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FEATURES OF THE FORMATION OF THE TRANSPORT DIALOGUE RUSSIA-INDIA-CHINA

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Abstract. *The authors consider the growing role of transport corridors and logistics interaction between the RIC countries - Russia, India and China, which is especially becoming relevant in the light of the expansion of BRICS to the BRICS + format and India's attempt to build, together with the United States, its own logistics route between Africa, the Middle East and Europe.*

Keywords: *Russia, China, India, USA, OBOR, BRICS+, Northern Sea Route, Northeast Russia, infrastructure, North, South, logistics, geo-economics.*

Cooperation between Russia, India and China in the field of transport has enormous potential and this can become the basic infrastructure of BRICS itself, in which the leadership ambitions of Russia and China are closely interconnected, the multi-vector nature of India, the decisive issue of membership in the UN Security Council and building an alternative to China's lobbying of the BRI and the Northern Sea Route, as his water insurance and a potential alternative in case of problems on land. Russia is a strategic transit point between Europe and Asia, India has access to the Indian Ocean and is a bridge to South Asia, and China is one of the largest economic centers in the world and is interested in a balance of interests while maintaining the primacy of its own advanced development in any

integration structures. This is due to the eternal rivalry between China and India both in Asia and for global markets, in which the main players should be the Brahmans, and not the communists of the Celestial Empire, by 2030, according to statistics and forecasts of UNCTAD and the UN.

The development of logistics infrastructure and transport links between these countries can create new transit routes, facilitate the safe and expedited movement of goods and stimulate the development of trade and economic ties. At the same time, planned joint investments in the development of common Eurasian transport infrastructure and the creation of international transport corridors between continents can contribute to the development of trade between Russia, India and China and strengthen their positions in the international arena, lobby for joint goods and services in innovative sectors such as NBICS and ICT -industry.

The development and modernization of transport infrastructure, including international transport corridors, provides opportunities to increase the volume of foreign trade between Russia, India and China, creating common approaches to the Asia-Pacific markets and taking into account national security interests between these states. By improving transport connectivity between these countries and due to the expected reduction in the delivery time of goods through international transport corridors, it becomes possible to increase the volume of trade transactions and improve access to markets for enterprises in each country, harmonizing the interaction of actors in these countries in the geo-economic zones of various preferences and industries, allowing step by step raise the quality standards of the "green agenda", promoting a more controlled decoupling between the US and China in the processes of leadership in the global digitalization of industries. The convergence of markets, resources and routes for the delivery of goods and services will determine the new framework of Industry 4.0 and will help strengthen their economic and political role in the international arena, as new "Asian" and "Eurasian" unicorn tigers.

Experts often mention as an example of an international transport strategy: the development of the international North-South transport corridor and its role in strengthening "Russia's turn to the South" [1] and in the concept of trans-Eurasian connectivity formed in the space of geographical priorities. Also, this ideology will allow one to take advantage of one of the main advantages of the North-South transport corridor, compared to other transport routes, including the deep-sea route through the Suez Canal, which will significantly reduce the delivery time of goods," especially in anticipation of the battle for Taiwan in Asia [2] This project is a 7,200 kilometer multimodal transport route that connects the Indian Ocean and Persian Gulf to the Caspian Sea via Iran and Northern Europe[1] [3].

[1] Vinokurov E. Yu., Akhunbaev A., Zaboev A. I. International North-South transport corridor: strengthening "Russia's turn to the South" and trans-Eurasian connectivity // Russian Journal of Economics. 2022. V. 8. pp. 159-173. DOI: 10.32609/j.ruje.8.86617.

However, despite the potential benefits, progress on the North-South transport corridor was initially greatly slowed by financial and technical difficulties associated with infrastructure construction[2]. Despite this, in recent years certain organizational and financial steps have been taken to promote this project.

The main directions of the transport strategy of the countries of the Russia-India-China dialogue include strengthening regional and global connections in Asia, as well as reviving the connectivity of the Silk Road. Experts emphasize the importance of physical, economic, human and digital connections in the region, their harmonization from the multiplication of infrastructure properties and the growing synergy of logistics and production solutions for all RIC countries simultaneously [4].

India, having historical ties with Eurasia through the Silk Road, continues to develop cooperation with the countries of Central Asia. It is important that "the Indian government is making efforts to maintain cooperation with the countries of Central Asia in the economic, trade, scientific and technical fields"[3]. This indicates India's desire to use its historical and cultural ties to strengthen economic and trade relations with these countries and become an outpost of Asian interests in the Asia-Pacific region [5].

Reviving the connectivity of the Silk Road is one of the main directions of the transport strategy of Russia, India and China. However, any economic benefits "are not a key goal" [4]. The study highlights the role of historical connections, the revival of the Silk Road and the importance of economic and political connections in achieving overall development in the region and improving its infrastructure.

Thus, the development of transport chains and the creation of international transport corridors through joint investments is becoming an important factor for the development of trade and strengthening the positions of Russia, India and China in the international arena and as stable actors in the field of movement of goods and the growth of transport traffic of various levels of saturation and intensity. This represents a strategic opportunity to strengthen cooperation and increase the influence of these countries in the global economy and politics [6].

[2] Vinokurov E. Yu., Akhunbaev A., Zaboev A. I. International North-South transport corridor: strengthening Russia's "turn to the South" and trans-Eurasian connectivity // Russian Journal of Economics. 2022. V. 8. pp. 159-173. DOI: 10.32609/j.ruje.8.86617.

[3] Mukhia, Anmol, and Xiaolong Zou. "Mapping India's (Re)Connection to Eurasia." Russia in Global Affairs 20, no. 2 (2022): 184-204. DOI: 10.31278/1810-6374-2022-20-2-184-204

[4] Mukhia, Anmol, and Xiaolong Zou. "Mapping India's (Re)Connection to Eurasia." Russia in Global Affairs 20, no. 2 (2022): 184-204. DOI: 10.31278/1810-6374-2022-20-2-184-204

Table 1.

Prospects for the development of transport infrastructure and transport connections

Russia	India	China
Railway communication		
A developed network of railways, including the Trans-Siberian Railway, provides effective transport links with China.	Wide network of railways within the country. Potential for developing links with China via the Trans-Himalayan railway route.	One of the most developed and largest railway networks in the world. Multiple borders with neighboring countries for cross-border connections.
Road traffic		
An extensive network of highways, including federal highways, provides transport links with India and China.	Large network of roads within the country. There is potential for the development of international road routes with Russia and China.	Large and developed network of roads. Many international road routes, including cross-border connections with Russia and India.
Maritime connections		
Extensive coastline with access to the Atlantic and Pacific seas. Developed seaports and shipping. Potential for developing maritime links with India and China.	Large coastline with access to the Indian Ocean. Developed seaports. Possibility of developing maritime connections with Russia and China.	Extensive coastline with access to the Pacific Ocean and the Yellow Sea. Developed seaports and shipping. There are already maritime connections with Russia and India.
Air communication		
Developed international airports in key cities. Potential for the development of direct aviation links with India and China.	Large network of domestic and international airports. There are direct aviation connections with Russia and China.	Large and developed network of domestic and international airports. Direct aviation links with Russia and India already exist.
Transport projects and initiatives		
Participation in the SCO Unified Transport System initiative. It is planned to develop railway, road and sea routes with India and China.	Participation in the International Northern Transport Corridor initiative. It is planned to develop railway and road connections with Russia and China.	Participation in the «One Belt, One Road» initiative. Development of railway, road and sea connections with Russia and India.

A study[5] of the potential and prospects for the development of transport infrastructure and transport links between Russia, India and China shows that each

[5] Belov (Yurtaev) V.I., Binish. India, Russia and Iran: a new reading of the international transport corridor "North-South" // Information and Innovation. 2021, V. 16, No. 4. p. 18-25. DOI: 10.31432/1994-2443-2021-16-4-18-25.

of these countries has strengths and potential for strengthening transport links. Russia has a developed railway network, including the Trans-Siberian Railway, as well as an extensive road network and access to sea routes. India has a large railway network, a wide coastline with developed seaports and the possibility of developing maritime connections. China, in turn, has one of the most developed and largest railway networks, an extensive network of highways and access to the seas. All three countries have the potential to develop international transport projects, such as the SCO Unified Transport System initiative and One Belt, One Road.

To form an effective transport strategy for the dialogue countries of Russia, India and China, it is necessary to take into account the characteristics of each country and their potential for interaction in the field of transport. It is important to establish priority areas of development, identify main projects and measures that promote cooperation and improve transport connections [7].

Therefore, possible recommendations, taking into account the above, could be as follows:

1. Promoting the development of international transport corridors connecting Russia, India and China, and creating favorable conditions for their functioning.

2. Increased investment in transport infrastructure and modernization of existing transport networks, including roads, railways, ports and airports.

3. Development of multimodal logistics centers and creation of effective logistics systems and transport connections.

4. Promoting cooperation in the field of technology and innovation in the transport sector, including digitalization and automation of processes.

5. Strengthening partnership and dialogue between dialogue countries, including the exchange of experience and transfer of knowledge in the field of transport and logistics.

The development of an effective transport strategy for the dialogue countries of Russia, India and China is of strategic importance for improving trade relations, expanding economic opportunities and increasing the competitiveness of these countries in the context of globalization. The implementation of joint projects and cooperation in the field of transport can create favorable conditions for the development and prosperity of all three countries of the dialogue, as well as strengthen their influence on the world stage, through the policies of “soft” and “smart” power [8].

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MULTI-COUNTRY INTEGRATED MODEL OF INVESTMENT RESOURCES FLOW

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Abstract. *This article reveals international economic aspects and trends, as well as their impact on the cross-border movement of capital and international investment resources. The article discusses the formation of a data-driven approach to the study of investment and economic data, the choice of complex mathematical methods of analysis for the study of trends in the world economy. The authors propose an economic and analytical integration model, which uses a two-level approach to the study of economic investment processes based on the developed mechanism for combining models that combine the "bottom-up" and "top-down" approaches.*

With the help of mathematical methods, the architecture of the platform has been formed, which allows forecasting macroeconomic indicators with the possibility of analyzing competitive factors of investment attractiveness of countries, trade policy and parameters of global capital movement. The proposed integration economic model can have practical application within the framework of the analytical tasks being formed. The characteristics of the model, flexibility and speed of adaptation to variable environmental parameters meet modern trends in the development of the world economy and solve the most pressing problems of players in the international market.

Keywords: *economic and mathematical modeling, macro forecasting, movement of investment resources, movement of capital, digital platform in the macroeconomic environment.*

The specifics of the movement of capital in cross-border markets are closely related to the economic course of the States participating in the relations, the macro parameters of their economies, as well as the general course of development of foreign policy in the regions and the world. The key trend in recent years of the development of international economic relations is the change of course towards the introduction of restrictions on international financial markets, which affects the global economy and factors affecting the movement of capital.

Relevance. The new reality for the global economy is consistently high uncertainty. As a result, economic systems have become more sensitive to macroeconomic shocks, geopolitical aggravations and other factors. This aspect is most relevant for the Russian economy – the legislative framework applicable to international transactions changes almost daily.

For example, the COVID-19 pandemic and the geopolitical crises of 2022 caused a much stronger drop in the Russian business climate index than, for example, the currency crisis of 2014-2015 [1]. Moreover, after February 2022, the Russian economy came out on top in terms of the number of sanctions imposed against it: more than 10,901 restrictions were imposed (totaling more than 13,596 units). Iran is in second place after Russia (more than 4,080 in total). [2]. In particular, the integration of the Russian financial market was significantly limited due to the disconnection of the largest banks from SWIFT, and NCC (National Clearing Center) from Euroclear Bank and Clearstream Banking systems [3], which practically deprives large businesses of the possibility of making payments in dollars and euros.

The issues of complicating the forecasting process, including at the macroeconomic level, have become increasingly raised in scientific research both in relation to Russia [4] and in relation to individual CIS countries [5]. The problems of the effectiveness of the existing macroeconomic forecasting apparatus are also raised in foreign studies by individual authors [6][7] and specialized organizations [8].

The relevance of creating new models and macro forecasting tools is confirmed by the fact that the Bank of Russia regularly uses experimental models to validate the results of conventional models [[9], p. 52]. Some authors offer various options for analysis and classification of existing macro forecasting problems [10] and options for modifying existing models [11]. Some studies separately emphasize the uncertainty and difficulties arising in forecasting related to sanctions [12]. There are also articles devoted to the study of the investment aspect [13][14]. Nevertheless, the available studies mainly suggest modifications of the existing tools and do not describe possible ways of combining economic theory with modern technologies to create new classes of models.

The purpose of the study. The purpose of the study is to develop a model of the movement of investment flows in cross-border markets using economic and mathematical methods.

Scientific novelty. The scientific novelty lies in the formation of a new combined approach to macroeconomic modeling and the development of principles and models of the movement of investment resources, taking into account the level of development of the international financial infrastructure, modern tools of mathematical modeling and analysis. In order to develop foreign economic policy and achieve the key goals of commercial cross–border investment - increasing profitability and increasing the volume of incoming investments, it is proposed to apply approaches based on synergetic effects and quantitative algorithms for analyzing economic and investment processes.

Using the formation of a data-driven approach in the study of capital flows in cross-border markets, it is proposed to model the parameters of economic and investment processes using mathematical apparatus to maximize the use of available data for more accurate estimates and forecasts of target variables that meet the requirements for the amount of data, ensuring high accuracy. This is a necessary reaction to the increase in the amount of data and their accuracy, for which it is proposed to use AI-analytics tools based on machine learning to analyze investment data in addition to traditional models such as DSGE [15] or CGE [16]. The key advantage of using machine learning methods, according to the authors, is the variable need for manual adjustment of the relationship between various factors of the movement of international capital. With the increase in the number of regressors, the probability of incorrect functional connection between parameters, the appearance of expert errors, as well as the amount of time required to fine-tune the model increases.

The authors assessed the allocation of key data structures in the space of international investment transactions in the global economy. When analyzing investment transactions and projects, the authors propose to combine all levels of economic processes. Firstly, at the global level, these are: demand for individual goods, international regulation (restrictions and sanctions). Secondly: at the country level: local regulation (macro indicators such as tax rates, price level, GDP, interest rates, population). At this level, industrial indicators of demand, production, capacity, price level, inventory estimates, technological development, etc. are also highlighted. At the level of an individual transaction: financial indicators of the project, ownership structure, the cost of current sources of capital, management forecasts, etc.

