BRANES IN STRING THEORY

D.P. Sorokin

INFN, Sezione di Padova & Dip. di Fisica, Università degli Studi di Padova, Padova, Italia;
e-mail: Sorokin@pd.infn.it;
Departamento de Física Teórica, Universidad de Valencia, Valencia, España

We give a simple overview of some basic aspects of the dynamics of branes in string theory and of their role in the attempts to get from String Theory a realistic model of fundamental interactions of elementary particles.

PACS: 11.25.Hf, 04.65.+e, 11.10.Kk, 11.30.Pb

1. INTRODUCTION

To avoid the confusion about the meaning of the word *Branes*, let me note from the beginning that this contribution is basically not about the Great Brains working in String Theory, but rather about some products of their mind, called *Branes*. The word *brane* is a derivative of the mem*brane*, which is a 2-dimensional surface. It stands for higher dimensional solitonic objects which appear in String Theory.

Modern String Theory has by now become the most powerful candidate on the role of the Unified Theory of fundamental interactions of elementary particles (electromagnetic, weak, strong and gravitational). A particular feature of this theory is that its quantum consistency requires that it should be formulated in space-time of dimension 10 or even 11. The eleven-dimensional extension of String Theory is called M-Theory. So the space-time in which String/M-theory lives has 6 or 7 extra spatial dimensions in comparison with our (3+1)-dimensional space-time. Thus, String Theory is a modern realization of an old idea of Norstrom (1914), Kaluza (1921) and Klein (1927) [1] that our World may have extra dimensions which can give the geometrical origin to the observable forces in Nature such as the electromagnetic interactions. A reason why these extra dimensions are invisible is that they are very small. One of the first mechanisms which explained why and how the extra dimensions are compactified was proposed in Kharkov by Volkov and Tkach in 1980 [2]. Using this mechanism it was shown [3] that a low energy field theoretical limit of String Theory called Type IIA D=10 supergravity can be compactified down to a four dimensional effective theory with a gauge symmetry SU(3)xSU(2)xU(1) similar to that of the Standard Model of elementary particles. Modern compactification machinery aimed at getting from String Theory all details of the Standard Model is much more complex (see [4] and also [5] for a review of modern trends) and the Volkov-Tkach mechanism is a part of it.

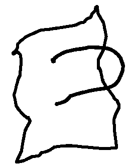
String Theory contains a large variety of physical objects:

- Fields: scalars (axion and dilaton), vector and tensor gauge fields, gravity, fermions and massive higher spin fields with $2 < s < \infty$.
- Dynamical (solitonic) objects:
  - particles (0-branes);
  - strings (1-branes);
  - membranes (2-branes);
  - *p*-branes (*p*=0,1,$\cdots$,9), where p counts the number of spatial dimensions.
- Other (more exotic) objects like D-instantons with $p = -1$, Kaluza-Klein monopoles, orientifold planes, etc.

2. BRANES AND THEIR WORLDS

Branes play an important role in String Theory [4-7]. E.g. the vibrations of fundamental strings (open and closed 1-branes) produce the perturbative sector of String Theory associated with fields which include a low energy limit of String Theory described by 10-dimensional supergravities.

Another important class of brains is formed by Dirichlet p-branes (D-branes). These are spatial surfaces on which open fundamental strings can end (string endpoints can move only along the brane, i.e. they satisfy the Dirichlet boundary condition, giving the name for these branes).



String endpoints (like charged particles) induce on the Dp-brane a vector gauge field. The surface can fluctuate and move in ambient 10-dimensional space-time (called bulk). The fluctuations of the brane orthogonal to its surface are described by scalar fields on the brane worldvolume. Thus, some string fields are trapped on the p-brane of 10D space-time and give rise to an effective field theory on the brane worldvolume.

It is tempting to associate the origin of our 4D space-time Universe with a stack of D3-branes (3-dimensional surfaces) interacting with other kinds of branes and fields in 10D bulk and which under certain conditions have acquired properties similar to the Standard Model of elementary particles.

To prove that such a point of view on the nature of our Universe indeed has physical grounds is one of the challenges of String Theory as a unified theory of fundamental interactions which strives to explain why our world is as it is. To reach this goal one should study various intertwining aspects of String Theory and in particular to understand in detail the dynamics of branes and their role in the possible formation of a universe with physical properties similar to our world (4 fundamental interactions: electro-weak, strong and gravity, (at least) three generations of elementary particles, CP-violation, spontaneous symmetry breaking, small gravitational and cosmological constant, dark matter etc.). A variety of phenomenological models having a brany origin have been proposed [7,5] and named Brane Worlds (see also [8] and references therein for earlier attempts in this direction).

