ПРЕГЛЕДНИ РАДОВИ
ОБЗОРНЫЕ СТАТЬИ
REVIEW PAPERS

Supersymmetry

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Abstract:

Introduction/purpose: Supersymmetry is a symmetry of the Lagrangian that goes beyond Lie groups. It allows the exchange of bosons and fermions. The most important model is the Minimal Supersymmetric Standard Model, or MSSM.

Methods: Supercharge algebra, superfields, Grassmann numbers, Berezin integral.

Results: Supersymmetric transformations are global, they do not depend on spacetime coordinates. In the case of Supergravity, they are local.

Conclusion: Supersymmetric models, and MSSM in particular, could describe more physics and more particles beyond the Standard Model.

Key words: supersymmetry, minimal supersymmetric standard sodel.

Supersymmetry

Supersymmetry – or SUSY for short – is a symmetry that interchanges bosons with fermions (Gervais & Sakita, 1971; Volkov & Akulov, 1972, 1973, 1974; Ramond, 1971). It is one of the best candidates for physics beyond the Standard Model, with the so–called Minimal Supersymmetric Standard Model, MSSM for short (Fayet, 1975, 1976, 1977; Fayet & Ferrara, 1977). In this extension to the Standard Model, each particle has its corresponding *superpartner* with same mass and other quantum numbers, but with different spin by one half. For instance, the electron has a selectron, a bosonic superpartner, while photon, Z and gluon have fermionic superpartners called photino, zino and gluino respectively. Names are assigned in following manner: bosonic superpartners gain the s- prefix, while fermionic superpartners gain the -ino suffix.

As we easily distinguish between bosons and fermions at current energies, this symmetry has to be spontaneously broken. After supersymmetry breaking superpartners masses may differ.

Supersymmetry algebra

A supersymmetric transformation brings a scalar to a fermion and viceversa. The generator Q_α of the transformation, known as the supercharge, brings from the boson field ϕ to the Weyl spinor ψ_α.

In order to describe supersymmetry transformation it is better to operate with Weyl spinors rather than Dirac ones, and to change usual notation a bit. Weyl spinors $\psi_{L,R}$ transform under Lorentz group as

$$\psi_{L,R}(x) \to \psi'_{L,R}(x') = \Lambda_{L,R}\psi_{L,R}(x) \ , \tag{1}$$

where the transformations $\Lambda_{L,R}$ are given by

$$\Lambda_{L,R} = \exp\left(\frac{1}{2}\vec{\sigma}\cdot(\vec{\omega} \mp i\vec{\nu})\right) \ , \tag{2}$$

$\vec{\sigma}$ being the three Pauli matrices

$$\sigma_1 = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}, \ \sigma_2 = \begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix}, \ \sigma_3 = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} \ , \tag{3}$$

$\vec{\omega}$ the three real rotational parameters, and $\vec{\nu}$ the three real boost parameters. The transformations Λ_L and Λ_R are related by

$$\Lambda_L^{-1} = \Lambda_R^{\dagger} \ . \tag{4}$$

The four component Dirac spinor Ψ is written as follows:

$$\Psi = \begin{pmatrix} \psi_L \\ \psi_R \end{pmatrix} \ , \tag{5}$$

equivalent to

$$\Psi = \begin{pmatrix} \psi_\alpha \\ \overline{\chi}^{\dot{\alpha}} \end{pmatrix} \ . \tag{6}$$