In the new conditions, participants in the international economic transactions market need innovative and more comprehensive analytical models, which will serve as a more solid and reasonable basis for the formation of transaction parameters. This need forms the basis of the problems of modeling the movement of international capital and investment resources in the cross-border space. Solving analytical, operational and infrastructure problems with the help of new tools

will increase investment flows between countries by searching for suitable assets (transactions), reducing the gap between expected and realized returns and reducing transaction risks and costs.

The formation of a model approach to the study of the investment potential of assets involves the identification of key properties of model (quantitative) strategies in international capital markets and investment resources. As part of the analysis of a single project, one of the key strategies is a factor analysis of the project to determine its expected profitability. To implement this approach, both classical econometric methods and more complex methods can be used. Individual data of investment schemes are necessary for the formation of a deeper analysis of investment indicators and the formation of refined estimates of the flow of capital between countries.

The authors propose a two-level approach to modeling (with the transition from individual interstate projects (schemes) first to the country, and then to the international level):

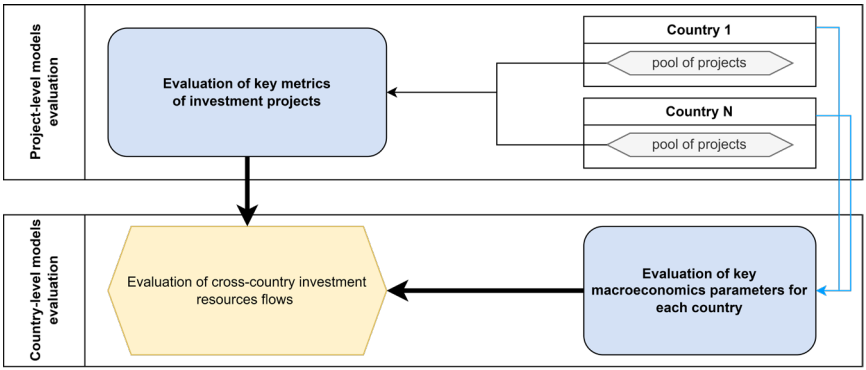

Figure 1. *Two-level model architecture*

Source: created by authors

At the first level, information is collected in the form of investment parameters in countries and the key parameter is evaluated – the real expected return. In addition, the formation of autonomous macro models of countries can also be used at this level. At the second level, the data obtained are used to model the flows of investment capital between countries. If at the first stage autonomous macro models were formed separately for each country, then at the second stage they can be used to create a more accurate dynamic algorithm for predicting capital flows [17].

The abundance of analyzed parameters and the low structuring of the problem of determining the expected profitability of investment projects and modeling

cross-border investment flows makes machine learning methods a priority tool. Within the framework of the study, the following characteristics and parameters of the use of ML, DL & AI methods and indicators for the selection of types of artificial intelligence in the economic processes of cross-border space have been developed. It is proposed to use a neural network model with RNN architecture [18] and reinforcement learning method [19]. This configuration has the characteristics necessary to solve the target problem: low sensitivity to the structure of incoming data, no need to assume a relationship between parameters, the possibility of additional training with the appearance of new data.

If we carry out a mathematical formalization of the goals of modeling the international movement of investments, then it is necessary to fix the target parameter and the direction of optimization, without which the machine learning procedure itself is impossible. In the current formulation of the problem, it seems most relevant to reduce the error between the predicted and real values of flows between countries (country interaction).

As part of the formation of the mathematical apparatus of macro forecasting, a comparison of quantitative strategies and intelligent algorithms in international financial markets is used. To form a full-fledged macroeconomic model, various models and algorithmic methods can be used, which are usually divided into groups, depending on the planning horizon. Families of stable and generally accepted computer macroeconomic submodels were analyzed: combining forecasts (MIDAS) [20], Dynamic stochastic general equilibrium (DSGE), Computable General Equilibrium (CGE), Bayesian vector autoregression (BVAR) [21], LT Solow-Swan Growth model [22] and other. On the estimated forecast horizon (2-5 years), the use of more dynamic DSGE, CGE and BVAR algorithms is relevant. As an element of the integration model, it is recommended to use DSGE, which adapts better to the data than BVAR and CGE and provides more space for making modifications (for example, modeling the financial sector).

The proposed structure allows updating the architecture of the economic model of digitalization of the international investment infrastructure. Additional modules with new functionality or the potential to improve the accuracy of existing ones can be added to it. For example, when forming the final forecast for a specific indicator, not one model presented above can be used, but the method of algorithm ensembling [23], which allows achieving higher accuracy of parameter estimates with the same data sample. In the macroeconomic terms, this will mean higher predictive power and accurate forecasts.

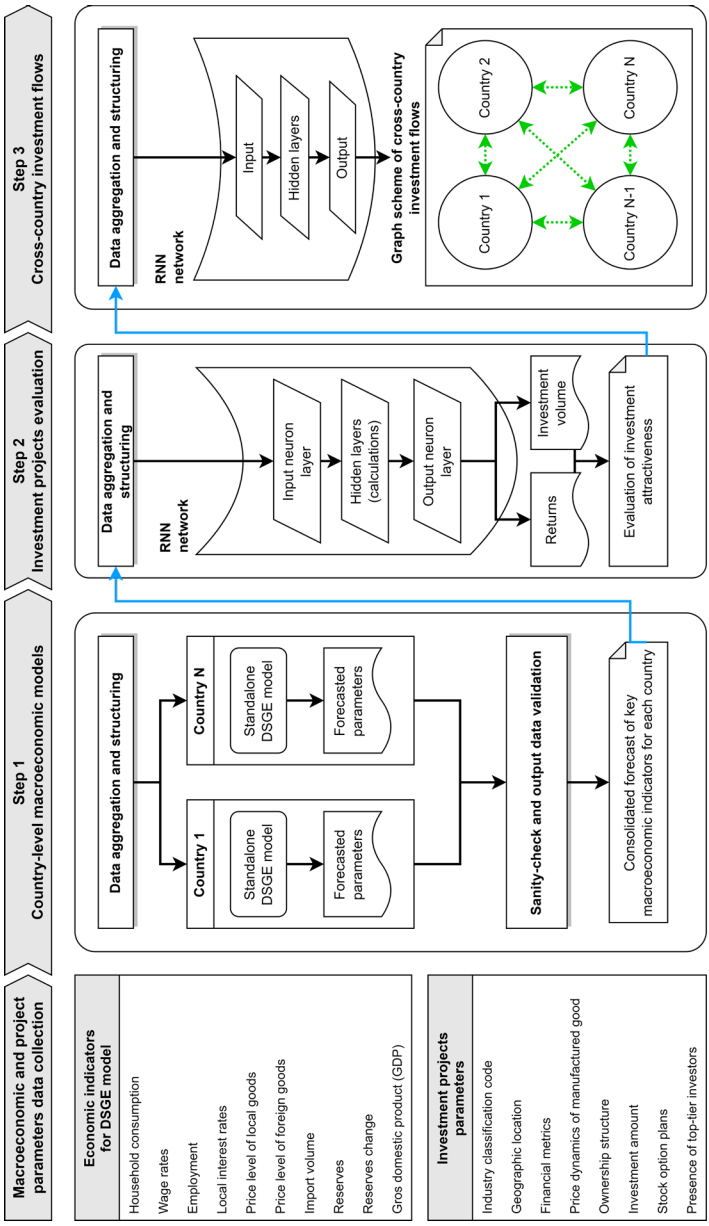

Figure 2. *Integrated model structure Source: created by authors*

The previously obtained economic algorithmic schemes were used to develop an intelligent integration economic model for making investment decisions, presented in Figure 3.

The scheme reflects the complete process of modeling economic indicators of the movement of investment resources in cross-border markets. The proposed model consists of 3 key blocks. In the auxiliary block, the necessary information is collected for the formation of macro-models and assessments of individual investment projects. In the first block, autonomous macroeconomic models of the DSGE type are built for each of the countries. It is proposed to use a DSGE model with input parameters presented in the diagram, which are grouped into solvable equations. Output forecasts of indicators are transmitted to the next block.

In the second block, the register of investment schemes is collected and analyzed. It is proposed to collect the following data on projects: industrial code, price indicators of manufactured goods, historical and forecast financial indicators, volume of attracted investments, ownership structure. Analytics takes place using the recurrent neural networks described earlier. As values of output neurons, it is proposed to use: expected profitability and the amount of capital raised.

A similar neural network is used to form vectors of indicators (selected country, formed outflow and inflow), which will be the output neurons. When training the model, the restriction is used, the sum of outflows and inflows is zero. This model outputs a forecast scheme of capital flows between countries for a given period.

Conclusion

The developed scheme can be used for further development of a digital platform model of economic assessment of the movement of investment and resource capital in international markets. The use of integration models will ensure an increase in the efficiency of forecasting the movement of investment flows. The use of the data-driven approach and intellectual analytics tools proposed by the authors within the framework of a two-level architecture allows to increase the accuracy of forecasting the movement of resources between countries, especially taking into account the influence of modern trends in the cross-border movement of investment resources and capital. The integration model formed with the help of mathematical methods makes it possible to change the approach to the study of the factors of investment attractiveness of countries, trade policy and parameters of the global capital movement.

The proposed analytical algorithm in the future can be used in the implementation of a platform model that will unite various market participants, establish information exchange and increase the transparency of transactions. This format of application of the integration model will provide direct monetary benefits for the participants of the process by reducing the cost of analytics and transaction

costs due to the emergence of a more efficient infrastructure for searching and concluding transactions. The new format of interaction will also reduce the negative effect of the main trend in the global market – a sharp increase in uncertainty and volatility.

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LEGAL VALUATION CATEGORIES IN REAL ESTATE: AN OBSTACLE OR AN INCENTIVE FOR THE DEVELOPMENT OF THE DIGITAL ECONOMY?

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Abstract. *The use of modern technologies, including the active introduction of massive data processing systems that allow for their automated analysis, contributes not only to reducing the costs of routine, technical and labor-intensive operations, but also to the development of all associated digital economy systems. At the same time, at the present stage, it is important to solve the problems of maximum protection of the analytical algorithms used from the risks of subjective interference. The solution of all these problems requires additional work from the modern legislator to systematize and harmonize the applicable norms, including by minimizing or even completely abandoning the use of legal categories in their text that require subjective and evaluative perception.*

Keywords: *real estate, civil legislation, valuation category, digital economy.*

Classical jurisprudence operates with such categories of the structure of a legal norm as “hypothesis”, “disposition”, “sanction”. These elements can be distributed between different laws. For example, sanctions for criminal offenses in Russia are concentrated in the text of the Criminal Code. In the event that one of these elements is not normatively defined, the rule of behavior itself may not work. In the system of Anglo-Saxon case law, this flaw may, in certain cases, be resolved by the decision of a judge acting in a new situation at his own discretion or on the basis of an analysis of similar precedents. In the system of Romano-Germanic law, this problem is also solvable for some branches. For example, in the field of contractual relations, it is possible to use prescriptions fixed directly in the contract or rules (including unwritten ones) that have developed in the field of business turnover.

Such an established system, taking into account the possibility of subjective interference of the will of a particular individual who has the necessary, somehow confirmed competence, functions, although not without problems and failures. But is it possible to transfer it to the digital era, the era of electronic justice? It can be assumed that at this stage the answer will be negative.

Yes, it should be recognized that today artificial electronic intelligence in the field of law in Russia has advanced to a new stage of its development. From various systems and algorithms that select similar documents for us according to their keywords, phrases and even similar concepts, we have already switched to using software complexes that involve a certain online dialogue between the system and the user (for example, the Contract Constructor module in the ConsultantPlus system: https://www.consultant.ru/promo/kd /), as well as the use of electronic assistants who select potential solutions for disputable situations for us based on the analysis of our claims (the "Litigant" module in the Garant system: http://sutyazhnik.garant.ru/).

Nevertheless, with a sufficient degree of confidence, it can be assumed that without a systematic restructuring of the entire current regulatory framework, the maximum rejection in the text of the legislation from referring to concepts that require an evaluative (and at the same time subjective-volitional) decision, an effective transition to the era of digital law and justice is impossible.

Quite serious problems may arise not only in relation to disputes concerning new legal phenomena, but also concepts that have been used for a long time and, it would seem, quite understandable at the everyday level. For example, the concept of "real estate".

The current legislation of many modern countries applies the model of dividing property into two categories: movable or immovable. From the assignment of a particular property to the category of movable or immovable, not only its legal status changes, but also possible legal encumbrances associated, for example, with the order of its accounting or taxation.

It would seem that common approaches to solving such issues could have been systematized and unified a long time ago. But if we analyze the acts of interstate agreements affecting the problems of real estate [2; 4], it turns out that in the vast majority of cases, representatives of contracting States prefer to keep in the text of interstate agreements indications that for the purposes of each of the parties, real estate objects are recognized only those that are recognized as such under the national legislation of the relevant state. In other words, what is recognized as a real estate object in one country may not be given such a status by the law of the partner state in the agreement.

Of course, this complicates the procedure of electronic harmonization of legal regulation and the creation of systems of interstate accounting of real estate and related encumbrances.

Moreover, for example, according to the law enforcement practice of the Russian Federation, a whole set of norms of civil and other legislation devoted to the definition of the concept of real estate and its specific objects is being considered, this legal concept has so far been attributed to the sphere of valuation categories.

For example, whether the object is movable or immovable property: a highway, a fence on a plot of land, a parking lot, a grocery stall... Does the answer to this question depend on the design features or materials used in construction?

As the author's analysis shows, in modern conditions it is far from uncommon for objects with similar characteristics, but, for example, located in different regions of the country, not even specific vessels, but specific real estate objects that have not mastered them, can be recognized as a solution.

Recognition of real estate objects as an appraised legal category at the level of law enforcement means, among other things, the absence of any one defining, prevailing feature for such objects, or a combination of them. Cash official documents, registration, expert opinion on the technical characteristics of the object, when resolving a specific dispute, do not have a determining role for a particular judge when making a decision [1; 3].

