partial \Psi}{\partial \chi_2} + L_3 \frac{\partial \Psi}{\partial \chi_3} + i\chi\Psi = 0 \qquad (1)$$

where L_k, $k = 0,1,2,3$ are four matrices of appropriate dimension depending on the representation according to which the wave function $\Psi = (\Psi_1, \Psi_2, \ldots \Psi_n)$ transforms and χ a constant related to the masses of the particles described by the field (1). In particular we shall concentrate on two kinds of fields namely the fields of maximum spin 5/2 and 7/2 respectively whose underlying representations belong to the group SO(4,1) and we shall give the masses and charge densities associated with these fields. The masses m_i associated with each field are directly related with the eigenvalues λ_i of the matrix L_0 via the formula $m_i = \frac{\chi}{\lambda_i}$. Also with each wave equation the quantity ρ can

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be associated known as the charge density and given by the formula $\rho = \Psi^{+} A L_0 \Psi$ where Ψ^{+} the hermitian conjugate of Ψ and A the hermitianizing matrix associated with the concerned field.

2. THE SPIN 5/2 FIELD

There are three different possible representations of the group SO(4,1) which can be used to describe particles of maximum spin 5/2. These representations are $R_5(5/2, 5/2)$, $R_5(5/2, 3/2)$, $R_5(5/2, 1/2)$. With respect to the four dimensional Lorentz group they acquire the decompositions[3]:

1) $R_5(5/2, 5/2) = R_4(5/2, 5/2) \oplus R_4(5/2, 3/2) \oplus R_4(5/2, 1/2)$
(56 - dim) (12 - dim) (20 - dim) (24 - dim)

2) $R_5(5/2, 3/2) = R_4(5/2, 3/2) \oplus R_4(5/2, 1/2) \oplus R_4(3/2, 3/2) \oplus R_4(3/2, 1/2)$
(64 - dim) (20 - dim) (24 - dim) (8 - dim) (12 - dim)

3) $R_5(5/2, 1/2) = R_4(5/2, 1/2) \oplus R_4(3/2, 1/2) \oplus R_4(1/2\ 1/2)$
(40 - dim) (24 - dim) (12 - dim) (4 - dim)

Case I: Representation $R_5(5/2, 5/2)$, (56-dim).

In the case of the field of maximum spin 5/2 the matrix L_0 breaks into three compartments corresponding to spins $l = 5/2$, $l = 3/2$, $l = 1/2$. The eigenvalues of L_0 (and hence the masses of the particles) are distributed among the three different spin states as follows:

For $l = 5/2$: $\lambda_1 = 5/2$, $\lambda_2 = -5/2$, $\lambda_3 = 3/2$, $\lambda_4 = -3/2$, $\lambda_5 = 1/2$, $\lambda_6 = -1/2$.

For $l = 3/2$: $\lambda_1 = 3/2$, $\lambda_2 = -3/2$, $\lambda_3 = 1/2$, $\lambda_4 = -1/2$.

For $l = 1/2$: $\lambda_1 = 1/2$, $\lambda_2 = -1/2$.

The matrix L_0 in the frame which makes it diagonal has the blocks:

$$L_0^{5/2} = \text{diag}\ \{5/2,\ -5/2,\ 3/2,\ -3/2,\ 1/2,\ -1/2\},$$

$$L_0^{3/2} = \text{diag}\ \{3/2,\ -3/2,\ 1/2,\ -1/2\},$$

$$L_0^{1/2} = \text{diag}\ \{1/2,\ -1/2\}.$$

The hermitianizing matrix A corresponding to L_0 is given by the formula[4]:

$$A = \frac{2L_0}{5!}\{16L_0^4 - 120L_0^2 + 149\}.$$

Hence:

$A_{5/2} = \mathrm{diag}\,\{1, -1, -1, 1, 1, -1\}$

$A_{3/2} = \mathrm{diag}\,\{-1, 1, 1, -1\}$

$A_{1/2} = \mathrm{diag}\,\{1, -1\}$

To decide about the charge associated with L_0 it is sufficient to find the eigenvalues of AL_0. This is equivalent to finding the eigenvalues of $A_l L^l_0$ for every l. Thus we have:

$A_{5/2}L_0^{5/2} = \mathrm{diag}\,\{5/2, 5/2, -3/2, -3/2, 1/2, 1/2\}$,

$A_{3/2}L_0^{3/2} = \mathrm{diag}\,\{-3/2, -3/2, 1/2, 1/2\}$,

$A_{1/2}L_0^{1/2} = \mathrm{diag}\,\{1/2, 1/2\}$.

We see immediately that the eigenvalues of AL_0 do not all have the same sign and hence the charge is indefinite.

Case II: Representation R (5/2, 3/2), (64-dim).

The eigenvalues of L_0 are distributed among the three spin state as follows:

For $l = 5/2$: $\lambda_1 = 1/2$, $\lambda_2 = -1/2$, $\lambda_3 = 3/2$, $\lambda_4 = -3/2$.

For $l = 3/2$: $\lambda_1 = 1/2$, $\lambda_2 = -1/2$, $\lambda_3 = 3/2$, $\lambda_4 = -3/2$,
$\lambda_5 = 5/2$, $\lambda_6 = -5/2$, $\lambda_7 = 1/2$, $\lambda_8 = -1/2$.

For $l = 1/2$: $\lambda_1 = 3/2$, $\lambda_2 = -3/2$, $\lambda_3 = 1/2$, $\lambda_4 = -1/2$,

and hence the blocks corresponding to L_0 are:

$L_0^{5/2} = \mathrm{diag}\{1/2, -1/2, 3/2, -3/2\}$

$L_0^{3/2} = \mathrm{diag}\{1/2, -1/2, 3/2, -3/2, 5/2, -5/2, 1/2, -1/2\}$,

$L_0^{1/2} = \mathrm{diag}\{3/2, -3/2, 1/2, -1/2\}$.

The hermitianizing matrix has blocks:

$A_{5/2} = \text{diag}\,\{1, -1, -1, 1\}$,

$A_{3/2} = \text{diag}\,\{1, -1, -1, 1, 1, -1, 1, -1\}$,

$A_{1/2} = \text{diag}\,\{-1, 1, 1, -1\}$,

and thus for the blocks of AL_0 we find:

$A_{5/2}L_0^{5/2} = \text{diag}\,\{1/2, 1/2, -3/2, -3/2\}$,

$A_{3/2}L_0^{3/2} = \text{diag}\,\{1/2, 1/2, -3/2, -3/2, 5/2, 5/2, 1/2, 1/2\}$,

$A_{1/2}L_0^{1/2} = \text{diag}\,\{-3/2, -3/2, 1/2, 1/2\}$.

Hence the total charge is again indefinite.

Case III: Representation R_5 (5/2, 1/2), (40-dim).

The eigenvalues of L_0 are distributed among the three spin states as follows:

For $l = 5/2$: $\lambda_1 = 1/2$, $\lambda_2 = -1/2$.

For $l = 3/2$: $\lambda_1 = 1/2$, $\lambda_2 = -1/2$, $\lambda_3 = 3/2$, $\lambda_4 = -3/2$.

For $l = 1/2$: $\lambda_1 = 1/2$, $\lambda_2 = -1/2$, $\lambda_3 = 3/2$, $\lambda_4 = -3/2$,
$\lambda_5 = 5/2$, $\lambda_6 = -5/2$,

and hence the blocks corresponding to it are:

$L_0^{5/2} = \text{diag}\,\{1/2, -1/2\}$,

$L_0^{3/2} = \text{diag}\,\{1/2, -1/2, 3/2, -3/2\}$,

$L_0^{1/2} = \text{diag}\,\{1/2, -1/2, 3/2, -3/2, 5/2, -5/2\}$.

