ANNOTATION

dissertation for the degree of Doctor of Philosophy (PhD) in the specialty "6D060400 - Physics" Nurtayeva Galiya Kadyrkhanovna on the topic "**Thick brane solutions in multidimensional theory of gravity**"

General description of the research

The dissertation work presents the results of calculations of hypothetical astrophysical objects in modified 4-dimentional, multidimensional theories of gravity, such as: domain walls and thick branes.

Relevance of the topic

In the basic physical theories of GR and Maxwell's electrodynamics, regular solutions are significant. Regular solutions are those that have finite energy and for which the corresponding fields are finite in the entire space: in the center and at infinity, respectively. Such regular solutions in the above theories are quite rare. For example, we can consider solutions of black holes: all these solutions are singular: there is a singularity at the center of a black hole - a point mass, a point charge, and so on. Within the framework of CED and QED, it is impossible to obtain regular solutions without sources. The reason for this is the linearity of Maxwell's equations. Only electromagnetic waves are the only solutions to Maxwell's equations without sources.

To obtain regular solutions, it is most likely necessary that the field equations are nonlinear. Therefore, in the GR there is a possibility of obtaining regular solutions. In fact, such solutions exist, for example, for scalar fields: these are so-called bosonic stars. Other examples include objects such as domain walls, branes, and wormholes.

For the first time, solutions of domain walls appear in theories where the potential of the scalar field has isolated minimum. Under these conditions, the domain wall is the surface that separates the various minima of the scalar potential. In this case, the scalar field changes in space and tends to one minimum in one direction and to another minimum in the opposite direction. The region of rapid variation of the scalar field corresponds to a domain wall. In the thin-wall approximation, the change in the scalar field energy density is localized on the surface of the domain wall and is replaced by a delta-function. In the case when all fields are constant on each side i.e. they are in minima, domain walls are called vacuum domain walls.

Consideration of the theory of the brane world (n-dimensional hypersurfaces embedded in a multidimensional external space-time) has become an important direction in the studies of the modern Universe in recent years. Within the framework of the brane world theories it is possible to describe the hierarchy of masses of elementary particles, as well as to solve a number of other problems in the theory of elementary particles. At the same time, theories of this type are successfully applied in modeling of dark energy. Branes can play a significant role in QG.

Due to the above, it becomes necessary to study the solutions in modified theories of gravity describing domain walls and branes, since all their properties are **relevant** for understanding the properties of these astrophysical objects.

According to the above, the dissertation work is devoted to the study of domain walls and thick branes.

The work investigated the directions that cause the description of cosmological evolution in the framework of modified (extended) theories of gravity. In reviewing these theories, it is difficult to take preferred directions, since important approaches have varying degrees of research and acceptance.

Modified theories of gravity or alternative theories of gravity are theories generalizing Einstein's theory of gravity. The purpose of alternative theories is to describe gravity in the framework of the modified theory, with this proposal a better description of phenomena in cosmology, and also not to contradict the existing experimental data at the moment.

GR has a number of problems, so there are always several reasons to create a new theory or start testing old theories with new experimental data. Consequently, there are new possibilities to test or maybe generalize the theory of gravity made by A. Einstein in 1916.

The modified gravitational approach works very well for late acceleration of the universe and dark energy applications. The modified theory of gravity provides a gravitational alternative for dark energy i.e. it can serve as a unified explanation for dark matter. Some cosmological effects (for example, rotation curves of galaxies) can be explained in terms of modified gravity. Cosmic acceleration is simply explained by the fact that the Universe is expanding, where some subdominant terms (for example, 1/*R*) can become significant at low curvature.

Within the framework of this approach, it is possible to create a class of modified theories of gravity that extend the general theory of relativity, while retaining its positive features. They do not require the presence of unknown particles, which have not yet been found experimentally, but require a different type of action. With this approach, the Einstein - Hilbert gravitational action is modified, for example, by adding an arbitrary function of the scalar Ricci curvature $R - f(R)$. A combined approach can also be considered, assuming the presence of other physical fields (for example, a scalar field) participating in the dynamics. More complex constructions from the Ricci, Riemann and Weyl tensors, non-minimal interaction theory, can be used. You can also consider theories of gravity in space larger than four, etc. So that, *f(R)* - gravity attracts the most attention due to the fact that it looks simpler than modified theories of gravity, and can also be rewritten in the form of a scalar-tensor theory.