It seems that the exclusion of opportunities for such law enforcement proceedings, including through the development of specific algorithms used, among other things, for evaluation and control using the capabilities of artificial intelligence technologies, can become an important factor in increasing economic efficiency for any state.

Do not forget that the digitalization of the decision-making procedure, including dispute resolution algorithms, somehow leads to the unification of the results obtained and their scaling. Any technical changes (including in order to improve it) to the algorithm used can lead to a fundamentally different result. At the level of national legislation, such a risk means the need to develop clear rules for making changes to the system, as well as an answer to the question of possible consequences of decision-making and responsibility not only for the perpetrators, but also for all interested persons, if any.

Of course, the use of modern technologies, including the active introduction of massive data processing systems that allow for their automated analysis, will contribute not only to reducing the costs of routine, technical and labor-intensive operations, but also to the development of all associated digital economy systems. At the same time, it should be borne in mind that in order to ensure the effectiveness of such a model, it is important not only to achieve a sufficient level of its stability and predictable, perceptible variability, but also to solve problems of maximum protection of the analytical algorithms used from the risks of subjective interference. The solution of all these problems requires additional work from the modern legislator to systematize and harmonize the applicable norms, including

by minimizing or even completely abandoning the use of legal categories in their text that require subjective and evaluative perception.

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FOLKLORE OF THE PEOPLES OF THE NORTH CAUCASUS: ETHNOPEDAGOGICAL POTENTIAL AND PLACE IN THE STRUCTURE OF ETHNOCULTURAL EDUCATION IN THE REGION

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Annotation. *The folklore of the peoples of the North Caucasus has always occupied and now continues to occupy a special place in the spiritual life of the peoples of the region; This material is especially effective as a meaningful basis for ethnocultural education in the modern practice of the educational process in preschool, school and university institutions. Folklore works contribute to the unobtrusive, harmonious formation of the preferred personality traits of children and adolescents, instilling a love of their native word and artistic taste. In a comparative study of the folklore heritage of different peoples, students visually perceive the typological relatedness and similarity of the folklore heritage of different ethnic groups, learn to understand and respect other ethnic values. The proposed approach to the study of folklore in modern conditions of the educational crisis, with a methodologically and methodologically competent approach, can become an essential component of the content base of the spiritual and moral education of younger generations.*

Keywords: *North Caucasus, folklore, ethnopedagogy, upbringing, education, spiritual heritage.*

For many centuries, the most important layer of the ethnocultural heritage of the peoples of the North Caucasus - folklore works of various genres have been an effective means of personality formation. In modern times, they have found their niche in the content of regional education. The use of fairy tale prose, Nart epic, song and ritual folklore, small folklore forms as a meaningful basis for the ethnopedagogization of the educational process of educational institutions in the region is especially relevant in our time, when the westernization of education is intensifying, and globalization challenges are reaching their most extreme forms. And although the share of the national-regional component in the total content of modern education is small, it makes it possible to maintain interest in ethnic roots, heroic plots and symbols, standard heroes, and ethical standards of epic folklore. An activity-based approach to the comparative study of North Caucasian versions of the nartiada and its poetics makes it possible to turn this material into a means of actively mastering linguistic and cultural vocabulary, a factor in the formation of dialectically interconnected all-Russian consciousness and national self-awareness (*Volkov 1999*).

In the North Caucasus region, ethno-connotated artistic education is often carried out based on an epic basis; exhibitions of student drawings demonstrate not only the skill of the brush, but also the ability to penetrate the spirit of the epic and the ability to convey it on canvas. The effectiveness of using the pedagogical potential of folklore in the practice of modern upbringing and education can be enhanced by: appropriate professional training of teachers; continuity of studying the material at all stages of the educational process; preparation of adapted publications, use of educational digitalization resources and popularization of artistic projections of folklore (screen adaptation, animation, fine arts, arts and crafts, music, choreography).

In light of the realities of today, the proposed direction of educational activity not only does not lose, but also acquires particular relevance in connection with the tasks facing domestic education, designed to ensure the strategic security of the state - the spiritual and moral development of the individual, countering the mass westernization of the information space, countering children's addictions . These questions have always worried the luminaries of national education and the answer to them is contained in the concepts they created, based on such humanistic ethnic values, deeply rooted in the soul of every person, as folklore means of education, ethnic methods, functions and factors of education, the child as an object and subject of education , as well as the main pedagogical concepts of the people, including care, education, re-education, instruction, training, etc. (*Volkov 2009: 36*).

Modern scientific and practical discussions of pedagogical communities help not only to clearly outline the achievements and prospects for the development of

educational policy, but to give a new assessment of the experience and traditions of domestic teacher education. First of all, this concerns the now so relevant experience of preserving the ethnocultural heritage of the peoples of the country and the formation of civic consciousness and national self-awareness of the younger generations. It is obvious that in order to achieve tangible results here, the scientific and pedagogical experience accumulated by the country in this direction is invaluable. And this is not only the unique experience and results of work over several decades by scientists of the Research Institute of National Schools and its regional laboratories throughout the Soviet Union, not only Soviet, but also Russian pre-revolutionary pedagogy, the legacy of scientists from Russian diaspora. Taking into account this rich scientific and pedagogical heritage will largely contribute to determining the value foundations for constructing educational systems in the modern sociocultural space, preparing teachers to implement teaching and educational practices aimed at solving problems of the influence of the social situation and ethnic environment on the correction and content of teacher training in the context of digitalization educational process.

This perspective of research thought, which allows us to retrospectively review the work experience of recent decades, confirms the fruitfulness of turning to the observations and heritage of the Russian thinker and philosopher Ivan Aleksandrovich Ilyin. After the revolution, he was expelled from the country and wandered a lot around the world, experiencing a personal drama of the collapse of plans and hopes; he saw different countries and peoples; philosophically summarizing his observations about the history and culture of nations in numerous publications, he concluded: “National depersonalization is a great misfortune and danger in the life of a person and a people.” He clearly saw this danger and gave his recommendations on how to avoid it. Among them are education in ethnic culture, turning to folklore, and immersion in the world of the native word. In the chapter “On National Education” of the book “The Path of Spiritual Renewal” he writes: “Educating children is precisely the awakening of their unconscious sensitivity to national spiritual experience, strengthening in it their heart, their will, their imagination and their creative plans” (*Ilyin 1993: 248*).

The outstanding philosopher called for enriching the souls of children with national treasures, among which he names the following among the first six: the native language, which “contains in a mysterious and concentrated way the entire soul, the entire past, the entire spiritual way of life and all the creative ideas of the people...”;

a song that “... constantly enriches a child’s soul with Russian melodies, ... choral singing nationalizes and organizes life”; prayer, which “...gives the child spiritual harmony, a source of spiritual strength”; a fairy tale that “...gives the first feeling of the heroic - a sense of challenge, danger, calling, effort and victory;

the lives of saints and heroes, for "... admiration for a saint and a hero elevates the soul, it gives it at once humility, self-esteem, and a sense of rank; poetry, for "poems are fraught with beneficial and magical power: as soon as a child begins to speak and read, then classical national poets should give him the first joy of verse and gradually reveal to him all their treasures" (*Ilyin 1993: 242*). I.A. Ilyin called "... to the extent possible... to open the child's access to all types of national art - from architecture to painting and ornament, from dance to theater, from music to sculpture. Then his soul will fully open up to perceive what song, fairy tale and poetry first gave it" (*Ilyin 1993: 246*).

These thoughts, which are the result of long observations and conclusions of an outstanding philosopher, are in tune with the extensive pedagogical experience and intentions of people who build the content of education. in the content of humanitarian and literary education, a sufficient amount of hours has always been allocated for studying the epic heritage of the people (*Arsaliev 2015; Volkov 2009; Kumakhova 2000*). For Russians, this is an epic epic, with excellent methods of teaching and studying it at various levels of the educational process. In regional schools, folk epics of the corresponding ethnic groups are studied in the course of native literature. Now, when constructing the proportions of the educational standard, teachers and methodologists pay attention to the fact that often the content of the school course of native literature is structured similarly to the course of Russian literature, in which the first lessons of the course are devoted to fairy tales and then epic folklore. But it should be taken into account that centuries-old Russian literature is so vast, the list of works of outstanding classics is so extensive, that the time allocated to folklore is a completely adequate proportion. At the same time, relatively newly written, let's say, North Caucasian literatures form a completely different proportion in relation to the monumental North Caucasian epic and other genres of folklore. And this, of course, should be taken into account by the authors and compilers of programs, textbooks, and educational standards. Much has already been done in this direction, and much more remains to be done (*Tsallagova 2013: 18-24*).

Another pillar of Russian culture, Konstantin Dmitrievich Ushinsky, who formulated the basic concepts of the success of the national education and upbringing system, spoke vividly and convincingly about the national depersonalization of education back in the middle of the 19th century and gave his recommendations. He developed unique textbooks, including the first mass-produced Russian textbooks, including the famous "Native Word" and "Children's World", "Guide to Teaching the "Native Word" for Teachers and Parents", which stood for about 150 years before 1917. publications Unfortunately, modern teaching pays little attention to this guidance, which has not lost its practical significance to this day. As for his theoretical works and their theoretical significance for solving the problems of

forming a culture of interethnic harmony, tolerance and patriotism, already in one of the first programmatic works "On Nationality in Public Education" the basic principle of his system is contained - nationality. This generalization is based on a comprehensive analysis of the specifics of education and upbringing in America, Germany, England, and France (*Ushinsky 1968: 245-249*). Unfortunately, during the Soviet period of development of pedagogical science, these ideas of K.D. Ushinsky were little known, and mass publication of his pedagogical works was carried out only in 1988-1990.

In the light of modern realities, in search of vectors to counter total Westernization, the legacy of K.D. Ushinsky, who scientifically substantiated the need to preserve the ethnic characteristics of folk education and introduce into the content of his contemporary educational practice a vast layer of folk culture, the native language of students and native folklore is significant a methodological basis for adjusting the ethnocultural orientation of the educational process in the North Caucasus, turning to the folklore heritage of the ethnic groups of the region (*Ushinsky 2002*).

Indeed, now, like 30-40 years ago, Russian educational practice at the beginning of the 21st century is faced with many difficulties, the solution of which involves relying on the ethnic origins of the formation of the personality of the younger generations and countering the total Westernization of education, which obviously actualizes the appeal to the folklore heritage of each ethnic group, consideration it as an important component of the content of education. The realities of the current time not only actualize the significance of folk oral and poetic creativity, but also force them to look at them in a new way, comprehend and use them with appropriate adaptation in solving problems of optimizing modern education (*Alieva 2019; Kumakhova 2000; Hadzhieva 1994: 8-67*).

Important in the study of North Caucasian folklore in educational institutions of a multinational region is the idea of studying it in close relation (comparison and contrast) with similar material from neighboring, genetically related and other peoples in the context of their historical and modern interaction within the region, country and world (*Volkov 2009: 6-7*).

The practice of ethnopedagogization of the educational process, carried out in many schools in the North Caucasus region in the 1990s, convincingly showed the effectiveness of using folk oral poetry in the formation of moral, ethical and behavioral attitudes of students. Such work, carried out with the involvement of material from a number of different folklore traditions, favors the choice of a position of non-violent interethnic interaction, the formation of the ability to hear and comprehend other points of view (*Alieva 2019; Arsaliev 2015; Volkov 1999: 8-13; Kumakhova 2000; Khadzhieva 1994: 8-13) 67; Tsallagova 2013*).

Such work acquires particular significance from the perspective of expanding the locus of understanding the general and special in the folklore heritage of the peoples of the world, attracting outstanding examples and masterpieces of world folklore into the educational mainstream.

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BACK TO THE ISSUE OF RENDERING ENGLISH DIPHTHONGS IN WRITING

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Abstract. *The article is devoted to the study of the problem of graphic spelling of diphthongs in educational activities of the pedagogical worker in English classes at educational institutions in the Russian Federation. The author identifies the main ways of graphic spelling of the phonemes, namely letters and combinations of letters used in the formation of the sounds in question. The study aims to define and describe the ways of graphic spelling of English sounds.*

Keywords: *diphthongs, educational activities, English, graphic spelling, pedagogical worker.*

First classes of English at the overwhelming majority of educational institutions in the Russian Federation make pedagogical workers solve a lot of vital issues while training their students within the main language aspects that are listening, speaking, reading and writing (such aspects as interpretation and translation are being omitted here since they are in the domain of a limited number of specialized Russian universities; for this reason transliteration, being a way of rendering lexical units in writing, is not the subject of our research). Writing universally seems to be the most complicated aspect in its mastering due to the fact that it is directly connected with grammar, lexicology, phonetics, punctuation, spelling and stylistics. One complexity of writing is "phonetics [12] vs spelling" problem. In short, we mean a case when one letter or a group of letters contained in various lexical units [1] has several ways to be pronounced, e.g.:

– vowel letter *a* in the following lexical units: *pl<u>a</u>que [a:], cr<u>a</u>dle [eɪ], <u>a</u>dorn [ə], g<u>a</u>ll [o:], <u>a</u>crid [æ], Bologn<u>a</u> [jə], vint<u>a</u>ge [ɪ], g<u>a</u>rish [ɛə], sw<u>a</u>b [ɔ]*;

- consonant letter *s*: *epi<u>s</u>ode [s], fu<u>s</u>ion [ʒ], controver<u>s</u>ial [ʃ], liai<u>s</u>on [z], A<u>s</u>ia [ʃ]* or *[ʒ], CI<u>S</u> [es]* [5], [8]*;*
- double *oo*: *fl<u>oo</u>d [ʌ], n<u>oo</u>k [ʊ], tatt<u>oo</u> [u:], fl<u>oo</u>r [o:], br<u>oo</u>ch [əʊ]*;
- a group of vowel and consonant letters *ough*: *thr<u>ough</u> [u:], s<u>ough</u>t [o:], d<u>ough</u> [əʊ], r<u>ough</u> [ʌf], c<u>ough</u> [ɔf], thor<u>ough</u> [ə];*
- a combination of consonant letters *ch*: *avalan<u>che</u> [ʃ], <u>ch</u>ime [tʃ], o<u>ch</u>re [k], Greenwi<u>ch</u> [dʒ]* [9], [10], [11].

To avoid bewildering in writing among students and to ensure that they will learn to write well is one of the primary tasks of the pedagogical worker in the initial and further stages of teaching English.