In this contribution I will discuss only very basic things regarding the dynamics of branes, and will try to show that indeed branes can carry enough fields with phenomenologically relevant properties.

3. P-BRANE DYNAMICS IN 10D BULK

The description of brane dynamics is based on the action principle, which generalizes that of the relativistic massive point-like particle. Moving in space-time parametrized by coordinates x^M (M=0,1…,9) a particle draws a worldline $x^M(\tau)$ parametrized by the time-like coordinate τ. From the geometrical point of view a natural candidate on the role of the particle action is the length element of the worldline from its initial to the final point

$$S = m\int d\tau\sqrt{-\partial_\tau x^M \partial_\tau x^N g_{MN}(x(\tau))}, \qquad (1)$$

where m is the particle mass and $g_{MN}(x)$ is the space-time metric, i.e. the gravitation field with which the particle interacts in a geometrical way. If the particle carries an electric charge e, its interaction with the electromagnetic field $A_M(x)$ is described by the minimal coupling term $e\int dx^M A_M(x(\tau))$. Then the action takes the form

$$S = m\int d\tau\sqrt{-\partial_\tau x^M \partial_\tau x^N g_{MN}(x(\tau))} + e\int dx^M A_M(x(\tau)). \qquad (2)$$

The action is invariant under the arbitrary reparametrization of the worldline coordinate $\tau'=f(\tau)$, under the general coordinate transformations of space-time coordinates $x'^M=f^M(x)$ and (up to a total derivative) under the electromagnetic field gauge transformations $\delta A_M = \partial_M \alpha(x)$.

In the same way, a p-brane (i.e. a spatial surface of dimension p) moving in space-time sweeps a $(p+1)$-dimensional surface $x^M(\xi)$ called brane worldvolume and parametrized by $p+1$ "internal" coordinates ξ^m (m=0,1,…p). From the geometrical point of view the action integral is proportional to the area of the worldvolume, with the proportionality coefficient being the brane tension T,

$$S = T\int d^{p+1}\xi\sqrt{-\det\partial_m x^M \partial_n x^N g_{MN}(x)}. \qquad (3)$$

As in the case of the particle, the p-brane may carry an "electric" charge and minimally couple to a tensor analog of the electromagnetic field described by the antisymmetric tensor field $A_{M_1\cdots M_{p+1}}(x)$ of rank p+1. Then the action (3) is extended by the corresponding coupling term and takes the form

$$S = T\int d^{p+1}\xi\sqrt{-\det\partial_m x^M \partial_n x^N g_{MN}(x)} + e\int dx^{M_1}\cdots dx^{M_{p+1}} A_{M_1\cdots M_{p+1}}(x). \qquad (4)$$

The brane action (4) is invariant under the worldvolume reparametrization $\xi'^m=f^m(\xi)$, the space-time general coordinate transformations $x'^M=f^M(x)$ and under the gauge transformations $\delta A_{p+1}(x) = d\alpha_p(x)$, with the parameter α_p being an antisymmetric tensor of rank p (or a differential p-form).

We see that, from the point of view of the observer living on the brane, the action (4) describes an effective (p+1)-dimensional field theory with $x^M(\xi)$ (M=0,1…,9) being the worldvolume *scalar* fields. The fields are scalar since from the worldvolume space-time point of view the indices M correspond to an *internal* space.

Let us now consider what are the physical fields of this theory using the example of a 3-brane, (so in (4) we take p=3). We can split 10 coordinate fields $x^M(\xi)$ in four ones $x^m(\xi)$ $(m = 0,1,2,3)$ which correspond to coordinates along the brane worldvolume and other six $x^i(\xi)$ which are orthogonal to the brane

$$x^M(\xi) = \left(x^m(\xi), x^i(\xi)\right), \quad m = 1,2,3; \quad i = 1,...6. \qquad (5)$$

Using the worldvolume reparametrization invariance we can identify ξ^m with x^m ($\xi^m = x^m$). In this, so called static gauge, the remaining fields $x^i(\xi)=:\varphi^i(\xi)$ are the independente physical scalar fields of the worldvolume theory taking values in the vector representation of the group SO(6). This reflects the fact that the 3-brane breaks the Lorentz symmetry SO(1,9) of the 10D flat space-time down to its subgroup SO(1,3)xSO(6). Ten-dimensional Poincaré transflations are also spontaneously broken by the 3-brane down to 4D translations along the worldvolume, the scalars $\varphi^i(\xi)$ being six Goldstone fields corresponding to the broken translation symmetry.