Often, it is found that Weyl spinors are written starting from Dirac spinors in the following way, as projections, see for instance (Fabiano, 2021):

$$\psi_{L,R} = \frac{1}{2}(1 \pm \gamma_5)\psi \ . \tag{7}$$

In this formalism we have the Weyl representation of the Dirac matrices

$$\gamma^\mu = \begin{pmatrix} 0 & \sigma^\mu \\ \overline{\sigma}^\mu & 0 \end{pmatrix} \ , \tag{8}$$

where $\sigma^\mu = (\mathbb{1}, \sigma^i) = (\sigma^\mu)_{\alpha\beta}$ and $\overline{\sigma}^\mu = (\mathbb{1}, -\sigma^i) = (\overline{\sigma}^\mu)^{\dot{\alpha}\beta} = (\sigma^\mu)^{\beta\dot{\alpha}}$. The matrices σ^μ and $\overline{\sigma}^\mu$ mix dotted and undotted indices, that is left and right spinor indices. The dot in the notation is similar to the covariant and contravariant – or upper and lower indices in general and special relativity. We always contract an upper with a lower index, and we have the additional rule that only dotted or undotted indices can be contracted together, not mixed dotted–undotted.

The generator Q_α transforms as a Weyl spinor, that means

$$[J^{\mu\nu}, Q_\alpha] = -i(\sigma^{\mu\nu})_\alpha^{\ \beta} Q_\beta \ , \tag{9}$$

where $J^{\mu\nu}$ is the generator of Lorentz group, while

$$\sigma^{\mu\nu} \equiv \frac{1}{4}(\sigma^\mu \overline{\sigma}^\nu - \sigma^\nu \overline{\sigma}^\mu) \ , \text{ and } \overline{\sigma}^{\mu\nu} \equiv \frac{1}{4}(\overline{\sigma}^\mu \sigma^\nu - \overline{\sigma}^\nu \sigma^\mu) \ . \tag{10}$$

Q_α is independent from spacetime coordinates, then

$$[P^\mu, Q_\alpha] = 0 \ . \tag{11}$$

Denoting the conjugate of Q_α as $\overline{Q}_{\dot{\alpha}}$ we have

$$[J^{\mu\nu}, \overline{Q}^{\dot{\alpha}}] = -i(\overline{\sigma}^{\mu\nu})^{\dot{\alpha}}_{\ \dot{\beta}} \overline{Q}^{\dot{\beta}} \ . \tag{12}$$

The conjugation of spinors works as follows:

$$(\psi^\alpha)^* = \overline{\psi}^{\dot{\alpha}}, \ \text{ and } \ (\psi_\alpha)^* = \overline{\psi}_{\dot{\alpha}} \ . \tag{13}$$

The supersymmetry algebra is given by the anticommutator

$$\{Q_\alpha, \overline{Q}_{\dot{\beta}}\} = 2(\sigma^\mu)_\alpha^{\ \dot{\beta}} P_\mu \ . \tag{14}$$

How to justify (14)? By inspection, the rhs of the expression should carry indices α and $\dot{\beta}$. The simplest object that carries those two indices is σ^μ,

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which also carries a Lorentz index. The latter has to be contracted with a vector index, that is P_μ, the generator of translations. The factor of 2 is for normalisation.

By the same line of reasoning we should have $\{Q_\alpha, Q^\beta\} = c_1(\sigma^{\mu\nu})_\alpha^{\ \beta} J_{\mu\nu} + c_2\delta_\alpha^{\ \beta}$, where c_1 and c_2 are constants. Commuting with P^λ results that $c_1 = 0$. Since we have that $Q_\alpha = \epsilon_{\alpha\beta}Q^\beta$ where $\epsilon_{01} = 1$, we obtain $\{Q_\alpha, Q_\beta\} = c_2\epsilon_{\alpha\beta}$, but because lhs is symmetric in α and β we deduce that $c_2 = 0$. The complete supersymmetry algebra is therefore given by relations:

$$\{Q_\alpha, \overline{Q}_{\dot\beta}\} = 2(\sigma^\mu)_\alpha^{\ \dot\beta} P_\mu \tag{15}$$
$$\{Q_\alpha, Q_\beta\} = 0 \tag{16}$$
$$\{\overline{Q}_{\dot\alpha}, \overline{Q}_{\dot\beta}\} = 0 \tag{17}$$
$$[Q_\alpha, J_{\mu\nu}] = \frac{1}{2}(\sigma^\mu)_\alpha^{\ \beta} Q_\beta \tag{18}$$
$$[\overline{Q}_{\dot\alpha}, J_{\mu\nu}] = -\frac{1}{2}\overline{Q}_{\dot\beta}(\overline{\sigma}_{\mu\nu})_{\dot\alpha}^{\ \dot\beta} \tag{19}$$
$$[Q_\alpha, P_\mu] = 0 \tag{20}$$
$$[\overline{Q}_{\dot\alpha}, P_\mu] = 0\ . \tag{21}$$

There is an immediate physical result coming from eq. (14): when contracted with $(\overline{\sigma})^{\dot\beta\alpha}$ one has

$$4P^\nu = (\overline{\sigma})^{\dot\beta\alpha}\{Q_\alpha, \overline{Q}_{\dot\beta}\}\ . \tag{22}$$

The first component P^0 is the Hamiltonian, so

$$4\mathcal{H} = \sum_\alpha \{Q_\alpha, \overline{Q}_{\dot\beta}\} = \sum_\alpha \{Q_\alpha, Q_\alpha^\dagger\} = \sum_\alpha (Q_\alpha Q_\alpha^\dagger + Q_\alpha^\dagger Q_\alpha)\ , \tag{23}$$

because the conjugate of Q_α is $\overline{Q}_{\dot\beta}$. It is clear that $\mathcal{H}$ is non negative definite (the value 0 is admitted), so in supersymmetric theory any physical state $|S\rangle$ has a non negative energy:

$$\langle S\,|\mathcal{H}|\,S\rangle = \frac{1}{2}\sum_\alpha\sum_{S'} \left|\langle S'\,|Q_\alpha^2|\,S\rangle\right|^2 \geq 0\ . \tag{24}$$

Superspace and superfields

From the relation (14), that could be also written as

$$\{Q_\alpha, Q_\alpha^\dagger\} = 2(\sigma^\mu)_{\alpha\alpha} P_\mu \;, \tag{25}$$

we could construct a so–called *superspace*, an abstract space with both bosonic and fermionic coordinates. The fermionic coordinates should be constructed with the aid of *Grassmann numbers* (Grassmann, 1844). Those are anticommuting numbers θ_i that commute with ordinary numbers x:

$$\theta_i\theta_j = -\theta_j\theta_i \;, \text{ and } \theta_i x = x\theta_i \;. \tag{26}$$

It is clear that

$$(\theta_i)^2 = 0 \text{ because } \theta_i\theta_i = -\theta_i\theta_i \;, \tag{27}$$

and therefore any function defined on Grassmann numbers has at most a constant and a linear term: $f(\theta) = a + b\theta$, where a, b are ordinary numbers. It is also easy to find out that a product of two Grassmann numbers, that is $\theta_i\theta_j$, obeys to Bose–Fermi statistics.

The integral over Grassmann functions is called *Berezin integral* (Berezin, 1966). It is a sort of integral over fermionic variables, and can be determined by asking basic properties of ordinal integration like linearity

$$\int \mathrm{d}\theta \; [af(\theta) + bg(\theta)] = a \int \mathrm{d}\theta \; f(\theta) + b \int \mathrm{d}\theta \; g(\theta) \tag{28}$$

translational invariance

$$\int d\theta f(\theta + \theta') = \int d\theta f(\theta) \;, \tag{29}$$

and partial integration formula

$$\int \mathrm{d}\theta \; \left[\frac{\partial}{\partial\theta} f(\theta)\right] = 0 \;. \tag{30}$$

Starting from formula (29), and the fact that any function of Grassmann numbers is linear one finds out that

$$\int d\theta(a + b\theta + b\theta') = \int d\theta(a + b\theta) \ , \tag{31}$$

$$a \int d\theta + b \int d\theta\theta + b\theta' \int d\theta = a \int d\theta + b \int d\theta\theta \ , \tag{32}$$

providing the result

$$\int d\theta = 0 \ . \tag{33}$$

This leads to very simple integration rules:

$$\int \mathrm{d}\theta \ 1 = 0 \ , \tag{34}$$

and

$$\int \mathrm{d}\theta \ \theta = 1 \ , \tag{35}$$

the latter formula is a matter of convention for normalisation, used originally by Berezin.