In this article, we endeavour to compile and systematize the ways of graphical spelling of eihgt diphthongs ([au], [ɔɪ], [ɪə], [əʊ], [aɪ], [uə], [ɛə], [eɪ]) [2], [3], [4], temporarily omitting other 12 vowel (10 monophthonhs, 2 diphthongoids) [14] and 24 consonant sounds [6], [7].

The relevance of the research work arose in the light of insufficient coverage of the multiple ways of graphical spelling of vowel and consonant phonemes and their combinations in textbooks currently applied in the educational process.

Our research is based on the material of various extracts taken for our consideration from pieces of fiction, periodicals, textbooks, the Internet. We also dealt with corporate letters, movie subtitles, pieces of advertising; off-line and on-line dictionaries; reference books to contemporary English pronunciation [13]. We examined the parts of English speech and their transformations regarding case, degree, mood, number, tense and voice categories. It seemed natural for us to view abbreviations, acronyms, clipped words, interjections, loan words, etc, paying particular attention to such toponyms as geographic names, corporate names, days of the week, months, nationalities, people's names, patronymics and sur-names, social networks, astronyms, types of drinks, meals and food, etc.

Paradoxically, some English consonant sounds can be rendered by vowel letters, e.g.:

- [f] can be rendered by vowel letter *u* (*lie<u>u</u>tenant [le<u>f</u>'tenənt]*);
- [j] can seldom be rendered by vowel letter *e (<u>E</u>ugene [ˈ<u>j</u>u:dʒi:n], <u>e</u>ureka [<u>j</u>uəˈrɪkə]* or *[<u>j</u>o:ˈrɪkə], <u>E</u>urope [ˈ<u>j</u>uərəp]* or *[ˈ<u>j</u>o:rəp]);* by vowel letter *u* (*<u>u</u>nique [<u>j</u>u:ˈni:k], <u>u</u>se [<u>j</u>u:z], <u>u</u>sual [ˈ<u>j</u>u:ʒəl]* or *[ˈ<u>j</u>u:ʒl]*); by vowel letter *y* (*<u>y</u>acht [<u>j</u>o:t], <u>y</u>ear[<u>j</u>ɪə]* or *[<u>j</u>ə:], <u>y</u>outh [<u>j</u>u:θ]*);
- [w] can sometimes be rendered by vowel letter *o* (*<u>o</u>ne [<u>w</u>ʌn]*, *<u>o</u>nce [<u>w</u>ʌns]*, *<u>o</u>neself [<u>w</u>ʌnˈself];* by vowel letter *u* (*c<u>u</u>isine [k<u>w</u>ɪˈzi:n]*, *per-s<u>u</u>ade [pəˈs<u>w</u>eɪd]*, *q<u>u</u>ake [k<u>w</u>eɪk]*.

We can observe a revearse process, when consonant letters render vowel sounds if they are pronounced under their names in the English Alphabet, e.g. letter *Pp* in *<u>PPP</u>* (that stands for *Power Point Presentation) [ˈ<u>p</u>i:ˈ<u>p</u>i:ˈ<u>p</u>i:]*. To be

more exact, consonant letters can render one (letter *Rr*), two (letters *Bb, Cc, Dd, Ff, Gg, Hh, Jj, Kk, Ll, Mm, Nn, Pp, Ss, Tt, Vv, Zz*, the latter in American variant of English), three (letters *Qq, Xx, Zz*) and six sounds (letter *Ww*):

- letter Rr rendered by one sound *[a:]*;
- letter Bb rendered by two sounds *[bi:]*;
- letter *Qq* rendered by three sounds *[kju:]*;
- letter *Ww* rendered by six sounds *[dʌblju:]*.

Letters rendered by two (*Bb [bi:], Hh [eɪtʃ], Nn [en]*), three (*Qq [kju:], Xx [eks], Zz [zed]*) and six sounds (*Ww [dʌblju:]*) involve both consonant and vowel sounds. This postulate says that if we pronounce the consonant letters in definite positions (in abbreviations and compound words, for instance), we have to use both consonant and vowel sounds to utter them, e.g. abbreviation *CIF [si:aɪˈef]* and compound word *X-ray [ˈeksreɪ]*:

- *CIF* is composed of letter *C – [si:]* rendered by two sounds, consonant *[s]* and vowel *[i:]*, letter *I [aɪ]* rendered by one vowel sound *[aɪ],* letter *F* rendered by two sounds, vowel *[e]* and consonant *[f]*;
- *X-ray* is composed of letter *X [eks]* and word *ray*.

Thus, a notable feature of this article is its inclusion of examples where consonant letters can take part in rendering vowel sounds.

The ways of graphical spelling of vowel phonemes described here correspond to the style which is currently the norm in Great Britain and the Commonwealth. Standard American usage differs in one respect; in this case examples of American spelling are marked in brackets, e.g. *o(u)r* (*vigour* or *vigor [ˈvɪgə]*).

In the pages that follow are to be found specimen letters and letter combinations depicting eight English diphthongs.

The vowel sound /aʊ/ can be represented by groups of English letters *au* (*Saudi Arabia – /saudɪəˈreɪbɪə/*), *ou* (*insurmountable – /ˌɪnsəˈmaʊntəbl/*), *ough* (*drought – /draʊt/*), *ow* (*powder – /ˈpaʊdə/*). This sound can be observed in the initial (*outrageous – /ˌaʊtˈreɪʤəs/*), middle (*downtown – /ˈdaʊntaʊn/*) and final (*allow – /əˈlaʊ/*) positions of words. This diphthong is represented by four groups of letters (*au, ou, ough, ow*). In two cases, this phoneme is formed in graphic spelling by groups of vowel letters (*au, ou*) and in two cases – by groups of vowel and consonant letters (*ough, ow*).

The vowel sound /ɔɪ/ can be represented by groups of letters *oi* (*poison – /ˈpɔɪz(ə)n/*), *ois* (*Illinois – /ɪlɪˈnɔɪ/*), *oy* (*soybean – /ˈsɔɪbiːn/*), *uoy* (*buoyant – /ˈbɔɪənt/*). This sound can be observed in the initial (*ointment – /ˈɔɪntmənt/*), middle (*royal – /ˈrɔɪəl/*) and final (*buoy – /ˈbɔɪ/*) position of words. The diphthong /ɔɪ/ is represented by four groups of letters (*oi, ois, oy, uoy*). In three cases, this phoneme is formed in spelling by groups of vowel letters (*oi, oy, uoy*) and in one case – by a combination of vowel and consonant letters (*ois*).

The vowel sound /ıə/ can be represented by the letter *e* (*deteriorate – /dɪ'tıərıəreıt/*) and by groups of letters *ea* (*theatre – /'θıətə/*), *ear* (*earphones – /'ıəfəʊnz/*), *eer* (*steerage – /'stıərıʤ/*), *eir* (*weird – /wıəd/*), *eo* (*Napoleon – /nə'pəulıən/*), *eou* (*hideous – /'hıdıəs/*), *ere* (*cashmere – /'kæʃmıə/*), *eu* (*museum – /mjʊ:'zi:əm/*), *hea* (*diarrhea – /ˌdaıə'rıə/*), *ia* (*editorial – /ˌedɪ'tɔ:rıəl/*), *iar* (*billiards – /'bılıədz/*), *ie* (*requiem – /'rekwıəm/*), *ier* (*frontier – /frʌn'tıə/* or */'frɔntıə/*), *io* (*champion – /'ʧæmpıən/*), *ior* (*senior – /'si:nıə/*), *iou* (*glorious – /'glɔ:rıəs/*), *ir* (*souvenir – /su:və'nıə/*), *iu* (*moratorium – /ˌmɔrə'tɔ:rıəm/*), *ya* (*Libya – /'lıbıə/*). This sound can be observed in the zero (*ear – /ıə/*), initial (*era – /'ıərə/*), middle (*period – /'pıərıəd/*) and final (*phobia – /'fəʊbıə/*) positions of words. The diphthong /iə/ is represented by one letter (*e*) and 19 groups of letters (*ea, ear, eer, eir, eo, eou, ere, eu, hea, ia, iar, ie, ier, io, ior, iou, ir, iu, ya*). In 10 cases, this phoneme is formed in spelling by groups of vowel letters (*ea, eo, eou, eu, ia, ie, io, iou, iu, ya*) and in nine cases – by groups of vowel and consonant letters (*ear, eer, eir, ere, hea, iar, ier, ior, ir*).

The vowel sound /əʊ/ can be represented by the letter *o* (*noble – /'nəʊbl/*), by groups of letters *aoh* (*pharaoh – /'fɛərəʊ/*), *au* (*chauffeur – /'ʃəʊfə/* or */ʃəʊ'fɜ:/*), *eau* (*bureau – /bjʊə'rəʊ/*), *eaux* (*Bordeaux – /bɔ:'dəʊ/*), *eou* (*Seoul – /səʊl/*), *ew* (*sew – /səʊ/*), *hau* (*haute couture – /əʊtkʊ:ˈtjʊə/, /əʊtkʊˈtjʊə/* or */əʊtkʊˈtʊə/*), *ho* (*ghost – /gəʊst/*), *oa* (*roam – /rəʊm/*), *oe* (*oboe – /'əʊbəʊ/*), *oh* (*Oh – /əʊ/*), *ol* (*Stockholm – /'stɔkhəʊm/*), *oo* (*brooch – /brəʊʧ/*), *ot* (*depot – /'depəʊ/*), *ou* (*shoulder – /'ʃəʊldə/*), *ough* (*although – /ɔ:l'ðəʊ/*), *ow* (*row – /rəʊ/*), *owe* (*owe – /əʊ/*) and by combination of vowel and consonant letters and the apostrophe *'ho* (*table d'hote – /ta:bəlˈdəʊt/* or */ta:blˈdəʊt/*). This sound can be observed in the zero (*owe – /əʊ/*), initial (*oak – /əʊk/*), middle (*roast – /rəʊst/*) and final (*snow – /snəʊ/*) positions of words. The diphthong /əʊ/ is represented by one letter (*o*) and by 19 groups of letters (*aoh, au, eau, eaux, eou, ew, hau, ho, 'ho, oa, oe, oh, ol, oo, ot, ou, ough, ow, owe*). In seven cases, this phoneme is formed in spelling by groups of vowel letters (*au, eau, eou, oa, oe, oo, ou*), in eleven cases – by groups of vowel and consonant letters (*aoh, eaux, ew, hau, ho, oh, ol, ot, ough, ow, owe*) and in one case – by combination of the apostrophe, vowel and consonant letters (*'ho*).

The vowel sound /aɪ/ can be represented by the letters *i* (*entitle – /ɪn'taɪtl/*), *y* (*byte – /baɪt/*) and by groups of letters *ae* (*paella – /paɪ'elə/*), *ai* (*Baikal – /baɪ'ka:l/*), *ay* (*kayak – /'kaɪæk/*), *ei* (*either – /ˈaɪðə/*), *eigh* (*height – /haɪt/*), *ey* (*geyser – /ˈgaɪzə/*), *eye* (*eye – /aɪ/*), *ie* (*petrified – /'petrɪfaɪd/*), *ig* (*sign – /saɪn/*), *igh* (*nightgown – /'naɪtgaʊn/*), *ui* (*guide – /gaɪd/*), *uy* (*guy – /gaɪ/*), *ye* (*rye – /raɪ/*). This sound can be observed in the zero (*I – /aɪ/*), initial (*eider – /'aɪdə/*), middle (*blind – /blaɪnd/*) and final (*pie – /paɪ/*) positions of words. The diphthong /aɪ/ is represented by two letters (*i, y*) and by 13 groups of letters (*ae, ai, ay, ei, eigh, ey, eye, ie, ig, igh, ui, uy, ye*). In ten cases, this phoneme is formed in spelling by

groups of vowel letters (*ae, ai, ay, ei, ey, eye, ie, ui, uy, ye*) and in three cases – by groups of vowel and consonant letters (*eigh, ig, igh*).

The vowel sound /ʊə/ can be represented by the letter *u* (*jury – /'ʤʊərɪ/*) and by groups of letters *ewer* (*skewer – /ˈskjʊə/*), *oor* (*poor – /pʊə/*), *our* (*tourist – /'tʊərɪst/*), *ua* (*obituary – /ə'bɪʧʊərɪ/*), *uar* (*Stuart – /ˈstjʊət/*), *ue* (*duel – /djʊəl/*), *ueur* (*liqueur– /lɪˈkjʊə/*), *uou* (*incongruous – /ɪn'kɔŋgrʊəs/*), *ure* (*pure – /pjʊə/*). This sound can be observed in the middle (*January – /'ʤænjʊərɪ/*) and final (*dour – /'dʊə/*) positions of words. The diphthong /ʊə/ is represented by one letter (*u*) and by nine groups of letters (*ewer, oor, our, ua, uar, ue, ueur, uou, ure*). In three cases, this phoneme is formed in spelling by groups of vowel letters (*ua, ue, uou*) and in six cases – by groups of vowel and consonant letters (*ewer, oor, our, uar, ueur, ure*).

The vowel sound /ɛə/ can be represented by the letters *a* (*barbarian – /baː'beərɪən/*), *e* (*whereas – /weə'ræz/*) and by groups of letters *ae* (*aerodynamics – /ɛərədaɪˈnæmɪks/*), *ai* (*fairy – /'fɛərɪ/*), *air* (*repair – /rɪ'peə/*), *aire* (*millionaire – /ˌmɪljə'neə/*), *ar* (*scarce – /skeəs/*), *are* (*glare – /gleə/*), *ayor* (*mayor – /mɛə/*), *ear* (*swear – /sweə/*), *eir* (*their – /ðɛə/*), *er* (*concierge – /konsɪˈɛəʒ/*), *ere* (*where – /(h)weə/*). This sound can be observed in the zero (*air – /eə/*), initial (*aerodynamics – /ɛərədaɪˈnæmɪks/*), middle (*staircase – /'steəkeɪs/*) and final (*blare – /bleə/*) positions of words. The diphthong /ɛə/ is represented by two letters (*a, e*) and by twelve groups of letters (*ae, ai, air, air, ar, are, ayor, eah, ear, eir, er, ere*). In two cases, this phoneme is formed in spelling by groups of vowel letters (*ae, ai*) and in ten cases – by groups of vowel and consonant letters (*air, aire, ar, are, ayor, eah, ear, eir, er, ere*).