In the static gauge (and in flat 10D space-time without the gauge field A_{p+1}) the 3-brane action (4) takes the form

$$S = T\int d^4\xi\sqrt{-\det(\eta_{mn} + \partial_m\varphi^i\partial_n\varphi^i)} \approx TV_4 - T\int d^4\xi(\frac{1}{2}\partial_m\varphi^i\partial^m\varphi^i + (\partial_m\varphi^i\partial_n\varphi^i)^2 + \cdots),$$

where V_4 is the area of the static 3-brane worldvolume (its contribution to the classical action plays no role). We see that the action for the scalar fields $\varphi^i(\xi)$ contains the standard kinetic term and an infinite series of terms describing non-linear self-interactions of the scalar fields.

So the brane carries scalar Goldstone fields, but these are not sufficient at all for phenomenological applications. Therefore, a natural question arises whether a brane can carry other types of fields such as vector gauge fields and fermions?

4. DIRICHLET 3-BRANE WITH BORN-INFELD GAUGE FIELD

As we have already mentioned, the gauge field is induced on the Dirichlet brane by the end point of the string. String computations showed that the world-volume dynamics of this field is governed by the action proposed many years ago by Born and Infeld [9] to describe a non-linear generalization of electrodynamics.

Thus, in the presence of the vector field the D3-brane action (4) gets generalized to the following one

$$\begin{aligned} S = T\int d^4\xi\sqrt{-\det(\partial_m x^M \partial_n x^N g_{MN}(x) + F_{mn}(\xi))} \\ + e\int [dx^{M_1} \cdots dx^{M_4} A_{M_1\cdots M_4}(x(\xi)) \\ + dx^M dx^N d\xi^m d\xi^n A_{MN}(x(\xi))F_{mn}(\xi) \qquad (6) \\ + \frac{1}{2} d\xi^{m_1} \cdots d\xi^{m_4} F_{m_1m_2}(\xi)F_{m_3m_4}(\xi)C_0(x(\xi))], \end{aligned}$$

where now, because of the presence of the generalized field strength of the worldvolume gauge field $F_{mn} = \partial_m A_n(\xi) - \partial_n A_m(\xi) + \partial_m x^M \partial_n x^N B_{MN}$, the D3-brane couples not only to the bulk gravity and the 4-rank gauge field $A_{M_1\cdots M_4}(x)$ but also to the 2-rank gauge fields B_{MN}(x) and $A_{MN}(x)$, and to the scalar (axion) field $C_0(x)$.

Note that when the 10D background fields are zero, in the quadratic approximation in F_{mn} the action (6) reduces (up to a constant term) to the Maxwell action

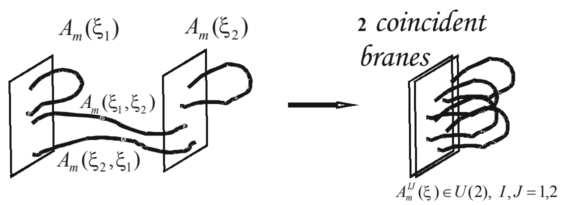
$$S = -\frac{1}{4}\int d^4\xi\sqrt{-\det g_{mn}}F_{mn}F^{mn},$$

where $g_{mn}=\partial_m x^M \partial_n x^N g_{MN}(x)$ is the induced metric on the 3-brane worldvolume.

5. MULTIPLE D-BRANES AND THE APPEARANCE OF NON-ABELIAN FIELDS

In the previous example the D3-brane carried an Abelian gauge field. But in our strive for getting the Standard Model on the brane, we should understand how a *non-Abelian* gauge structure may arise which might give rise to SU(3)xSU(2)xU(1) symmetry.

As was demonstrated by Witten [10], the Yang-Mills type interactions between worldvolume gauge fields arise when several parallel Dirichlet branes, on which strings end in all possible ways, approach each other and coincide. For instance, if we have two D-branes there are four possibilities of how strings can end on them. They are shown in the picture



Two strings end on each of the branes and two strings connecting the branes differ by orientation. These four strings give rise to four different gauge fields which, when the branes coincide, combine into a Yang-Mills field with U(2) gauge symmetry. In the case of N coincident Dirichlet branes their gauge fields acquire U(N) gauge symmetry which for N large enough may contain SU(3)xSU(2)xU(1) as a subgroup.