Formally, the polynomials constructed by n Grassmann variables $\theta_1, \ldots, \theta_n$, form the Grassmann algebra G_n. The Grassmann algebra uses the wedge product as multiplication, being anticommutative and associative, which is similar to the more familiar cross product of two vectors. The Berezin integral on G_n is defined as a linear functional having the following properties:

$$\int_{G_n} d\theta\theta_1, \ldots, \theta_n = 1 \ , \tag{36}$$

and

$$\int_{G_n} d\theta \frac{\partial f}{\partial \theta_i} = 0, i = 1 \ldots n \ ; \tag{37}$$

it could be shown that Berezin integral is the only possible functional with the above mentioned properties.

The superspace is formed from bosonic and fermionic coordinates, $\{x^\mu, \theta^\alpha, \overline{\theta}^{\dot{\beta}}\}$. Here θ^α is a two component left handed Weyl spinor $(\theta^{(0)}, \theta^{(1)})$, $\overline{\theta}^{\dot{\beta}}$ a two component right handed Weyl spinor $(\overline{\theta}^{(0)}, \overline{\theta}^{(1)})$. We have a total of 4 bosonic dimensions and 4 Grassmann dimensions. This combination of ordinary coordinates x^μ and one couple of Weyl spinors $\{\theta^\alpha, \overline{\theta}^{\dot{\beta}}\}$ is called $N = 1$ supersymmetric space.

The basic relation (14) for supersymmetry generators shows that the application of two consecutive transformations leads to P^μ, a translation in ordinary bosonic space. So we expect that operators Q_α and $\overline{Q}_{\dot\beta}$ generate a translation in superspace, respectively in θ^α and $\overline{\theta}^{\dot\beta}$ Grassmann coordinates. The supercharges are explicitly represented by

$$Q_\alpha = \frac{\partial}{\partial\theta^\alpha} - i(\sigma^\mu)_{\alpha\dot\alpha}\overline{\theta}^{\dot\alpha}\partial_\mu \tag{38}$$

and

$$\overline{Q}_{\dot\beta} = -\frac{\partial}{\partial\overline{\theta}^{\dot\beta}} + i\theta^\beta(\sigma^\mu)_{\beta\dot\beta}\partial_\mu \; . \tag{39}$$

These expressions satisfy the anticommutation relation (14). Notice that the "naive" guess $Q_\alpha = \partial/\partial\theta^\alpha$ and $\overline{Q}_{\dot\beta} = -\partial/\partial\overline{\theta}^{\dot\beta}$ would give 0 in the anticommutator, thus not satisfying (14).

A *superfield* is a function defined on superspace: $\Phi(x^\mu, \theta^\alpha, \overline{\theta}^{\dot\beta})$. An infinitesimal supersymmetric transformation acts on Φ in the following manner

$$\Phi' - \Phi = \delta\Phi = i(\xi^\alpha Q_\alpha + \overline{\xi}_{\dot\alpha}\overline{Q}^{\dot\alpha})\Phi \; , \tag{40}$$

where ξ and $\overline{\xi}$ are Grassmann variables. Looking at the explicit form of the supersymmetric generators in eqs. (38)–(39), we could define also another set of independent generators:

$$D_\alpha = \frac{\partial}{\partial\theta^\alpha} + i(\sigma^\mu)_{\alpha\dot\alpha}\overline{\theta}^{\dot\alpha}\partial_\mu \tag{41}$$

and

$$\overline{D}_{\dot\beta} = -\frac{\partial}{\partial\overline{\theta}^{\dot\beta}} - i\theta^\beta(\sigma^\mu)_{\beta\dot\beta}\partial_\mu \; . \tag{42}$$