The vowel sound /eɪ/ can be represented by the vowel letters *a* (*inflation – /ɪn'fleɪʃ(ə)n/*) and *e* (*forte – /fɔːteɪ/*), by the consonant letter *h* (*h – /eɪʧ/*), by the French letter *é* (*fiancé – /fɪ'aːn(t)seɪ/*) and by groups of letters *ae* (*Gaelic – /ˈgeɪlɪk/*), *ag* (*champagne – /ʃæmˈpeɪn/*), *ai* (*complain – /kəm'pleɪn/*), *aig* (*arraign – /ə'reɪn/*), *aigh* (*straightforward – /ˌstreɪt'fɔːwəd/*), *ao* (*gaol – /dʒeɪl/*), *au* (*gauge – /geɪʤ/*), *ay* (*essay – /'eseɪ/*), *ea* (*great – /greɪt/*), *ee* or *ée* (*puree – /'pjuəreɪ/, crème brûlée – /ˌkrembruː'leɪ/*), *ei* (*reindeer – /'reɪndɪə/*), *eig* (*reign – /reɪn/*), *eigh* (*neighbour – /'neɪbə/*), *er* (*couturier – /kuː'tjuərɪeɪ/*), *et* (*parquet – /'paːkeɪ/*), *ey* (*decay – /dɪ'keɪ/*), *uet* (*bouquet – /bʊˈkeɪ/*). This sound can be observed in the zero (*Eh – /eɪ/*), initial (*eighteen –/ˌeɪ'tiːn/*), middle (*entertain – /ˌentə'teɪn/*) and final (*prey – /preɪ/*) positions of words. The diphthong /eɪ/ is represented by four letters (*a, e, h, é*), three of which are vowels and one is consonant, three are English and one is French, by 17 graphic groups of letters (*ae, ag, ai, aig, aigh, ao, au, ay, ea, ee* or *ée, ei, eig, eigh, er, et, ey, uet*). In nine cases, this phoneme is formed in spelling by groups of vowel letters (*ae, ai, ao, au, ay, ea, ee* or *ée, ei, ey*) and in

eight cases – by groups of vowel and consonant letters (*ag, aig, aigh, eig, eigh, er, et, uet*).

For detailed information on diphthongs and patterns of letters and letter groups representing them, we refer our readers to Table 1.

Table 1

Patterns of Diphthong Spelling

#	Diph-thong	Pattern of Diphthong Spelling		
		Vowel Letters and Vowel Letters Groups	**Vowel and Consonant Letter Groups**	**Apostrophe, Consonant and Vowel Letters**
1	/aʊ/	au, ou	ough, ow	
2	/ɔɪ/	oi, oy, uoy	ois	
3	/ɪə/	e, ea, eo, eou, eu, ia, ie, io, iou, iu, ya	ear, eer, eir, ere, hea, iar, ier, ior, ir	
4	/əʊ/	o, eau, au, eou, oa, oe, oo, ou	aoh, eaux, ew, hau, ho, oh, ol, ot, ough, ow, owe	’ho
5	/aɪ/	ae, ai, ay, i, y, ei, ey, eye, ie, ui, uy, ye	eigh, ig, igh	
6	/ʊə/	u, ua, ue, uou	ewer, oor, our, uar, ueur, ure	
7	/ɛə/	a, e, ae, ai	air, aire, ar, are, ayor, eah, ear, eir, er, ere	
8	/eɪ/	a, e, é, ae, ai, ao, au, ay, ea, ee or ée, ei, ey	ag, aig, aigh, eig, eigh, er, et, h, uet	

To sum up, we must note that the solution to the problem of graphic spelling of diphthongs is still for the most part in its infancy. No single spelling rule can guarantee uniformed pronunciation of this or that vowel phoneme, that is why the best way to specify correct pronunciation of a lexical unit remains in looking it up in off-line and on-line dictionaries. However, the ways of graphic spelling of eihgt diphthongs ([au], [ɔɪ], [ɪə], [əʊ], [aɪ], [uə], [ɛə], [eɪ]) described by us can simplify to some extent this process in the initial and further stages of teaching English at educational institutions in the Russian Federation.

Our brief outline of the modes of graphical spelling of the vowel sounds shows that further more careful and scrupulously detailed investigation is necessary to get the objective data by which we can more fully ascertain each method to render the vowel phonemes. Nevertheless, the research allowed us to work out and prepair for publishing a guide-book containing drills to consolidate the skills of spelling and pronunciation of lexical units.

The logical outcome of our work permits to state that the data of the review can be helpful in the pedagogical reality of Russian schools, colleges, universities

when teaching English phonological and spelling nuances to students who master English as a foreign language. However, we cannot purport to have covered the entire range of variations of letters and groups of letters depicting the diphthongs. For this reason, we invite our fellow scholars to join us in further more thorough research of this issue.

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TYPES OF MAIN WORK OCCUPATIONS OF THE MOUNTAIN PEOPLE OF THE NORTH CAUCASUS

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Abstract. *Labor education is the transfer of life experience from the older generation to the younger, one of the most necessary conditions for the activities of all ethnic communities, without exception. The article discusses the transfer of life and practical experience of the older generation to the younger - one of the most necessary conditions for the activities of all ethnic communities, without exception.*

Keywords: *education, cattle breeding, agriculture, labor skills, highlanders, plowing, plots of land, labor, customs, rituals.*

Let us consider the range of basic labor occupations that required skills, production knowledge from the younger generation and determined the content of labor education. First of all, it should be noted that the most important occupations were cattle breeding and agriculture. They were the oldest occupations of the Caucasian highlanders. Agriculture, depending on natural (geographical) conditions, had far from the same scale among different peoples inhabiting the North Caucasus. For example, flat Kabarda, compared to mountainous Balkaria, had great opportunities in this area of work. However, the extreme scarcity of land suitable for plowing in the mountains did not mean that it was poorly developed there. Arable plots of land in the mountains required enormous labor from the peasants and, of course, were expensive. The Chechens and Ingush, who cultivated fields of considerable size, were in a better position than their mountain neighbors [8, p.56].

But no matter what areas of land the mountaineers had, large or small, no matter where they lived, on the plane or high in the sky, their leading occupation was cattle breeding. Domestic animals “dressed” and “fed” the mountaineer. His main food was dairy products. Cattle once replaced banknotes for the mountaineers and served as the subject of loans. This is what N.P. wrote about the importance of cattle breeding in the life of the Balkars. Tulchinsky: “Cattle breeding in the moun-

tains is the only source of people's well-being... This is the pulse of the people's life of the mountain population. Its intense or weak beating serves as a criterion; economic wealth or distress." This review by N.P. Tulchinsky is characteristic, to a certain extent, of the economic structure of all the mountain peoples of the North Caucasus. Not only men and women, but even young children of the mountaineers actively participated in this hard work [2, p. 101].

People highly valued practical skills in caring for domestic animals in young people and always attracted them to this activity. The childhood of mountain boys and girls was closely connected with the practice of caring for domestic animals. In many fairy tales and legends there are images of young shepherdesses helping a traveler and showing signs of respect to visiting people. Sometimes a girl in the family was assigned to herd calves, cows, and sheep. Children witnessed how elders taught animals to "adopt" other people's young when this had practical benefits for the peasant farm.

Children were involved in caring for pets from the age of 5-6 years. So they told the boy's father that he already had a real shepherd, although the shepherd himself needed care. The peasants especially respected young people who had proven themselves to be skilled sheep breeders. Sheep farming, having unlimited opportunities for its development due to the geographical and climatic conditions of the mountainous area, served as the source of many household crafts in the Karachay-Balkarian economy. In their sayings, reflecting the practical experience of peasants in this area, the people condemn people who do not know how to care for domestic animals: "A lazy shepherd walks far after his flock" (Ossetian); "There were many shepherds, but they did not notice how the sheep died" (dag.); "Whoever does not know how to herd sheep drives them all from place to place" (Karach., Balk.) [10, p.89].

It should be said that thanks to these proverbs, rural workers of our days not only get ac-quainted with the labor experience of their ancestors, but also draw valuable advice from them.

Agriculture was of no small importance in the life of the North Caucasian highlanders. During the division of small plots of arable land, parents gave their children various instructions: measure the width of the plot with a stick or shovel, place pyramids of stones in its corners, clear it before plowing. There was no planting of potatoes with the participation of children. Moreover, the children, on the advice of their elders, tried to arrange the potatoes in the hole so that in the future their roots would not crowd each other. The mountaineers had to fight with piles of stones, adapting the arable land for sowing. Obtained at a price Such hard work meant that arable land was valued very dearly. Therefore, the ancestors left advice to the younger generation in proverbs expressing their agricultural experience: "Taunu makhta yes, tyuznyu al." - Praise the mountains, but choose the plain [4, p.230].

Among the people there were many signs and observations of natural phenomena that affected the success of the farmer's work. The peasants sought to pass on this experience to their children. The younger generation had to learn how to skillfully use natural phenomena. For example, the speed, direction and amount of expected rain could be determined by the wind before the rain.

The hard work of the farmer required careful treatment of its results. Meager harvests from tiny patches of land could not provide the mountaineers with bread. "Essays on the history of the Balkar people" provides reliable facts about the extremely difficult situation of the Balkars, deprived of bread. The peasant had to carry the grain purchased in the neighboring flat areas on his back off-road. At the same time, he lost precious working days on the way. The situation was complicated by the lack of roads. That is why the inhabitants of the mountains in 1880-1890, on their own, "without any assistance from the treasury," spending a lot of money, paying extra with livestock, laid wheeled roads with incredible difficulty. The opening of the wheeled road was celebrated as a holiday [5, p.95].

Thus, it became possible to bring grain and other barter goods on carts. The peasants themselves had such meager pieces of land that they could barely sow a few handfuls of barley. The size of crops in the mountains can be judged by the units of land measurement common at that time - "the length of a foot"; "a place under one stone"; "an arable place that produces one haystack."

It is also interesting to note the attitude towards bread as a means of establishing humane relations between people. More than once, children heard deeply truthful words that bread brings people together. If workers shared their hard-earned bread with each other, this was the path to close spiritual rapprochement. "You and I ate bread and salt together," these words were often enough to maintain friendship and camaraderie. Echoing the adults, the children swore an oath to each other:

"I swear on bread!" The holiness of peasant bread in this case approached the holiness of mother's milk. The time of spring sowing turned into a holiday for the common people. Children eagerly awaited its arrival, when the elders went to congratulate each other on a safe exit from winter, on the new arrival of the spring sowing season, and the youth organized dances and fun games.

The children also expected the arrival of the "arable bird" - the wagtail, since its appearance was usually associated with the onset of the arable season. They most often went out to the north in groups (supryags). This was convenient: if one family had enough male labor, the other, with the presence of draft animals, did not have enough workers. Uniting during sowing was beneficial to every family. Yes, not only profit could motivate farmers to unite their labor efforts, but also a deep sense of labor solidarity, the humane attitude of workers towards each other, and the desire for mutual assistance [7, p. 126].

Although cattle breeding and agriculture were the basis of the economic life of mountain workers, their work activity was not limited to this. They also engaged in various crafts. Developed sheep breeding, for example, led to the emergence among the mountaineers of such a craft as the manufacture of coarse homespun cloth.

Cloth production in the Karachay and Balkar villages was quite significant. This work, according to N.P. Tulchinsky, walked "incessantly" and "hurriedly." In the previously mentioned work by N.P. Tulchinsky noted that cloth production was the pride of the Balkar national economy. It was also an integral part of the national economy of all mountaineers of the Caucasus [1, p. 206]. In addition to cloth, burkas and felt felts were made from dyed wool with various ornaments. In such crafts, children, of course, played only an auxiliary role. The wool production workers could not do without their help. As evidenced by the complete description of Karachay-Balkar and Adyghe crafts given by Professor G.Kh. Mambetov, children from the age of ten were involved in numerous drilling processes. During the felling (chepgen baskhan), the labor of young men of 15-16 years was used. The felting process was the most difficult in cloth production: wet cloth was trampled underfoot for 4-5 and even 10-15 hours continuously until the required density of the cloth was achieved and its size was reduced by 20-25%. It was here that the already mentioned Karachay-Balkar labor song "Erey" was sung by adults and children, designed by its content to support the strength of workers, drive away fatigue, help achieve a labor goal, and even express encouragement to the hard-working, censure to the lazy . Let us remember the lines that a hardworking person will have a beautiful posture, and a lazy person will have the result of labor like the toothless mouth of an old woman [3, p.84].

Wood processing occupied a significant place in the life and work of the peasant. The wooden utensils of the Caucasian mountaineers were famous for their craftsmanship. Young people adopted the art of their elders to carve various agricultural tools and household items from wood (combs for processing wool, spindles, furniture, dishes, musical instruments, etc.).

In peasant life among the mountain peoples, a wooden savory bowl with skillful carvings is held in high esteem. Among the Balkars and Karachais it was called goppan and was decorated with elegant sculptural figures in the shape of ram heads with curled horns, which simultaneously served as handles. This bowl is the common property of the material culture of the peoples of the North Caucasus [9, p. 108].

A number of folk sayings instill and cultivate a love for metal production. They captured the labor experience of their ancestors-masters of blacksmithing, jewelry and weapons and introduced their heirs to this experience. For example, all mountaineers know the saying: "A silversmith knows the price of silver"; "Cold iron

will not stretch." In the Karachay-Balkar Nart legends, the blacksmith-hero Debet enjoys well-deserved respect. The chain mail he made for the Marches is so strong that an iron arrow cannot pierce it and a damask dagger cannot destroy it. The legend "Debet the Blacksmith of the Narts" ends with Debet's call for people to study the "iron craft." The people valued the craft of a blacksmith so highly that they even attributed to the latter the ability of a surgeon. Thus, the "Karachay-Balkar" Debet riveted the skull of the evil-tongued Gilyakhsyrtan with a plate. This same information reached all subsequent generations of mountaineers through the Ossetian "Narts": the divine Kurdalagon puts a copper patch on Chelahsartan's broken skull. "Iron and steel are found in legends at every step" among other inhabitants of the Caucasus mountains: Chechens, Ingush, Dagestanis[3, p.121].