The hermitianizing matrix A has blocks:

$A_{5/2} = \text{diag}\,\{1, -1\}$,

$A_{3/2} = \text{diag}\,\{1, -1, -1, 1,\}$,

$A_{1/2} = \text{diag}\,\{1, -1, -1, 1, 1, -1\}$,

and the blocks of AL_0 then are:

$A_{5/2}L_0^{5/2} = \text{diag}\,\{1/2, 1/2\}$

$A_{3/2}L_0^{3/2} = \text{diag}\,\{1/2, 1/2, -3/2, -3/2\}$,

$A_{1/2}L_0^{1/2} = \text{diag}\,\{1/2, 1/2, -3/2, -3/2, 5/2, 5/2\}$.

Thus the total charge is again indefinite.

3. THE SPIN 7/2 FIELD

There are four different possible representations of the group SO(4,1) which can be used to describe particles of maximum spin 7/2. These representations are $R_5(7/2, 7/2)$, $R_5(7/2, 5/2)$, $R_5(7/2, 3/2)$, $R_5(7/2, 1/2)$. With respect to the four dimensional Lorentz group they decompose as follows:

1) $R_5(7/2, 7/2) = R_4(7/2, 7/2) \oplus R_4(7/2, 5/2) \oplus R_4(7/2, 3/2) \oplus$
   (120 - dim) (16 - dim) (28 - dim) (36 - dim)
   $R_4(7/2, 1/2)$
   (40 - dim)

2) $R_5(7/2, 5/2) = R_4(7/2, 5/2) \oplus R_4(7/2, 3/2) \oplus R_4(7/2, 1/2) \oplus$
   (160 - dim) (28 - dim) (36 - dim) (40 - dim)
   $R_4(5/2, 5/2) \oplus R_4(5/2, 3/2) \oplus R_4(5/2, 1/2)$,
   (12 - dim) (20 - dim) (24 - dim)

3) $R_5(7/2, 3/2) = R_4(7/2, 3/2) \oplus R_4(7/2, 1/2) \oplus R_4(7/2, 1/2) \oplus$
   (140 - dim) (36 - dim) (40 - dim) (20 - dim)
   $R_4(5/2, 1/2) \oplus R_4(3/2, 3/2) \oplus R_4(3/2, 1/2)$
   (24 - dim) (8 - dim) (12 - dim)

4) $R_5(7/2, 1/2) = R_4(7/2, 1/2) \oplus R_4(5/2, 1/2) \oplus R_4(3/2, 1/2) \oplus$
   (80 - dim) (40 - dim) (24 - dim) (14 - dim)
   $R_4(1/2, 1/2)$
   (4 - dim)

Case I: Representation $R_5(7/2, 7/2)$, (120-dim)

In the case of the field of maximum spin 7/2 the matrix L_0 breaks into four compartments corresponding to spins $l = 7/2$, $l = 5/2$, $l = 3/2$, $l = 1/2$. The eigenvalues of L_0 are distributed among the four different spin states as follows:

For $l = 7/2$: $\lambda_1 = 7/2$, $\lambda_2 = -7/2$, $\lambda_3 = 5/2$, $\lambda_4 = -5/2$,
$\lambda_5 = 3/2$, $\lambda_6 = -3/2$, $\lambda_7 = 1/2$, $\lambda_8 = -1/2$.

For $l = 5/2$: $\lambda_1 = 5/2$, $\lambda_2 = -5/2$, $\lambda_3 = 3/2$, $\lambda_4 = -3/2$,
$\lambda_5 = 1/2$, $\lambda_6 = -1/2$.

For $l = 3/2$: $\lambda_1 = 3/2$, $\lambda_2 = -3/2$, $\lambda_3 = 1/2$, $\lambda_4 = -1/2$.

For $l = 1/2$: $\lambda_1 = 1/2$, $\lambda_2 = -1/2$.