The D set is "orthogonal" to the Q set: in fact D_α and $\overline{D}_{\dot\beta}$ anticommute with Q_α and $\overline{Q}_{\dot\beta}$. So if we impose the condition $\overline{D}_{\dot\beta}\Phi = 0$ because of (40) also $\overline{D}_{\dot\beta}\Phi' = 0$ holds true. Such superfields are called *chiral superfields*. An analogy in the ordinary $\mathbb{R}^2$ space is the following: find a function $f(x,y)$ such that $[x(\partial/\partial y) - y(\partial/\partial x)]\, f(x,y) = 0$. Defining $r \equiv (x^2+y^2)^{1/2}$ any $f(r)$ will satisfy this condition.

Now if we call $y^\mu = (x^\mu + i\theta^\alpha(\sigma^\mu)_{\alpha\dot{\alpha}}\overline{\theta}^{\dot{\alpha}})$, which is a bosonic variable as x^μ and $\theta\theta'$ are such, the application of $\overline{D}_{\dot{\beta}}$ gives

$$\overline{D}_{\dot{\beta}}y^\mu = \left[-\frac{\partial}{\partial\overline{\theta}^{\dot{\beta}}} - i\theta^\beta(\sigma^\nu)_{\beta\dot{\beta}}\partial_\nu\right](x^\mu + i\theta^\alpha(\sigma^\mu)_{\alpha\dot{\alpha}}\overline{\theta}^{\dot{\alpha}}) =$$
$$-\frac{\partial}{\partial\overline{\theta}^{\dot{\beta}}}x^\mu - i\frac{\partial}{\partial\overline{\theta}^{\dot{\beta}}}\left[\theta^\alpha(\sigma^\mu)_{\alpha\dot{\alpha}}\overline{\theta}^{\dot{\alpha}}\right] - i\theta^\beta(\sigma^\nu)_{\beta\dot{\beta}}\partial_\nu x^\mu +$$
$$\theta^\beta(\sigma^\nu)_{\beta\dot{\beta}}\partial_\nu\theta^\alpha(\sigma^\mu)_{\alpha\dot{\alpha}}\overline{\theta}^{\dot{\alpha}} =$$
$$0 + i\theta^\alpha(\sigma^\mu)_{\alpha\dot{\beta}} - i\theta^\beta(\sigma^\mu)_{\beta\dot{\beta}} + 0 = 0\ . \tag{43}$$

A chiral superfield depends only on a two component spinor beyond the bosonic coordinate, $\Phi(y,\theta)$. Because of that and of Grassmann numbers properties we can form an object with at most two powers of θ, that is $\theta\theta$. Upper powers of θ vanish, so for a chiral superfield we have

$$\Phi(y,\theta) = \phi(y) + \sqrt{2}\theta\psi(y) + \theta\theta F(y)\ , \tag{44}$$

where ϕ and F are complex scalar fields, ψ a Weyl spinor. Expanding with Taylor (44) around x we obtain

$$\Phi(y,\theta) = \phi(x) + \sqrt{2}\theta\psi(x) + \theta\theta F(y) +$$
$$i\theta\sigma^\mu\overline{\theta}\partial_\mu\phi(x) - \frac{1}{2}\theta\sigma^\mu\overline{\theta}\theta\sigma^\nu\overline{\theta}\partial_\mu\partial_\nu\phi(x) + \sqrt{2}\theta i\theta\sigma^\mu\overline{\theta}\partial_\mu\psi(x)\ . \tag{45}$$

The conjugate of a chiral superfield, $\overline{\Phi}$, will satisfy the relation

$$D_\alpha\overline{\Phi} = 0\ , \tag{46}$$

and is called *antichiral superfield*.