Many folklore monuments of the highlanders of the North Caucasus allow us to judge that the people, in the practice of labor education, sought to comply with certain rules. First of all, it should be noted his attention to the age characteristics of children. Above we described the range of activities and assignments performed by peasant children of various ages. But the economic and social conditions in which labor education was carried out often forced the Karachai and Balkar peasants to burden their children with hard, exhausting work. The peasant could not exist "without straining himself at work and without forcing his children to work twice as hard." This situation of peasant children, who often had to work on an equal basis with adults, was most accurately conveyed by the people in the well-known saying: "A poor man, without an ox, harnesses a calf," meaning by calf, the fragile, fragile body of a teenager, early harnessed to hard physical work [6, p.95].

Taking into account the labor experience of previous generations is also one of the main methods of labor education in the folklore of the Caucasian highlanders. In a number of fairy tales, sons listen to the advice of their father, who is on his deathbed and does not forget, even at such a fateful moment, to pass on his life experience to his heirs. In other fairy tales, the labor experience of ancestors is conveyed through the mouth of a nameless folk narrator.

Very often old women act as advisers and mentors, but often teachings also come from the mouths of young women. However, both in folklore and in reality itself, old people took priority in teaching the young minds. "He who has lived a lot has seen a lot," and someone who has seen a lot has something to share, for example, in preparing children for working life.

Clarification was of great importance in the practice of labor education. The children were explained what significance this or that work had in the life of the family, and how it should be done. While getting ready to harvest hay with his father, the son heard him explain why he had to be in such a hurry with the harvesting. It often rains in the mountains. And while the weather is sunny, you need to stack dry hay. If you don't have time to do this before the rains, it may rot, and

then during the long winter the cattle will be left without food. The main food of a mountain family is dairy products; not saving hay means, ultimately, starving yourself and losing food. The child often heard such simple and intelligible explanations from adults. This was especially noted when teaching teenagers any crafts. For a little girl who picked up knitting needles for the first time, her older sister or mother explained and showed how to hold the thread, how to pass it through a loop, and how to place her fingers on the knitting needles. The girls watched as their older sisters attached silk fringe to their scarves, forming intricate openwork braids, and they themselves sought to do the same [4, p. 238].

Thus, from here it becomes clear that his educational influence on the growing shift was also the same, which in turn brought closer and led to commonality the folk experience of education among all mountaineers.

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PHYSIOLOGICAL INDICATORS OF WATER METABOLISM IN PLANTS OF MEDIUM-FIBER COTTON SPECIES *G.HIRSUTUM* L. WITH DIFFERENT FIBER COLORS

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Abstract. *The creation and introduction of varieties of medium-fiber cotton with naturally dyed fiber allows you to save a lot of money spent on dyeing yarn and fabrics, and makes it possible to produce environmentally friendly, completely harmless to the human body, with antiseptic properties. The article presents the results of studies on the physiological indicators of plant water metabolism in medium-fiber cotton samples with colored fiber in different agro-ecological environments - under conditions of optimal water supply, limited water supply, and medium-level sulfate-chloride salinity. It was shown that there are differences in the physiological parameters of plant water metabolism in samples of medium-fiber cotton with colored fiber and their genetic response according to the studied traits to different cultivation conditions.*

Keywords: *cotton, G. hirsutum L., colored fiber, sample, physiology, trait, water regime, drought, variability.*

According to scientists, cotton fiber comes in various shades: white, cream, green, brown, i.e. brown [5].

The experiments were carried out in different agro-ecological conditions created using lysimeters. Under conditions of limited water supply, the simulated drought was created by a decrease in the number of irrigations in the flowering phase and the absence of irrigation in the ripening phase at an irrigation rate of 2800-3000 m3/ha of water, and under conditions of optimal water availability, irrigation was carried out at all phases of plant development at an irrigation rate

of 4800-5000 m3 /ha of water. The volume of irrigation water was measured using a UVK-20 apparatus. Other agricultural conditions were leveled out. Mineral fertilizers were applied according to the generally accepted rate, that is, during the growing season, 3 feedings were carried out with a total annual rate: N-250 kg/ha, P2O5-180 kg/ha, K2O-115 kg/ha. The first feeding was carried out at the beginning of budding, the second - at the height of budding, the third - at flowering.

Sowing was carried out manually with a plant arrangement of 60:25:1. The seeding depth is 4-5 cm. Samples were sown in three randomized repetitions, 10 plants in each repetition. Physiological analyzes of plant water metabolism were carried out in the flowering-fruiting phase simultaneously in all experimental variants, at a soil moisture level of 70% -72% of the maximum field moisture capacity (MFC) against the background of optimal water availability and salinity, as well as at a soil moisture level of 48% -50 % of PPV against the background of insufficient water supply.

For the corresponding laboratory physiological analyses, the top 3 leaves along the main stem, taken from 10 representative plants, were used. The total water content of the leaves, i.e. Leaf water content was determined using the described method [6]; The intensity of transpiration was determined according to A. A. Ivanov and others [2]; The water-holding capacity of leaves was determined according to the method of M. D. Kushnirenko and others [4].

Adaptation of varieties, lines, samples and hybrids to water stress conditions was determined by the percentage of decrease or increase in the indicators of the studied traits compared to the optimal background water supply [3]. At the same time, the adaptability coefficient (K.ad) was determined by the formula Kad.(%) = XI/X2 x100-100%, where X1 is the value of the trait against an unfavorable background, X2 is the value of the trait against an optimal background.

The results obtained for each studied characteristic were statistically processed using the analysis of variance method [1] to prove the significance of the difference between the samples through the F criterion. The generalized experimental error SH, the error in the difference in mean SD and the least significant difference (LSD) were calculated at a significance level of 0.05.

Medium-fiber samples of cotton of the species *G.hirsutum L.* with different fiber colors served as the object of research. - varieties Gulshan and Sadaf with white fiber, samples A-800, 010108, 04489,010765 with brown fiber, 011460 and A-2953 with green fiber.

Under conditions of optimal water supply, the highest indicators of leaf water content were in samples 011460, A-800 and A-2953, 78.8%, 78.1% and 78.0%, respectively. The lowest value of the trait was observed in the Gulshan variety with white fiber – 74.6%. In the remaining genotypes studied, leaf water content was in the range of 76.3 – 77.6%.

Compared to control, i.e. optimal water supply, with a deficit of soil moisture in all cotton samples, the water content of plant leaves decreased to varying degrees (from 5.0% for the Gulshan variety and sample 010108 to 10.3% for A-800). If we take the indicators of the optimal background water supply as 100%, then the deviations from them in percentage terms for the last two genotypes were -6.7% and -6.5%, respectively, i.e. these genotypes responded very weakly to changes in water supply conditions for this trait. The strongest response to water stress was demonstrated by samples A-800 and 011460, which, compared to the control, reduced leaf water content by 10.3% and 9.5%, respectively, based on the adaptability coefficient (CAD). In general, under conditions of limited water supply, the highest leaf water content was characteristic of samples A-2953 and 010108 (72.3% and 71.8%, respectively), while sample A-800 had the lowest value of the trait - 67.8%.

Under salinity conditions, among the studied cotton samples, the highest indicators of leaf water content were samples 04489,A-800 and the Sadaf variety (75.7%, 75.1% and 75.1%, respectively). For the remaining samples, except for 011460, the water content of the leaves was 73.3-73.9%, and for 011460 -74.8%. Compared to the control, under salinity conditions in all studied cotton samples, the water content of the leaves decreased to varying degrees, which was especially evident in samples 010765, A-2953 and 011460, in which the decrease in the indicators of this trait compared to the control was 4.0-4 .3%. Samples 04489 and the Gulshan variety had weak reactions for this trait to different backgrounds, in which the decrease was 0.6% and 0.7%, respectively. It is interesting to note that, compared with the data of limited water availability, under salinity conditions all samples had higher leaf water content, especially the A-800 sample and the Sadaf variety (an increase of 7.3% and 6.5%, respectively).

Under conditions of optimal water supply, the intensity of leaf transpiration was the highest in samples Sadaf, A-800 and 010765 (140.68 mg, 137.87 mg and 135.45 mg, respectively) and the lowest in samples A-2953 and Gulshan (91.34 mg, respectively) and 96.38 mg). The remaining samples took an intermediate position in terms of the value of the trait.

Under conditions of limited water supply, the intensity of leaf traspiration decreased to varying degrees in all studied cotton samples. At the same time, samples 04489, 011460 and A-800 had relatively high indicators of this trait, 74.77 mg, 69.63 mg and 69.07 mg, respectively). According to the adaptability coefficient (Kad.), according to the intensity of transpiration of plant leaves, the Sadaf variety responded most strongly to water stress, in which the decrease compared to the control was 59.3% and a weaker reaction was noted in the Gulshan variety, samples 04489 and 011460 (decrease by 34.4%, 36.5% and 37.7%, respectively).

Under salinity conditions, plants of samples 010765 and A-800 had high leaf transpiration rates, respectively - 130.38 mg and 125.74 mg. The lowest value of the trait was in sample A-2953 – 40.57 mg. Compared to control, i.e. with the option of optimal water supply, under salinity conditions, the intensity of leaf transpiration decreased to varying degrees in all samples. The maximum decrease was observed in sample A-2953 (by 55.6%0, the minimum - in sample 010765 (by 3.7%). Compared to the background of water deficiency, under salinity conditions in sample A-2953 the intensity of transpiration decreased by 14%. leaves, and in other samples, on the contrary, an increase in the intensity of leaf transpiration was observed from 5.9% (94489) to 96.1% (010765).

Under conditions of optimal water supply, the variety Sadaf (22.1%) and samples 010765, A-800 and 04489 (21.6%, 20.6% and 20.3%, respectively) had a relatively low water-holding capacity of leaves, and the variety Gulshan, on the contrary, it had the highest leaf water-holding capacity of 15.8%.

With a shortage of irrigation water, the water-holding capacity of the leaves increased in all cotton samples studied experimentally, but to varying degrees. Under these conditions, the highest value of the trait was in sample A-2953 with a red bush and green fiber - 10.4%, while in samples 04489 and A-800 lower water-holding capacity of leaves was noted (respectively, 15.8% and 15 .0%) than in the other studied genotypes. Judging by the indicators of Kad., the Sadaf variety responded more strongly to water stress for this trait, in which the water-holding capacity of the leaves significantly increased in these unfavorable conditions of water supply, compared to other samples.

Under salinity conditions, sample A-2953 had a high water-holding capacity of leaves - 9.2%; the lowest values were for samples 010765 and A-800, 20.2% and 20.0%, respectively. Compared to control, i.e. condition of optimal water supply, under salinity conditions, the water-holding capacity of leaves increased to varying degrees, especially to a strong extent in sample A-2953 (by 47.4%), a slight increase was in sample A-800, Gulshan and 010765 (by 2.9 %,6.3% and 6.5%). Compared to the background of limited water supply, under salinity conditions in the studied cotton samples, the water-holding capacity of leaves increased from 20.9% in the Gulshan variety to 43.4% in the Sadaf variety.

Thus, the conducted studies showed the presence of differences in the physiological indicators of plant water metabolism in samples of medium-fiber cotton with colored fiber in different agro-ecological conditions, which must be taken into account when carrying out genetic breeding work on colored cotton.

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USAGE OF USEFUL PLANTS BY ETHNIC POPULATIONS OF AZERBAIJAN

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Abstract. *The study reported on the attitudes of ethnic groups living in Azerbaijan towards the issue of plant use. From the study, it is clear that equal utilization of useful wild plants by different ethnic groups is important to maintain peaceful coexistence among different ethnic groups. The science of ethnobotany combines precisely these issues, and this science includes several areas that are truly transdisciplinary; it is the main bridge between sociocultural and natural medical sciences. More importantly, ethnobotanical research is important for improving human livelihoods, health and well-being. During the conducted research, the latest methodologies were applied and numerous data were collected. According to records in the study area, some plants were found to be used more than others: thyme 45 times, rosehip 2 times, hollyhock 19 times, sage 18 times, hogweed 15 times, and other species were used 1-14 times among all ethnic groups due to its useful properties.*

Keywords: *ethnic group, population, ethnobotany, useful plants.*

Introduction

The collection and consumption of wild industrially important plants are still traditional practices applied in many parts of the world, and increasing their importance in food security, as well as in meeting the need for natural-based medicines and nutritional supplements rather than synthetic therapeutics, has been increasingly discussed in recent years [Bharucha and Pretty, 2010; Neudeck et

al., 2012; Nolan and Pieroni, 2014; Ong and Kim, 2017; Shaheen et al., 2017; Shumsky et al., 2014; Ibadullayeva et al., 2017].

Although the traditional methods of using medicinal and food plants are widespread among ethnic groups, in some countries of the world, the shortage of medicines and food remains an actual issue today [Ibadullayeva, 2013; 2017; 2020; Heywood 2013], indicating that there is a lack of knowledge about ways to use wild industrially important plants. The various aspects and scale of such searches have been in constant focus by local communities in many regions of the world.

The industrialization of wild industrially important plants in the world, especially in the southern and eastern regions where these practices are still alive, threatens the mass collection of traditional useful plants as a result of the social role of women. Cultivation of wild plant resources to maintain health and well-being is an important issue, and the search for traditionally used plants among communities is not taken very seriously by scientists [Cucinotta and Pieroni 2018; Saytar and Ibadullayeva et all., 2020]. Furthermore, these two aspects are not only factors that slow down the decline of traditional foraging, but also create the need to the new trend of wild plant foods and folk medicine methods that sometimes spread among communities, including to new experiment with the "back to nature" effect.

Material and methods

The research was carried out in all economic-geographic regions of Azerbaijan in 2010-2022, interviews were conducted mainly in villages inhabited by different ethnic groups and detailed information about the ways of using plants was collected. Survey respondents included middle-aged and elderly local communities, teachers, pharmacists, farmers and shepherds, who were identified as predominantly indigenous knowledge holders who knew the plants.

Verbal consent was always obtained before each interview and the Code of Ethics of the International Society for Ethnobiology (ISE 2008) was followed. Semi-structured interviews were conducted in Azerbaijani. During the interviews, attention was paid to the wild plants collected and consumed from the areas and the following were the most frequently listed: wild plants for making shirnak (the initial mixture of the fermentation process) in baking or making yogurt or wild plants used in homemade fermented products; wild fruits used in sweet preserves and other wild plants or berries used in liqueurs; wild plants used for medicinal herbal teas; edible mushrooms in hot dishes and preserved in salt. We also noted several unusual uses of cultivated plants. For each of the listed plants, local names, exact details for harvesting and use were mentioned.