L_0 in the frame which makes it diagonal has the blocks:

$L_0^{7/2} = \text{diag}\{7/2, -7/2, 5/2, -5/2, 3/2, -3/2, 1/2, -1/2\}$,

$L_0^{5/2} = \text{diag}\{5/2, -5/2, 3/2, -3/2, 1/2, -1/2\}$,

$L_0^{3/2} = \text{diag}\{3/2, -3/2, 1/2, -1/2\}$,

$L_0^{1/2} = \text{diag}\{1/2, -1/2\}$.

The hermitianizing matrix A corresponding to L_0 is given by the formula:

$$A = \frac{2L^0}{7!}\left\{64L_0^6 - \frac{4928}{4}L_0^4 + \frac{97216}{4^2}L_0^2 - \frac{414912}{4^3}\right\}.$$

Hence the corresponding blocks of A are:

$A_{7/2} = \text{diag}\{1, -1, -1, 1, 1, -1, -1, 1\}$,

$A_{5/2} = \text{diag}\{-1, 1, 1, -1, -1, 1\}$,

$A_{3/2} = \text{diag}\{1, -1, -1, 1\}$,

$A_{1/2} = \text{diag}\{-1, 1\}$

and the blocks of AL^0 are:

$A_{7/2}L_0^{7/2} = \text{diag}\{7/2, 7/2, -5/2, -5/2, 3/2, 3/2, -1/2, -1/2\}$,

$A_{5/2}L_0^{5/2} = \text{diag}\{-5/2, -5/2, 3/2, 3/2, -1/2, -1/2\}$,

$A_{3/2}L_0^{3/2} = \text{diag}\{3/2, 3/2, -1/2, -1/2\}$,

$A_{1/2}L_0^{1/2} = \text{diag}\{-1/2, -1/2\}$

which implies that the charge is indefinite.

Case II: Representation $R_5(7/2, 5/2)$, (160-dim).

The eigenvalues of L_0 are distributed among the spin states as follows:

For $l = 7/2$: $\lambda_1 = 5/2$, $\lambda_2 = -5/2$, $\lambda_3 = 3/2$, $\lambda_4 = -3/2$, $\lambda_5 = 1/2$, $\lambda_6 = -1/2$.

For $l = 5/2$: $\lambda_1 = 5/2$, $\lambda_2 = -5/2$, $\lambda_3 = 3/2$, $\lambda_4 = -3/2$, $\lambda_5 = 1/2$, $\lambda_6 = -1/2$, $\lambda_7 = 7/2$, $\lambda_8 = -7/2$, $\lambda_9 = 3/2$, $\lambda_{10} = -3/2$, $\lambda_{11} = 1/2$, $\lambda_{12} = -1/2$.

For $l=3/2$: $\lambda_1=3/2,\quad \lambda_2=-3/2,\quad \lambda_3=1/2,\quad \lambda_4=-1/2,$
$\lambda_5=3/2,\quad \lambda_6=-3/2,\quad \lambda_7=1/2,\quad \lambda_8=-1/2.$

For $l=1/2$: $\lambda_1=1/2,\quad \lambda_2=-1/2,\quad \lambda_3=1/2,\quad \lambda_4=-1/2.$

L_0 in the diagonalizing frame has the blocks:

$L_0^{7/2}=\text{diag}\{5/2,-5/2,3/2,-3/2,1/2,-1/2\},$

$L_0^{5/2}=\text{diag}\{5/2,-5/2,3/2,-3/2,1/2,-1/2,7/2,-7/2,3/2,-3/2,$
$1/2,-1/2\},$

$L_0^{3/2}=\text{diag}\{3/2,-3/2,1/2,-1/2,3/2,-3/2,1/2,-1/2\},$

$L_0^{1/2}=\text{diag}\{1/2,-1/2,1/2,-1/2\}.$

The corresponding hermitianizing matrix has blocks:

$A_{7/2}=\text{diag}\{-1,1,1,-1,-1,1\},$

$A_{5/2}=\text{diag}\{-1,1,1,-1,-1,1,1,-1,1,-1,-1,1\}$,

$A_{3/2}=\text{diag}\{1,-1,-1,1,1,-1,-1,1\},$

$A_{1/2}=\text{diag}\{-1,1,-1,1\},$

and hence the blocks of AL_0 are:

$A_{7/2}L_0^{7/2}=\text{diag}\{-5/2,-5/2,3/2,3/2,-1/2,-1/2\},$

$A_{5/2}L_0^{5/2}=\text{diag}\{-5/2,-5/2,3/2,3/2,-1/2,-1/2,7/2,7/2,3/2,3/2,$
$-1/2,-1/2\},$

$A_{3/2}L_0^{3/2}=\text{diag}\{3/2,3/2,-1/2,-1/2,3/2,3/2,-1/2,-1/2\},$

$A_{1/2}L_0^{1/2}=\text{diag}\{-1/2,-1/2,-1/2,-1/2\}.$

The charge is again indefinite.

Case III: Representation $R_5(7/2,3/2)$, (140-dim).

The eigenvalues of L_0 are distributed among the spin states as follows:

For $l=7/2$: $\lambda_1=1/2,\quad \lambda_2=-1/2,\quad \lambda_3=1/2,\quad \lambda_4=-1/2.$

For $l=5/2$: $\lambda_1=1/2,\quad \lambda_2=-1/2,\quad \lambda_3=1/2,\quad \lambda_4=-1/2,$
$\lambda_5=3/2,\quad \lambda_6=-3/2,\quad \lambda_7=3/2,\quad \lambda_8=-3/2.$

For $l=3/2$: $\lambda_1=1/2,\quad \lambda_2=-1/2,\quad \lambda_3=1/2,\quad \lambda_4=-1/2,$
$\lambda_5=3/2,\quad \lambda_6=-3/2,\quad \lambda_7=3/2,\quad \lambda_8=-3/2,$
$\lambda_9=7/2,\quad \lambda_{10}=-7/2,\quad \lambda_{11}=5/2,\quad \lambda_{12}=-5/2.$

For $l = 1/2$: $\lambda_1 = 1/2$, $\lambda_2 = -1/2$, $\lambda_3 = 3/2$, $\lambda_4 = -3/2$,
$\lambda_5 = 5/2$, $\lambda_6 = -5/2$.

L_0 has the blocks:

$L_0^{7/2} = \text{diag}\{1/2,-1/2,1/2,-1/2\}$,

$L_0^{5/2} = \text{diag}\{1/2,-1/2,1/2,-1/2,3/2,-3/2,3/2,-3/2\}$,

$L_0^{3/2} = \text{diag}\{1/2,-1/2,1/2,-1/2,3/2,-3/2,3/2,-3/2,7/2,-7/2,$
$5/2,-5/2\}$,

$L_0^{1/2} = \text{diag}\{1/2,-1/2\ 3/2,-3/2,5/2,-5/2\}$.

The corresponding hermitianizing matrix has blocks:

$A_{7/2} = \text{diag}\{-1,1,-1,1\}$,

$A_{5/2} = \text{diag}\{-1,1,-1,1,1,-1,1,-1\}$,

$A_{3/2} = \text{diag}\{-1,1,-1,1,1,-1,1,-1,1,-1,-1,1\}$,

$A_{1/2} = \text{diag}\{-1,1,1,-1,-1,1\}$,

and hence AL_0 has the blocks:

$A_{7/2}L_0^{7/2} = \text{diag}\{-1/2,-1/2,-1/2,-1/2\}$,

$A_{5/2}L_0^{5/2} = \text{diag}\{,-1/2-1/2,-1/2,-1/2,3/2,3/2,3/2,3/2\}$,

$A_{3/2}L_0^{3/2} = \text{diag}\{-1/2,-1/2,-1/2,-1/2,3/2,3/2,3/2,3/2,7/2,7/2,$
$-5/2,-5/2\}$,

$A_{1/2}L_0^{1/2} = \text{diag}\{-1/2,-1/2,3/2,3/2,-5/2,-5/2\}$.

Thus the charge is again indefinite.