The action describing the dynamics of the non-Abelian worldvolume gauge fields is a highly non-trivial generalization of the Born-Infeld action (6) and its description is far beyond the scope of this article.

6. FERMIONS ON THE BRANE

Let us now consider how fermionic fields appear on the brane worldvolume. This happens because String Theory is supersymmetric. So all bosonic fields of the theory have their fermionic superpartners and vice versa. Here it is the appropriate point to mention that among the pioneer papers on supersymmetry [11-13] the work of Kharkov theorists Volkov and Akulov [12], who proposed a field theoretical model with spontaneously broken supersymmetry, turned out to be directly related to the structure of the fermionic sector of the supersymmetric brane action.

To make supersymmetry manifest, one formulates supersymmetric theory in a generalized space-time whose bosonic directions x^M are enlarged with fermionic directions parametrized by Grassmann-odd spinor coordinates θ^α. In the case of ten-dimensional String Theory there are 32 Grassmann-odd coordinates (α=1,…,32). The generalized space-time parametrized by the supercoordinates $Z^{\mathcal{A}}=(x^M,\theta^\alpha)$ is called *superspace*. The (rigid) supersymmetry transformations act on the superspace coordinates as follows

$$\delta\theta^\alpha = \varepsilon^\alpha,\ \delta x^M = -i\bar{\varepsilon}\gamma^M\theta, \qquad (7)$$

where ε^α is the supersymmetry parameter and γ^M are the 10D Dirac matrices.

The branes are assumed to move in the superspace, so its worldvolume in superspace is parametrized by coordinate functions $Z^{\mathcal{A}}(\xi^m)=(x^M(\xi^m),\theta^\alpha(\xi^m))$ of the worldvolume parameters ξ^m. Thus, $x^M(\xi^m)$ play the role of bosonic scalar worldvolume fields (as we have already seen), and $\theta^\alpha(\xi^m)$ are the fermionic fields.

The supersymetry invariant action for a D3-brane moving in flat superspace has the following form

$$\begin{aligned} S = T\int d^4\xi\{-\det[(\partial_m x^M + i\partial_m\bar{\theta}\gamma^M\theta) \\ \times(\partial_n x^N + i\partial_n\bar{\theta}\gamma^N\theta)\eta_{MN} + F_{mn}(\xi)]\}^{1/2} \\ + T\int [dZ^{A_1} \cdots dZ^{A_4} A_{A_1\cdots A_4}(Z(\xi)) \\ + dZ^A dZ^B d\xi^m d\xi^n A_{AB}(Z(\xi))F_{mn}(\xi) \qquad (8) \\ + \frac{1}{2} d\xi^{m_1} \cdots d\xi^{m_4} F_{m_1m_2}(\xi)F_{m_3m_4}(\xi)C_0(Z(\xi))], \end{aligned}$$

where $A_{\mathcal{A}_1\cdots\mathcal{A}_4}(Z)$, $A_{\mathcal{AB}}(Z)$, $C_0(Z)$ and $B_{\mathcal{AB}}(Z)$ (contained in F_{mn}) are *superfields* depending on the superspace coordinates $Z^{\mathcal{A}}$, and $dx^M + id\bar{\theta}\gamma^M\theta$ is the Volkov-Akulov supersymmetry invariant differential form. Note that the "electric" charge of the brane (in front of the second integral of (8)) is taken to be equal to the D3-brane tension. This is a requirement of a local fermionic symmetry (called kappa-symmetry) under which the D-brane action (8) is invariant.

Before discussing this symmetry in more detail let us note that if in Eq. (8) we put to zero the fields $A_{\mathcal{A}1\cdots\mathcal{A}4}$(Z), $A_{\mathcal{A}\mathcal{B}}$(Z), C_0(Z) and $F_{mn}(\xi)$, impose the static gauge explaind below Eq. (5) and assume that the D3-brane does not fluctuate in transverse directions, the action (8) reduces to

$$S_{VA} = T\int d^4\xi \Big\{ -\det(\delta_m^M + i\partial_m\bar{\theta}\gamma^M\theta) \times(\delta_n^N + i\partial_n\bar{\theta}\gamma^N\theta)\eta_{MN}\Big\}^{1/2}, \quad (9)$$

which is the Volkov-Akulov action for a Goldstone fermion field proposed in 1972 [12].

The fermionic fields on the brane are indeed the Volkov-Akulov Goldstones associated with half of ten-dimensional supersymmetry which is spontaneously broken by the presence of the brane.