Field study was conducted in spring and fall of each year. The industrially important wild plants used from the flora of Azerbaijan were determined by classical methods [Flora of Az., 1950–1961], their compatibility with modern nomenclature, "The Plant List" database (2013) was specified, determination of families

were conformed with the "Angiosperm Phylogeny Website" (Stevens, 2017). Collected herbarium specimens were transferred to the Herbarium Fund of the Institute of Botany. Dried plant samples are packed and stored in the Ethnobotany Department of the Institute of Botany.

All local plant names are transcribed in Azerbaijani (for Azeri, Tat, Molokans, Lezgi, Avar, Kurdish, Lahij, Talish and Udi folk names).

The data were compared with the worldwide literature on wild food plants [Facciola 1990; Hedrick 1919; Pieroni et al. 2017, 2018; Cakır 2017; Marouf və başqaları 2015; Tanaka 1976], as well as ethnobotanical studies of wild plants conducted in the last 10 years [Munir et al., 2018; Ibadullayeva et al., 2010-2022].

The degree of suitability of each plant in the treatment of various diseases by the local population is determined by data use value (UV) [Philips OL, et al., 1994].

$$UV= \sum U/n$$

where U is the number of references given by each informant about the use of the plant species, n is the number of respondents.

Conclusions and discussion

Although the search for industrially important plants in wild flora in society is defined as the search for food resources by wild animals in behavioral ecology, in human ecology, it is considered an adaptive strategy that assigns to both hunter-gatherer societies and, to a lesser extent, horticultural and especially local communities.

For more than 10 years, researches related to the ethnobotanical evaluation of Azerbaijan and the collection of industrially important wild plants of the local flora have been started, including, it was considered important to pay special attention to the study of the ways of using plants by local communities and religious-ethnic groups. It is appropriate to carry out these studies in the following directions: traditional collection and research of industrially important wild plants in the country in a systematic manner during the last few decades; tolerance reigns in our country, it is home to various ethnic groups in terms of language and religion, and determination of ways to preserve the culture of collecting food, fodder, medicine, vegetables, aromatic plants and folk medicine as part of their heritage; the country has a low Global Food Security Index (GFSI 2018) and neglected fodder, medicinal, vegetable, technical and food plant resources are considered particularly important among communities, including refugees and displaced persons, and can play a role in formulating policies based on their appropriate use. Here, as a result of the 30-year war with Armenia, the vulnerable population in terms of food security was especially taken into account.

Although the population in Azerbaijan is mainly Azerbaijanis, in the botanical-geographical regions of the Greater Caucasus, Tats mainly live in the mountainous areas of the region - in Lahic settlement, Gandab, Namazgah, Zarnava, Mushkamir, Mudru, Ahan, Eregit, Brovdal, Zarat and etc. The Tats were moved to the Greater Caucasus 1600 years ago, during the time of the Sasanians (Yazdigird, Khosrov Anushiravan), to prevent raids by nomadic Turkic tribes (Khazar, Khaylandur, Hun, Kenger, Savir) to the northern borders of the empire in the IV century and to spread Zoroastrianism among the local population (they were moved from the south and south-west areas of Iran (Isfahan, Tabiristan, Lahijan, etc.) to the north-east areas of Azerbaijan and the Caspian Gate. The word "Tat" was formed on the basis of the name given by nomadic Turkic tribes to sedentary tribes.

Lezgis live in Galajik, Ivanovka, Sumaghalli, Istisu, Gurbanafandi and other villages. 12 km from the Ismailli district center, in the front mountains of Ajinohur, is the village of Ivanovka, the main inhabitants of which are ethnic Molokans living under the former Soviet-communal economic system. These are the successors of the Molokan sect worshipers of orthodox christians.

The selected communities (Azeris, Tats, Udis, Lezgis, Avars, Talish, Lahijs) lived in the studied areas for many centuries, while the Molokans came from Russia in the 19th century, and the Azerbaijanis who were refugees from Karabakh came to their villages about 27 years ago (Photo-map).

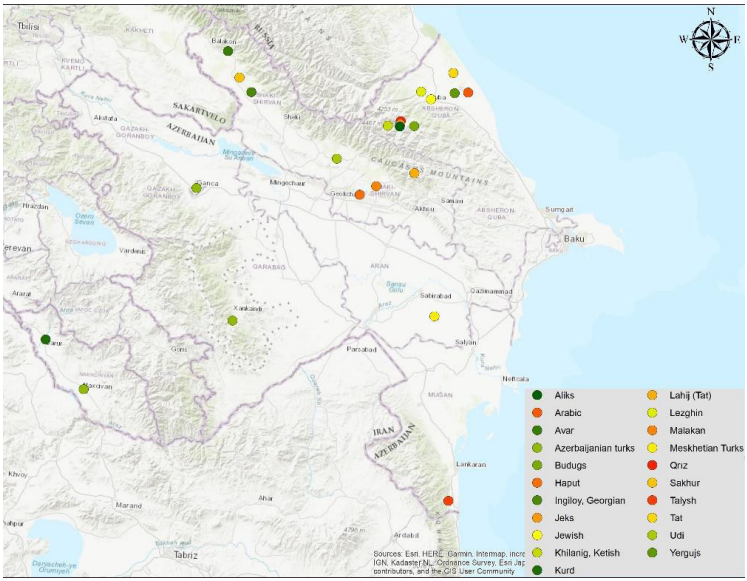

Photo-map. Areas inhabited by ethnic groups

Taking all this into account, the following goal was achieved in developing the article:: To note useful plants traditionally used among 8 communities living in Azerbaijan with different language, ethnicity and religion; to compare data between communities to illustrate cultural markers of food plants and folk medicine practices, as well as, to compare the same data with neighboring countries, to familiarize with food ethnonomy and to formulate hypotheses to clarify possible differences.

The collection and consumption of industrially important plants is a traditional practice in many countries around the world, and their role in enhancing food security has been increasingly discussed in recent years. The research conducted in this field is dedicated to the traditional use of industrially important plants among different ethnic groups living in Azerbaijan (Tats, Lezgins, Talysh, Lahijs, Avars, Udis, Kurds and Molokans). From data obtained through interviews with 8 ethnic communities more than 200 folk taxa used as wild medicines, vegetables, and food additives were registered. Talysh and Udis living in Azerbaijan use a limited number of industrially important wild plants compared to other groups, in contrast, on the contrary, ethnobotany is displayed in the most different ways by Tats and Lahijs (more than 50 folk taxa used by them alone were identified), which may be due both to their geographic isolation and to the fact that just a few decades ago these communities were endogamous.

While the plant cultural signs of Azerbaijani Turks are mainly preserved by communities from Karabakh and living in the territory of the Nakhchivan Autonomous Republic, the Molokans, who represent a different, conservative ethno-religious group, mainly belonging to the Slavic peoples living in the Greater Caucasus and relatively (only 2-3 families in one neighborhood) territory of Nakhchivan AR, have their own worldviews. Thus, they preserved the use of wild plants in several ancient Slavic culinary practices, including they used trees and shrubs for technical purposes (making tanks, dishes, doors, roofs, fences, etc.) and medicinal plants for specific purposes.

An ethnobotanical study was conducted on wild vegetables traditionally used among communities in the villages where Kurds live in Azerbaijan. Most of the informants through interviews were representatives of the older generation. Folk usage methods of more than 40 plants were identified and recorded. Some of these plants are also cultivated by them. The study shows that in the peaceful coexistence of different cultural and religious groups, it is important that the areas are rich in local wild plants and that they are used equally.

Tat and Lezgi used berberry, different species of cherry plum (especially as an original lacto-fermented preparation) and medicinal plants such as hollyhock, dock, mint, cephalaria, yarrow etc. from local taxa, Udi used vegetable oyster, alexander, onion species to the same extent as the Azeris, Azerbaijani Turks pre-

ferred medicinal plants. Azerbaijanis, the country's main inhabitants, use up to 600 vegetable plants directly from wild flora in more than 1,000 traditional medicine methods. In general, the traditional practice of industrially important plants is more pronounced in the most remote mountainous areas of Azerbaijan, and this heritage is the result of a complex co-evolution. Both human ecological trajectory and cultural attachment to certain tastes played a role here, and a special search for plants has formed itself in patterns over the centuries.

For each nation, the local names of the families and species, the plant parts used, the precise details of their use in folk medicine, technical purposes, and cooking, and the frequency of citations were studied (table 1). Ethnic groups settled in the territories as follows: on Gakh district Georgians - Ingiloys, Tsakhur, Lezgins, Avars; Shaki district -Lezgins, Kurds, Avars, Georgians - Ingiloys; Zagatala: Tsakhur, Lezgins, Udis, Kurds, Georgians - Ingiloys, Avars; Balakan: Lezgins, Kurds, Avars, Georgians - Ingiloys, Mountain Jews; Oghuz district: Lezgins, Kurds, Jews, Udis, Avars; Gabala district: Lezgins, Udis, Turks; Ismayilli district Lezgins, Tats, Lahijs; Masalli, Lankaran, Lerik district Talysh; Shamakhi district Tats, Molokans; in Sharur district of Nakhchivan Autonomous Republic Kurds, Nakhchivan city Molokans; Azerbaijani Turks who have become refugees in the Karabakh administrative region live in villages included in the botanical geographical regions of the Lesser Caucasus, as well as in other regions. Information about traditionally collected and consumed wild plants was collected and it is planned to be published in book format in the near future.

Table 1.

Plants used among ethnic groups and frequencies of their usage

№	Latin names of medicinal plants used among ethnic groups	Local names of medicinal plants used among ethnic groups as used by ethnos	UV
1.	Adonis aestivalis L.	Khoruzgili	0,34
2.	Alcea rosea L.	Gulkhatmi	0,67
3.	Allium cepa L.	Soghan	0,87
4.	Allium sativum L.	Sarimsag	0,91
5.	Amaranthus albus L.	Amarant, pancar	0,56
6.	Anethum graveolens L.	Shuyud	0,66
7.	Asparagus officinalis L.	Marachoyud	0,75
8.	Astragalus dasyanthus Pall	Gavan	0,44
9.	Arctium lappa L.	At pitraghi	0,60
10.	Athyrium filix femina (L.) Roth	Galkhansiz	0,38
11.	Berberis vulgaris L	Zirinj	0,69
12.	Bifora radians Bieb.	Daghkeshnishi	0,51

13.	Bistorta carnea (C.Koch) Kom.	Bistorta	0,33
14.	Brassica juncea (L.) Czern	Khardal	0,73
15.	Bryonia alba L.	Kustusham	0,56
16.	Bupleurum tenuisssimum L.	Okuzboghan	0,29
17.	Capsella bursa-pastoris (L.) Medik	Gushappayi	0,74
18.	Capsicum annum L.	Girmizi bibar	0,66
19.	Castanea sativa Hill.	Shabalid	0,79
20.	Carum carvi L.	Zire	0,73
21.	Cephalaria gigantea (Ledeb.)Bobr.	Gantapar	0,82
22.	Ceratonia silinqua L.	Kechibuynuzu	0,84
23.	Celtis caucasica Willd.	Daghdaghan	0,56
24.	Centranthus longiflorus Stev.	Mahmizchichak	0,45
25.	Citrus limon (L.) Burm.	Limon	0,75
26.	Citrus sinensis (L.) Osbeck	Portaghal	0,66
27.	Clematis orientalis L.	Aghasma	0,47
28.	Coriandrum sativum L.	Keshnish	0,70
29.	Crataegus curvisepala Lindm.	Yemishan	0,61
30.	Cucumis sativus L.	Khiyar	0,57
31.	Cydonia oblonga Mill.	Heyva	0,62
32.	Cynara scolymus L.	Anginar	0,48
33.	Datisca cannabina L.	Dalichatana	0,37
34.	Daucus carota L.	Yerkoku	0,39
35.	Dryopteris filix-mas. (L.) Schott	Ayidosheyi	0,23
36.	Equisetum arvense L.	Gatirguyrughu	0,65
37.	Elaeagnus angustifolia L.	Iyda	0,72
38.	Eremogone dianthoides (Sm). İkonn.	Gumluja	0,39
39.	Eremurus spectabilis Bieb.	Chirish	0,72
40.	Elymus repens L.	Ayrigotu	0,36
41.	Ferula communis L.	Chashir	0,23
42.	Ficus carica L.	Anjir	0,57
43.	Foeniculum vulgare Mill.	Razyana	0,78
44.	Fumaria officinalis L.	Shahtara	0,64
45.	Galega officinalis Lam.	Kechisadafi	0,57
46.	Glycyrrhiza glabra L.	Biyan	0,79
47.	Gypsophila paniculata L.	Choghan	0,46
48.	Helichrysum plicatum DC.	Solmazchichak	0,42
49.	Hippophae rhamnoides L.	Chaytikani	0,58
50.	Hordelymus europaeus (L.)Harz.	Arpa	0,33
51.	Humulus lupulus L.	Mayaotu	0,59