The most general Lagrangian with two derivatives constructed from chiral superfields Φ_i is written as

$$\mathcal{L} = K(\Phi_i, \overline{\Phi}_j)\big|_{\theta^2\overline{\theta}^2} + W(\Phi_i)|_{\theta^2} + \overline{W}(\overline{\Phi}_i)\big|_{\overline{\theta}^2}\ , \tag{47}$$

where the subscripts denote the coefficients in power expansion of θ and $\overline{\theta}$. K is a real function, the *Kähler potential* (Kähler, 1933), W is a holomorphic function, the *superpotential*. We have the relations of integration over

Grassmann coordinates

$$\int \mathrm{d}^2\theta\, \mathrm{d}^2\overline{\theta}\; K \equiv K|_{\theta^2\overline{\theta}^2} \tag{48}$$

and

$$\int \mathrm{d}^2\theta\; W \equiv W|_{\theta^2} \ . \tag{49}$$

The Lagrangian (47) is renormalisable if and only if K is quadratic and W is at most a cubic function.

A standard example of a supersymmetric model is the Wess–Zumino model (Wess & Zumino, 1974), the first known supersymmetric interacting model. It is defined as

$$K = \overline{\Phi}\Phi \ , \quad W = \frac{m^2}{2}\Phi^2 + \frac{\lambda}{3}\Phi^3 \ , \tag{50}$$

where parameters m and λ are real. Plugging in the expansion of the superfield (45) we have

$$\mathcal{L} = \int \mathrm{d}^2\theta\, \mathrm{d}^2\overline{\theta}\; \overline{\Phi}\Phi + \int \mathrm{d}^2\theta \left(\frac{m^2}{2}\Phi^2 + \frac{\lambda}{3}\Phi^3\right) + \int \mathrm{d}^2\overline{\theta} \left(\frac{m^2}{2}\overline{\Phi}^2 + \frac{\lambda}{3}\overline{\Phi}^3\right) \ , \tag{51}$$

obtaining

$$\mathcal{L} = \overline{F}F + m\phi F + \lambda\phi^2 F - \frac{m}{2}\psi\psi - \lambda\phi\psi\psi + m\overline{\phi F} + \lambda\overline{\phi}^2\overline{F} - \frac{m}{2}\overline{\psi\psi} - \lambda\overline{\phi\psi\psi} + \text{ derivative terms acting on } \phi \text{ and } \psi \ . \tag{52}$$

The F field can be eliminated from equation of motion which reads

$$\frac{\partial\mathcal{L}}{\partial F} - \partial_\mu \frac{\partial\mathcal{L}}{\partial(\partial^\mu F)} = 0 = \frac{\partial\mathcal{L}}{\partial F} = \overline{F} + m\phi + \lambda\phi^2 \ . \tag{53}$$

So we obtain two equations

$$F = -m\overline{\phi} - \lambda\overline{\phi}^2 \ , \quad \overline{F} = -m\phi - \lambda\phi^2 \ . \tag{54}$$

Substituting this expressions for F and $\overline{F}$ into eq. (52) we eventually obtain

$$\mathcal{L} = -\partial_\mu\phi\partial^\mu\overline{\phi} + i\overline{\psi}\sigma^\mu\partial_\mu\psi - \frac{m}{2}(\psi^2 + \overline{\psi}^2) - \lambda\phi\psi^2 - \lambda\overline{\phi\psi}^2 -$$

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$$|m\phi - \lambda\phi^2|^2 \ . \tag{55}$$

This is the Lagrange for ϕ^4 theory of a massive complex scalar coupled with Yukawa interactions to a massive two component Weyl spinor ψ. As we have already discussed, a consequence of supersymmetry is that the scalar and spinor masses are equal.