Modified theories of gravity are one of the competing models to explain the modern accelerated expansion of the Universe discovered in recent times. These theories are, apparently, the simplest geometric generalization of GR. They are based on replacing the Einstein-Hilbert Lagrangian R by an arbitrary function of the scalar curvature $f(R)$. From a mathematical point of view, field equations obtained by a modified action on a metric have a richer ability to use them, which

allows new processing methods to be applied.

In the dissertation work researches that were carried out in the framework of 4-dimentional and multidimensional modified theories of gravity, in which types of regular solutions for domain walls, thick branes are found were presented; and also a qualitative analysis of the obtained solutions was carried out.

Connection of the dissertation topic with the plans of scientific works

The dissertation work was carried out in accordance with the plans of fundamental research work (RW) Ministry of Education and Science of the Republic of Kazakhstan “Program-targeted financing of scientific research" on the topic: "Research of fundamental problems of physics of plasma and plasma-like media”, IRN of the program: BR05236730. (2017-2020, state registration number 0115РК02918, code 0263 / ПЦФ-14).

Objectives of the research:

Obtain and study in detail the regular solutions in modified theories of gravity, describing 4-dimensional domain walls in 4-dimensional and n-dimensional thick branes in D-dimensional space-times within the framework of modified theories of gravity type $f(R)$.

To achieve this goal, it is necessary to solve the following **tasks**:

- Using the equations of modified theory of gravity, obtain equations describing domain walls and thick branes in 4-dimensional and multidimensional cases;
- Based on the equations describing flat-symmetric 4-dimensional and multidimensional metrics in modified theories of gravity, obtain regular solutions describing domain walls and thick branes;
- Investigate the properties of domain walls and thick branes.

Object of the research. Modified theories of gravity and flat-symmetric solutions.

Subject of the research. Field equations of modified theories of gravity type $f(R)$.

Research methods. Numerical and analytical methods for studying nonlinear differential equations of modified theories of gravity describing domain walls and thick branes.

The novelty of the research. The novelty and originality of the research lies in the fact that **for the first time**:

- it has been obtained new flat-symmetric solutions in 4-dimentional and multidimensional modified theories of gravity;
- it has been investigated the properties of domain walls and thick branes in modified theories of gravity;
- it has been demonstrated that the possibility of the appearance of domain walls and thick branes in the modified theories of gravity is essentially determined by the form of the function $f(R)$.

Theoretical and practical significance of the research. Obtaining new regular solutions in gravitational theories is an interesting and necessary task for understanding the nature of gravity. Domain walls and thick branes are

hypothetical objects that may be discovered in the future. Therefore, the study of their properties is an important task in theoretical physics.

Provisions for Defense:

- All regular solutions to the equations derived from the modified theory of gravity for domain walls and thick branes in 4-dimensional and multidimensional cases have antidessiter asymptotics;

- Regular solutions of modified theory of gravity $f(R) = -\alpha R^n$ have a special point which located in its center and existing at the following parameters n: $1 < n < 2$;

- Regular vacuum solutions in the modified theory of gravity $f(R) = -\alpha R^n$ for D - branes with codim = 1 do not require the presence of matter.

The personal contribution of the author lies in the fact that the entire volume of the dissertation work, the choice of the research method, problem solving and numerical calculations were performed by the author independently. The setting of tasks and discussion of the results were carried out with the scientific advisers.

The reliability and validity of the obtained results. In the dissertation work, the well-known multidimensional modified theories of gravity and proven mathematical methods for numerical solutions of ordinary differential equations in the Wolfram Mathematica and Maple packages were used. The results obtained on the basis of numerical calculations are consistent with a qualitative study of the obtained differential equations, as well as with studies previously conducted by other authors. Also, the reliability and validity of the results obtained are confirmed by publications in non-CIS journals with high impact factors and in publications recommended by the Committee for Control in Education and Science of the Ministry of Education and Science of the Republic of Kazakhstan, and in the proceedings of international scientific conferences of the near and far abroad.