7. KAPPA-SYMMETRY

This symmetry, which was first found in actions for supersymmetric particles [14, 15], is a fundamental ingredient of all super-branes. Under the kappa-transformations the superspace coordinates transform in the following way:

$$\delta\theta^\alpha = \kappa^\beta(\xi)(1+\bar{\Gamma})_\beta{}^\alpha, \quad \delta x^M = i\delta\bar{\vartheta}\gamma^M\theta, \quad \delta\mathcal{A}_m(\xi)\neq 0,$$

$\frac{1}{2}(1+\bar{\Gamma})_\beta{}^\alpha$ being a projector matrix, which allows one to eliminate half of $\theta^\alpha(\xi)$.

Note that the Born-Infeld vector field is also transformed under kappa-symmetry. Note also that the form of the kappa-symmetry transformations for x^M is similar to the supersymmetry transformations, but with the sign + instead of –, *i.e.* x^M is kappa-transformed in the opposite direction.

In the case of the Dp-branes the matrix $\bar{\Gamma}$ has the following form

$$\bar{\Gamma} = \frac{1}{(p+1)!\sqrt{-\det(g+F)}}\varepsilon^{m_0\cdots m_p} \times(\gamma_{m_0}\cdots\gamma_{m_p} + F_{m_0m_1}\gamma_{m_2}\cdots\gamma_{m_p} + \cdots)$$

where +· stands for higher order terms in powers of F_{mn}, γ_m are ten-dimensional Dirac matrices projected (pulled-back) onto the (p+1)-dimensional worldvolume, and the square root of the determinant in the denominator is the Dirac-Born-Infeld term of the supersymmetric generalization of the D-brane action (6).

Notice that the form of $\bar{\Gamma}$ in the kappa-symmetry projector exactly simulates the form of the second integral (so called Wess-Zumino term) of the D-brane action (8) whose schematic form is

$$L_{WZ} = A_{p+1} + A_{p-1}F_2 + \frac{1}{2}A_{p-3}F_2F_2 + \cdots$$

To construct $\bar{\Gamma}$ one should just replace the r-rank fields A_r with the corresponding antisymmetric products of r Dirac matrices γ_m.

Kappa symmetry implies the following properties of supersymmetric p-branes:

- Brane tension T is related to the "electric" charge *e* [An example of the brane for which T and *e* are related already in the purely bosonic case is the 5 brane of M-theory. It is required by the self-duality of the M5-brane tensor gauge field [16]];
- The brane ground state, being supersymmetric, has a minimal energy and is *stable* (so called BPS-state). The gravitational force between two static branes is compensated by their "electric" repulsion.
- The superbrane breaks half of the supersymmetries of the space-time background and its effective worldvolume field theory is supersymmetric with equal number of bosonic $x^i(\xi)$, $A_m(\xi)$ and fermionic $\theta^\alpha(\xi)$ fields.

We should note that the fermionic fields on a *single* brane considered above are not exactly the ones which we could associate with the fermionic fields of the Standard Model. The latter are in the chiral representation of SU(2). In phenomenologically relevant brane models chiral fermions appear at intersections of several branes (see [5] for a review).

8. SUMMARY AND HOPES

I have tried to demonstrate that branes may carry on their worldvolume enough fields to reproduce elementary particles of the Standard Model. It gives a hope to explain within a brane framework all main features of the fundamental interactions of elementary particles.

The worldvolume gauge fields are those of the Yang-Mills type and their symmetry may include the group SU(3)xSU(3)xU(1) and chiral fermions arise at brane intersections. So multiple intersecting branes may explain why the matter is chiral, i.e. asymmetry between the right-handed and left-handed fermions in each generation of elementary particles.

Effective field theory on the brane is supersymmetric. So it may provide a version of the supersymmetric extension of the Standard Model and may give a solution to the Hierarchy Problem, *i.e.* explain why the energy scale of the electro-weak symmetry breaking is so small in comparison with the Grand Unification scale?

Phenomenological models provided to us by String Theory also predict a number of new phenomena. For instance, *supersymmetry and extra dimensions* of space-time are inherent features of string theory required by its quantum consistency, so their existence should manifest itself in new particles (e.g. supersymmetric partners and Kaluza-Klein particles) and/or in non-conservation of the 4D energy-momentum due to its flow in extra dimensions (orthogonal to the brane).

These (and other) phenomena will be tested at experiments on the new **L**arge **H**ardron **C**ollider (LHC) to be put into operation at CERN (Genève) in 2007.