Supersymmetry transformations we have seen are global. When they are combined with general relativity and become local, we have *supergravity* or SUGRA for short (Kähler, 1933; Volkov & Soroka, 1973; Gol'fand & Likhtman, 1971; Nath & Arnowitt, 1975; Gol'fand & Likhtman, 1989). This theory has become less popular after meeting various shortcomings, among others having an unrealistically large cosmological constant and gauge anomalies (Fabiano, 2022).

There are many existing supersymmetric theories. In particle physics, the MSSM has been extensively searched for, in particular at Cern with the Large Hadron Collider - LHC - for years, without even a hint of new observed phenomena. The lack of experimental evidence, united to the absence of indications for a new energy scale beyond the electroweak model to search for, have ruled out some supersymmetric extensions to the Standard Model, and, albeit supersymmetry has not been completely excluded as a theory, those facts are responsible for the decline towards the interest in the subject.

References

Berezin, F.A. 1966. *The Method of Second Quantization, 1st edition*. New York, London: Academic press. ISBN-13: 978-0120894505.

Fabiano, N. 2022. Anomalies in quantum field theories. *Vojnotehnički glasnik/Military Technical Courier*, 71(1), pp.100-112. Available at: https://doi.org/10.5937/vojtehg71-38164.

Fabiano, N. 2021. Quantum electrodynamics divergencies. *Vojnotehnički glasnik/Military Technical Courier*, 69(3), pp.656-675. Available at: https://doi.org/10.5937/vojtehg69-30366.

Fayet, P. 1975. Supergauge invariant extension of the Higgs mechanism and a model for the electron and its neutrino. *Nuclear Physics B*, 90, pp.104-124. Available at: https://doi.org/10.1016/0550-3213(75)90636-7.

Fayet, P. 1977. Spontaneously broken supersymmetric theories of weak, electromagnetic and strong interactions. *Physics Letters B*, 69(4), pp.489-494. Available at: https://doi.org/10.1016/0370-2693(77)90852-8.

Fayet, P. 1976. Supersymmetry and weak, electromagnetic and strong interactions. *Physics Letters B* Volume 64, Issue 2, Pages 159-162. Available at: https://doi.org/10.1016/0370-2693(76)90319-1.

Fayet, P. & Ferrara, S. 1977. Supersymmetry. *Physics Reports*, 32(5), pp.249-334. Available at: https://doi.org/10.1016/0370-1573(77)90066-7.

Gervais, J.-L. & Sakita, B. 1971. Field theory interpretation of supergauges in dual models. *Nuclear Physics B*, 34(2), pp.632-639. Available at: https://doi.org/10.1016/0550-3213(71)90351-8.

Gol'fand, Yu.A. & Likhtman, E.P. 1971. Extension of the algebra of the Poincare group generators and violation of P invariance. *JETP Letters*, 13(8), pp.452-455 (in Russian) [online]. Available at: http://jetpletters.ru/ps/717/article_11110.shtml [Accessed: 20 September 2022]. (In the original: Гольфанд Ю.А. и Лихтман Е.П. 1971. Расширение алгебры генераторов группы Пуанкаре и нарушение P-инвериантности. *Письма в ЖЭТФ*, 13(8), стр.452-455 [онлайн]. Доступно на: http://jetpletters.ru/ps/717/article_11110.shtml [Дата обращения: 20 Сентябрь 2022].)

Gol'fand, Yu.A. & Likhtman, E.P. 1989. Extension of the algebra of Poincaré group generators and violation of p invariance. In: Salam, A. & Sezgin, E. (Eds.) *Supergravities in Diverse Dimensions Commentary and Reprints (In 2 Volumes)*. Singapore: World Scientific. Available at: https://doi.org/10.1142/9789814542340_0001.

Grassmann, H. 1844. *Die Lineale Ausdehnungslehre – Ein neuer Zweig der Mathematik* (in German). Leipzig: Verlag von Otto Wigand [online]. Available at: https://gdz.sub.uni-goettingen.de/id/PPN534901565 [Accessed: 20 September 2022].