Approbation of dissertation work. The results obtained in the dissertation work were reported and discussed:

- at the International Conference "10th Alexander Friedman International Seminar on Gravitation and Cosmology and 4th Symposium on the Casimir Effect" (2019, Saint-Petersburg, Russia);

- at the International Conference "57th Workshop on Gravity and Cosmology" (2019, Jecheon, South Korea);

- at the International Scientific Conference "Abdildin's Readings: Topical Issues of Modern Physics" (2018, Almaty, Kazakhstan);

- at the International Scientific Conference of Students and Young Scientists "Farabi Alemi" (2018, 2019, Almaty, Kazakhstan);

- and also discussed with Professor Kim S.V. (Seoul, South Korea) in the framework of international cooperation.

Publications. Based on the materials of the dissertation work, 9 printed works were published: 3 - in journals from the List of KKSON MES RK for publishing the main results of dissertations for PhD degrees and 2 articles in journals from far abroad with high impact factor included in the international information resource

Web of Knowledge (Thomson Reuters, USA) and Scopus (Elsevier, Netherlands); 4 works in collections of International scientific conferences.

The volume and structure of the research. The dissertation work consists of the introduction, 4 chapters, a conclusion and the list of references contains 174 items, contains 94 pages of basic computer text, including 35 figures.

The main results of this work:

- It has been considered a class of modified theories of gravity, which expand GR, while retaining its positive features. In them, the gravitational action of Einstein-Hilbert is modified by adding an arbitrary function of the scalar Ricci curvature *R–f (R).*

- Theories of gravitation in spaces with dimensions higher than four are considered, etc. The most attention of them attracts *f (R)*- gravity due to the fact that it looks simpler than other modified theories of gravity, and can also be rewritten in the form of a scalar-tensor theory.

- It has been investigated 4-dimensional domain walls, 5- and 6-dimensional thick branes in $-\alpha R^n$gravity. Regular flat-symmetric solutions are obtained in vacuum for certain values of the parameter n and δ. The obtained solutions are of great interest, since they are vacuum solutions, in contrast to similar solutions in general relativity. As a result:

1) All regular solutions have AdS asymptotics.
2) While increasing parameters α, $n \to \infty$, the solutions tend to a certain limit, which is no longer dependent on the values of these parameters.
3) Not all values of the parameter n have solutions:

- if $n = (2p+1)/(2q+1)$, where p, q – are whole numbers, then the solution is regular for $x^N > 0$ and can be singular for $x^N < 0$;

- if the exponent n is an irrational number, then in the general case there are no solutions.

4) According to the equation $R_A^B - \frac{1}{2}\delta_A^B R = \hat{T}_A^B$, the right-hand side plays the role of the effective energy-momentum tensor $\hat{T}_{\mu\nu}$. It was shown that in this case the effective energy density T_0^0 is negative and its dependence on the values of the parameters $\gamma, \delta, \alpha, N$.

- Phase portraits for a 4-dimensional domain wall, 5 and 6-dimensional brane models, as well as a graph of scale factors were obtained. The obtained thick branes and domain wall solutions can become an interesting model for cosmological research.

- It is shown that regular solutions have a singular point located in the center of the brane. As follows from the analytical analysis of the behavior of solutions in this point, such point exists only for certain values of the parameter n i.e. $1 < n < 2$. In this case, the first three derivatives of the metric function *y* are equal to 0, which allows the brane to be placed directly at the singular point $z = z_{fp}$.

-The existence of a singular point ensures the presence of the flatsymmetric solutions, depending on the values of the parameters n was shown.

- It is shown that D-branes with codim = 1 can be obtained as regular

vacuum solutions in modified theories of gravity. This means that the presence of matter is not necessary for the construction of such D -branes.

To obtain all extended astrophysical objects obtained in this dissertation, modified theories of gravity were applied without using ordinary matter. The main advantage of these models is that the corresponding solutions are vacuum, in contrast to previously obtained solutions based on the use of matter.

The advantage of modified theories of gravity over GR is that they provide more freedom in finding a solution, which means that they make it possible to build cosmological models that are devoid of some of the shortcomings of GR.