Case IV: Representation $R_5(7/2, 1/2)$, *(80-dim).*

The eigenvalues of L_0 are distributed among the spin states as follows:

For $l = 7/2$: $\lambda_1 = 1/2$, $\lambda_2 = -1/2$.

For $l = 5/2$: $\lambda_1 = 1/2$, $\lambda_2 = -1/2$, $\lambda_3 = 3/2$, $\lambda_4 = -3/2$.

For $l = 3/2$: $\lambda_1 = 1/2$, $\lambda_2 = -1/2$, $\lambda_3 = 3/2$, $\lambda_4 = -3/2$,
$\lambda_5 = 5/2$, $\lambda_6 = -5/2$.

For $l = 1/2$: $\lambda_1 = 1/2$, $\lambda_2 = -1/2$, $\lambda_3 = 3/2$, $\lambda_4 = -3/2$,
$\lambda_5 = 5/2$, $\lambda_6 = -5/2$, $\lambda_7 = 7/2$, $\lambda_8 = -7/2$.

L_0 has the blocks:

$L_0^{7/2} = \text{diag}\{1/2, -1/2\}$,

$L_0^{5/2} = \text{diag}\{1/2, -1/2, 3/2, -3/2\}$,

$L_0^{3/2} = \text{diag}\{1/2, -1/2, 3/2, -3/2, 5/2, -5/2\}$,

$L_0^{1/2} = \text{diag}\{1/2, -1/2, 3/2, -3/2, 5/2, -5/2, 7/2, -7/2\}$.

The corresponding hermitianizing matrix has blocks:

$A_{7/2} = \text{diag}\{-1, 1\}$,

$A_{5/2} = \text{diag}\{-1, 1, 1, -1\}$,

$A_{3/2} = \text{diag}\{-1, 1, 1, -1, -1, 1\}$,

$A_{1/2} = \text{diag}\{-1, 1, 1, -1, -1, 1, 1, -1\}$,

and hence the matrix AL_0 has blocks:

$A_{7/2}L_0^{7/2} = \text{diag}\{-1/2, -1/2\}$,

$A_{5/2}L_0^{5/2} = \text{diag}\{-1/2, -1/2, 3/2, 3/2\}$,

$A_{3/2}L_0^{3/2} = \text{diag}\{-1/2, -1/2, 3/2, 3/2, -5/2, -5/2\}$,

$A_{1/2}L_0^{1/2} = \text{diag}\{-1/2, -1/2, 3/2, 3/2, -5/2, -5/2, 7/2, 7/2\}$.

Thus the charge is indefinite.

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ΠΕΡΙΛΗΨΗ

ΚΑΤΑΝΟΜΗ ΤΩΝ ΜΑΖΩΝ ΚΑΙ ΠΥΚΝΟΤΗΤΕΣ ΦΟΡΤΙΟΥ ΤΩΝ ΚΥΜΑΤΟΕΞΙΣΩΣΕΩΝ ΠΡΩΤΗΣ ΤΑΞΕΩΣ ΜΕ ΣΠΙΝ 5/2 ΚΑΙ 7/2 ΠΟΥ ΜΕΤΑΣΧΗΜΑΤΙΖΟΝΤΑΙ ΒΑΣΕΙ ΤΩΝ ΣΤΟΙΧΕΙΩΝ ΤΗΣ ΟΜΑΔΟΣ SO(4,1)

Ὑπὸ

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Στὴν ἐργασία αὐτὴ μελετοῦμε τὴν κατανομὴ τῶν μαζῶν καὶ τὶς πυκνότητες φορτίου τῶν κυματοεξισώσεων πρώτης τάξεως μὲ σπιν 5/2 καὶ 7/2 ποὺ μετασχηματίζονται βάσει τῶν στοιχείων τῆς ὁμάδος SO(4,1) καὶ ἀποδεικνύομε ὅτι τὸ φορτίο ποὺ ἔχει σχέση μὲ αὐτὲς τὶς κυματοεξισώσεις εἶναι ἀπροσδιόριστο.

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