Kähler, E. 1933. Über eine bemerkenswerte Hermitesche Metrik. *Abh.Math.Semin.Univ.Hambg.*, 9, pp.173-186. Available at: https://doi.org/10.1007/BF02940642.

Nath, P. & Arnowitt, R. 1975. Generalized super-gauge symmetry as a new framework for unified gauge theories. *Physics Letters B*, 56(2), pp.177-180. Available at: https://doi.org/10.1016/0370-2693(75)90297-X.

Ramond, P. 1971. Dual Theory for Free Fermions. *Physical Review D*, 3(10), pp.2415-2418. Available at: https://doi.org/10.1103/PhysRevD.3.2415.

Volkov, D.V. & Akulov, V.P. 1972. Possible Universal Neutrino Interaction. *JETP Letters*, 16(11), pp.438-440 [online]. Available at: http://jetpletters.ru/ps/1766/article_26864.shtml [Accessed: 20 September 2022].

Volkov, D.V. & Akulov, V.P. 1973. Is the neutrino a goldstone particle? *Physics Letters B*, 46(1), pp.109-110. Available at: https://doi.org/10.1016/0370-2693(73)90490-5.

Volkov, D.V. & Akulov, V.P. 1974. Goldstone fields with a spin one half. *Teor. Mat. Fiz.*, 18(1), pp.39-50 (in Russian).

Volkov, D.V. & Soroka, V.A. 1973. Higgs effect for Goldstone particles with spin 1/2. *JETP Letters*, 18(8), pp.529-532 [online]. Available at: http://jetpletters.ru/ps/1568/article_24038.shtml [Accessed: 20 September 2022].

Wess, J. & Zumino, B. 1974. Supergauge transformations in four dimensions. *Nuclear Physics B*, 70(1), pp.39-50. Available at: https://doi.org/10.1016/0550-3213(74)90355-1.

Суперсимметрия

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РУБРИКА ГРНТИ: 29.05.03 Математические методы теоретической физики,
29.05.23 Релятивистская квантовая теория. Квантовая теория поля
29.05.33 Электромагнитное взаимодействие
ВИД СТАТЬИ: обзорная статья

Резюме:

Введение/цель: Суперсимметрия — это симметрия лагранжиана, выходящая за пределы Группы Ли. Это позволяет обмениваться бозонами и фермионами. Большинство важной моделью является минимальная суперсимметричная стандартная модель или MSSM.

Методы: Алгебра суперзарядов, суперполя, числа Грассмана, интеграл Березина.

Результаты: Суперсимметричные преобразования глобальны, они не зависят от координат пространства-времени. В случае Супергравитации они локальны.

Выводы: Суперсимметричные модели и, в частности, MSSM могли бы описывать больше физики. и больше частиц за пределами Стандартной модели.

Ключевые слова: суперсимметрия, минимальная суперсимметричная стандартная модель.

Суперсиметрија

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ОБЛАСТ: физика
КАТЕГОРИЈА (ТИП) ЧЛАНКА: прегледни рад

Сажетак:

Увод/циљ: Суперсиметрија је симетрија Лагранжиана која у опису симетрија иде даље од Лијевих група. Суперсиметрија омогућава размену бозона и фермиона. Најважнији модел је минимални суперсиметрични стандардни модел, или MSSM.

Методе: Алгебра супернабоја, суперпоља, Грасманови бројеви, интеграл Березина.

Резултати: Суперсиметричне трансформације су глобалне, не зависе од просторно-временских координата. У случају супергравитације, оне су локалне.

Закључак: Суперсиметрични модели, а посебно MSSM, могли би унапредити опис физике честица у односу на стандардни модел.

Кључне речи: суперсиметрија, минимални суперсиметрични стандардни модел.

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