Whatever results of these experiments are, they will be certainly crucial for the trends in which the Unified Theory of Fundamental Interactions will develop. So we are living in an interesting time of the eve of great events and possible crucial changes in the minds of our brains and may be even in our "brane" world.

ACKNOWLEDGEMENTS

This work was partially supported by research grants of the Ministerio de Educación y Ciencia (FIS2005-02761) and EU FEDER funds, the Generalitat Valenciana (ACOMP06/187, GV05/102), the EU MRTN-CT-2004-005104 grant "Forces Universe", by the INTAS Research Grant 2005-2006-7928, by the MIUR-PRIN-2005 contract and by INFN Special Initiative TS11. I would like to thank the MEC of Spain for the sabbatical grant, and Jose de Azcárraga and Igor Bandos for warm hospitality extended to me in Valencia.

REFERENCES

1. G. Nordstrom //*Z. Phys*. 1914, v.15, p. 504; Th. Kaluza //Sitzungsber. Preuss. Akad. Wiss. Berlin, Math Phys 1921, K v. p. 966; O. Klein //*Z. Phys*. 1926, v. 37 p. 895.
2. D.V. Volkov, V.I. Tkach. On spontaneous compactification of space for Einstein field interaction with gauge fields //*Pisma Zh. Eksp. Teor. Fiz.* 1980, v. 32, p. 681-684.
3. D.V. Volkov, D.P. Sorokin, V.I. Tkach. Mechanisms of spontaneous compactification of N=2, D = 10 supergravity //*JETP Lett.* 1983 v. 38, p. 481-485.
4. M.B. Green, J.H. Schwarz, E. Witten. *Superstring Theory.* Cambridge: "Cambridge University Press", 1987, v. 1, p. 469, v. 2, p. 596.
5. R. Blumenhagen, B. Kors, D. Lust, S. Stieberger. *Four-dimensional string compactifications with D-branes, orientifolds and fluxes*, hep-th/0610327.
6. C.V. Johnson. *D-branes*. Cambridge: "Cambridge University Press", 2003, p. 548.
7. L. Randall. *Warped Passages: Unraveling the Mysteries of the Universe's Hidden Dimensions.* New York: "Harper Collins Publishers", 2005, p. 512.
8. I.A. Bandos. String-like description of gravity and possible applications for F-theory //*Mod. Phys. Lett.* 1997, v. A12, p. 799.
9. M. Born, L. Infeld. Foundations of the new Field Theory //*Roc. Roy. Soc.* 1934, v. A144, p. 425; On the quantization of the new field equations //*Roc. Roy. Soc*. 1934, v. A147, p. 522; 1935, v. A150, p. 141.
10. E. Witten. Bound states of strings and p-branes //*Nucl.Phys.* 1996 v. B460, p. 335-350.
11. Yu.A. Golfand, E.P. Likhtman. Extension of the algebra of Poincaré group generators and violation of P invariance //*Pisma Zh. Eksp. Teor. Fiz*. 1971, v. 13, p. 452-455.
12. D.V. Volkov, V.P. Akulov. Possible universal neutrino interaction //*Pisma Zh.Eksp.Teor.Fiz*. 1972, v. 16, p. 621-624.
13. J. Wess, B. Zumino. Supergauge transformations in four-dimensions //*Nucl. Phys.* 1974, v. B70, p. 39-50.
14. J de Azcárraga, J. Lukierski. Supersymmetric particles with internal symmetries and central charges //*Phys. Lett.* 1982, v. B113, p.170.
15. W. Siegel. Hidden local supersymmetry in the supersymmetric particle action //*Phys. Lett.* 1983, v. B128, p. 397.
16. P. Pasti, D. Sorokin, M. Tonin. Covariant action for a D=11 five-brane with the chiral field //*Phys. Lett.* 1997, v. 398B, p. 41-46.

БРАНЫ В ТЕОРИИ СТРУН

Д.П. Сорокин

Настоящая работа представляет собой элементарный обзор основных свойств динамики релятивистских протяженных объектов (бран) в теории струн и их роли в построении на основе струнной теории, реалистических моделей фундаментальных взаимодействий элементарных частиц.

БРАНИ У ТЕОРІЇ СТРУН

Д.П. Сорокін

Робота являє собою елементарний огляд основних властивостей динаміки релятивістських протяжних об'єктів (бран) у теорії струн й їхньої ролі в побудові на основі струнної теорії, реалістичних моделей фундаментальних взаємодій елементарних часток.