52.	Hypericum perforatum L.	Daziotu	0,81
53.	İnula racemosa Hook.f	Andiz	0,34
54.	Juglans regia L.	Qoz	0,63
55.	Juniperus oblonga Bieb.	Ardij	0,34
56.	Laurus nomilis L.	Dafna	0,41
57.	Lavandula angustifolia Mill.	Lavanda	0,59
58.	Lepidium sativum L.	Tara	0,66
59.	Levisticum officinale Koch.	Yabani karaviz	0,60
60.	Lolium temulentum L.	Dalija	0,42
61.	Malus domestica Borkh.	Alma	0,56
62.	Malva neglecta Wallr.	Amakomechi	0,61
63.	Matricaria chamomilla L.	Chobanyastighi	0,80
64.	Medicago sativa L.	Garayonca	0,71
65.	Melissa officinalis L.	Badranj	0,83
66.	Mentha longifolia (L.) Huds.	Nana	0,92
67.	Mentha pulegium L.	Yarpiz	0,89
68.	Mesipulus germanica L.	Azgil	0,67
69.	*Momordica charantia L.	Gudrat nari (Aci govun)	0,54
70.	Morus alba L.	Tut	0,75
71.	Nigella orientalis L.	Chorekotu	0,87
72.	Olea europaea L.	Zeytun	0,68
73.	Orchis purpurea Huds.	Sahlab	0,69
74.	Oxalis acetosella L.	Guzu gulaghi, turshang	0,53
75.	Papaver somniferum L.	Khashkhash	0,32
76.	Pastinaca sativa L.	Ximi-havuc	0,77
77.	Peganum harmala L.	Uzarlik	0,72
78.	Persicaria hydropiper (L.) Delarbre	Subibari	0,44
79.	Petroselinum crispum (Mill.) Fuss.	Jafari	0,78
80.	Polygonum aviculare L.	Girkhbughum	0,56
81.	Populus alba L.	Govag	0,49
82.	Potentilla reptans L.	Qaytarma	0,43
83.	Pimpinella angustifolia Gilib.	Yalanchi jira	0,66
84.	Prunus domestica L.	Gavali	0,44
85.	Prunus armeniaca L.	Arik	0,32
86.	Prunus avium L.	Gilas	0,57
87.	Prunus cerasifera Ehrh.	Alcha	0,61
88.	Prunus dulcis D.A.Webb	Badam	0,32
89.	Punica granatum L.	Nar	0,69
90.	Pyrus caucasica Fed.	Armud	0,45
91.	Rhamnus pallasi Fisch.& C.A.Mey	Murdarcha	0,51

92.	Rheum ribes L.	Ushghun, qaraghatvari ravand	0,56
93.	Rhus coriaria L.	Sumag	0,78
94.	Rosa canina L.	Itburnu	0,89
95.	Rubus ideaus L.	Boyurtkan	0,78
96.	Rumex acetosa L.	Avalik	0,67
97.	Salix caprea L.	Soyud	0,41
98.	Salvia officinalis L.	Adachayi	0,80
99.	Sambucus nigra L.	Gandalash	0,41
100.	Secale cereale L.	Chovdar	0,32
101.	Sedum stevenianum Rouy&E.G.Camus	Dovshankalami	0,26
102.	Sesamum indicum L.	Kunjut	0,43
103.	Silene humilis C.A.Mey.	Goyunqulaghi	0,25
104.	Silybum marianum (L.)Gaertn	Davatikani	0,58
105.	Solanum nigrum Acerbi ex Dunal	Garagile	0,34
106.	Solanum lycopersicum L.	Tomat	0,63
107.	Solanum tuberosum L.	Kartof	0,57
108.	Sorbus aucuparia L.	Qusharmudu	0,46
109.	Stellaria holostea L.	Jinjilim	0,43
110.	Spinacia oleracea L.	Ispanag	0,60
111.	Tamarix ramosissima Ledeb.	Yulghun	0,37
112.	Tanacetum vulgare L.	Daghtarkhunu	0,49
113.	Taxus baccata L.	Garachohre	0,37
114.	Thymus vulgaris L.	Kaklikotu	0,84
115.	Thuja orientalis L.	Sharg tuyası	0,37
116.	Tilia cordata Mill.	Joka	0,78
117.	Tribulus terrestris L.	Damirtikan	0,45
118.	Triticum durum Desf.	Bughda	0,55
119.	Ulmus glabra Huds.	Garaghaj	0,36
120.	Urtica dioica L.	Gijitikan	0,82
121.	Vaccinium myrtillus L.	Garagile,marjangile	0,68
122.	Valeriana officinalis L.	Pishikotu	0,71
123.	Verbascum pyramidatum M.Bieb.	Sighir guyrughu	0,56
124.	Viola tricolor L.	Uchrang banovsha	0,43
125.	Wendia incana (Boiss.&A.Huet) Grossh. (syn.=Heracleum albovii Manden)	Baldirghan	0,39
126.	Zea mays L.	Garghidali	0,56
127.	Ziziphus jujuba Mill.	Innab	0,61
128.	Zosima absinthifolia Link.	Atilbatil	0,45

A small part of the plants is collected near villages in spring (this is synanthropic weeds, especially for Udis and to a lesser extent for Molokans), while most of the plant elements are collected from hayfields and pastures up to the mid-mountain belts. Wild plants are collected by both women (mostly herbs) and men (especially species relatively far from villages), while wild fruits and berries are mainly collected by young community members and consumed locally.

An ethnobotanical study of the traditional use of wild vegetables was conducted in the villages where Kurds live in Azerbaijan. The data was mainly collected through interviews with elderly people (52 persons) about the folk use of more than 35 plants. Differences in the use of wild vegetables among Kurds and other ethnic groups were observed. They use wild vegetables widely in animal feeding.

According to records from the study areas, some plants were used more frequently than others by all ethnic groups. Among them, thyme, rosehip, hollyhock, and sage are used by almost all ethnic groups for their medicinal properties.

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PLANTS UNDER INDUSTRIAL AND MILITARY STRESS (POLEMOSTRESS)

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Abstract. *The territory of modern Donbass is a huge testing ground for intensive influence on natural ecosystems. Over the years of industrialization from the 19th century to the present day, extremely unfavorable environmental situations have developed in the Donetsk economic region. The most basic indicator of endurance is the air, water and soil pollution index. But these were historical and economic prerequisites. The main thing that is happening in Donbass now is active hostilities that are destroying landscapes and introducing a huge amount of additional pollutants of a chemical and physical nature. Previously studied indicator plants (as indices of pollution from industry) began to be intensively used to indicate high levels of exposure to military action (2014-2023). Our task is to highlight evolutionary directions and establish trends in the structural transformation of plant organisms in the conditions of both outdated industrial geochemical provinces and new disturbances of the natural environment. Also, with this publication we are trying to attract the attention of the scientific community to what is happening on the territory of modern Donbass - in the industrial center of Eastern Europe.*

Keywords: *phytoindication, polemostress, environmental monitoring, Donbass, ecosystem transformation, ecological analysis, plant survival strategies.*

In the current agenda for the development of industrial regions, monitoring environmental risk processes and the state of public health is fundamentally important. Issues of assessing the state of the environment are the object of study by many experimenters and analysts [1-5]. In the basic studies that we carried out from 2014 to 2023, many observations were made of the state of the natural environment, indicator plant species were identified, and indicators of plant response to the influence of factors in the technogenic environment were generalized, especially in the context of the increasing impact of war on the territory of Donbass.

The main purpose of this publication is to highlight trends in changes in plants that are indicators of structural transformation with increasing militarization of the region. At the same time, we use the basic term - polemostress - as a process of active adaptation of plants in conditions of active military operations.

To diagnose the state of the environment in the Donbass (the current state of geochemical contrast), many different methodological approaches and techniques were used to obtain adequate data and average statistical background indicators, on the basis of which it was necessary to identify zones of direct impact from local transformations. With the help of our colleagues from international institutes for chemical and ingredient analysis of plants, we have established the characteristics of pollution with various toxic elements [6, 7], built monitoring maps, laid out monitoring networks and established locations for permanent and mobile observations of the state of the natural environment [8].

We used multivariate analysis, statistics, field collections of results, monitoring and laboratory studies, analyzed the state of plants and related processes occurring in landscapes. It was a situation that was dangerous to life and health - collecting material on plants under conditions of shelling, explosions, and the action of numerous unfavorable factors.

We applied the method of ecological scales for plants that have indicator properties [9], summarized information about phytoindicative monitoring and phytomonitoring studies in general for Donbass [10] and Donetsk as a central city in particular [11, 12]. Using previously collected conceptual approaches in assessing the state of industrial ecosystems [13], we proposed a method for analyzing a bank of seeds that are preserved in the soil for a long time as reserve organisms for restoration and indication of the state of disturbed ecosystems [14]. These data were also supplemented by the results of a rapid analysis of the embryonic structures of indicator plants [15]. We separated the available data and published facts into separate headings during bibliographic analysis [16] and ecological-toxicological analysis of the state of plants under conditions of military action [17]. In recent years, based on the data obtained, we have developed a method for an integral assessment of the state of ecosystems based on generalized information [18], as well as based on data on plant teratogenesis in these conditions of the state of ecosystems in the Donetsk economic region [19]. The need for such research is consistent with the international environmental agenda and the requirements for the implementation of experiments to establish adverse effects on the ecosystems in which people live [20-22].

The Department of Botany and Ecology is an integral part of Donetsk State University. There is no revelation in this. All employees and students carry out both educational, scientific and other types of work to the required extent. A year ago, we registered the scientific direction “Botany of Anthropotechnogenesis: In-

dication and Optimization" at the state level. And this capacious scientific name combines all those regional and exclusive tasks that the team entrusted to me conscientiously performs. Our hydrobiologists have achieved special achievements in monitoring the Kalmius River basin (under the leadership of Eduard Mirnenko), a lot is being done to understand the development of vegetation on waste heaps and in urban systems (developments by Angela Kalinina), attempts have been made to form a digital herbarium (headed by Tatyana Demyanenko); an important indicator of air quality is allergenic pollen (topic curator – Natalya Mirnenko). It must be admitted that all these topics are included in the roadmap for cooperation between our university and M.V. Lomonosov Moscow State University.

It is more correct to calculate damage and suffering based on the fact. Those since the onset of peaceful life. Everything that is done in the process is just blanks. In botanical diversity there are many contradictory indicators: the percentage of adventive (alien) species is definitely growing, the phenomenon of landscape transformation and the associated process of evolutionary adaptation of plants to new realities are definitely intensifying. But from the point of view of science it is important to understand that you cannot operate "badly" and "goodly" - this is natural for the created conditions. Exactly what needs to be preserved is those 4% of the Donbass territories that today constitute a natural reserve fund; these are unique and standard areas of our land. And the biodiversity in cities and farmland - all this is absolutely quickly saturated in the process of peaceful life.

In the near future, it is necessary to initiate the formation of a full-fledged release of the next bibliographic publication "Ecology in the Donetsk People's Republic (2019-2023)". This will be the 5th issue of the publication, in which I have been serving as a scientific editor since 2000 at the request of our central library named N.K. Krupskaya. Ecology uniquely unites all areas of human employment, all branches of production, all the latest technologies for life. And the bibliography structures everything - it will be a chronicle of our achievements and a bank of ideas in the pursuit of harmonious development.

Ingredient analysis in bioassays and soil samples was carried out in the laboratory of analytical chemistry of Donetsk State University (Donetsk), in the monitoring department of the State Committee on Environmental Policy and Natural Resources (Donetsk) and the laboratory of the Joint Institute for Nuclear Research (Dubna). The system of priority pollutants identifies active forms of heavy metals, rare earth elements and a few other elements that exhibit toxic effects on plant organisms. All identified terat manifestations (exposure of monitoring work from 1996 to 2023) are regarded as examples of phenotypic plasticity of plants in specific geolocalities with established high concentrations of toxic elements of technogenic origin. The non-heritable endemicity of the established structural transformations of plants has been proven.

The basic methodology of the experiment being implemented is the method of identification and statistical accounting of manifested plant polymorphism, which is actually expressed in registered plant teratomorphs mainly at the anatomical and morphological level. The system of methodological approaches to the implementation of the botanical-ecological monitoring program has been described previously. According to the functional gradient of studying natural environments using indicator plants, several fundamentally different blocks of information collection are identified: 1) according to physical-chemical and botanical-geographical patterns in the analysis of nonlinear processes in phytocenology and mechanisms that ensure the stability of biosystems; 2) territorial-ecological zoning in terms of unfavorable environmental factors, pollution by individual elements, groups of elements, biotic interactions; 3) methods of data visualization and visual procedures for decision-making in management at the regional level in balance sheet systems.

As a result of geochemical screening, 22 technogenic provinces of the following groups (or monotypic) pollution were identified: Cu-Sb-La (48001’10.2’’N; 37047’26.3’’E) – petaloid transformation of leaves of Capsella bursa-pastoris (L.) Medik., dystopia of leaf arrangement and change in the branching pattern of Polygonum aviculare L.; Rb (48001’22.1’’N; 37048’03.1’’E) – shortening of the axis due to crowding of inflorescences of Bromopsis inermis (Leyss.) Holub; hypogenesis and fasciation of shoots of Diplotaxis muralis (L.) DC., dystopia of leaf arrangement of Galinsoga parviflora Cav., fasciation of sporophyte axes of Campylopus pulvinatus (Hedw.) Brid.; Tb-U (48001’22.9’’N; 37048’50.3’’E) – specialization of retort-shaped trichomes and polymerization of leaves of Tripleurospermum inodorum (L.) Sch. Bip., atypical proliferation of the sporophyte of Bryum caespicium Hedw.; Nd-Zr (48000’34.2’’N; 37047’22.4’’E) – false branching of inflorescences (splitting) of Sisymbrium polymorphum (Murray) Roth; hypergenesis of Plantago lanceolata L. leaves; Pb (48000’35.7’’N; 37048’00.1’’E) – fasciation of inflorescence axes and matrix heterocarp of Senecio vulgaris L., proliferation of flowers and inflorescences of Plantago major L.; Zn-U (48000’35.5’’N; 37048’56.2’’E) – folding and deformation of the leaf blade of Berteroa incana (L.) DC.; Ni-Ta (48000’10.3’’N; 37047’34.0’’E) – hypogenesis of the Calamagrostis epigeios (L.) Roth shoot, twisting and bending of the stem, teratological schizocotyly of Reseda lutea L., hypogenesis of the Didymodon purpureus leaf (Hedw.) Hook. & Taylor; Co-Sb-La (47059’49.2’’N; 37047’52.4’’E) – terate pollen grains and fasciation of inflorescence axes of Dactylis glomerata L., fasciation of shoots of Centaurea diffusa Lam.; Hg-Eu (47059’47.1’’N; 37048’32.0’’E) – dystopia and deformation of the shoot of Atriplex patula L.; Al-Yb-Th-Ce (47059’32.8’’N; 37047’46.6’’E) – proliferating flowers, specialization of filamentous trichomes of Cichorium intybus L.; Ni-Sm (48001’55.3’’N; 37053’45.7’’E) – polymerization of the shoot of Amaranthus retroflexus L.; Cs-Ce-Zr-Zn (47059’56.1’’N; 37058’25.5’’E) – ma-

trix heterocarp of Stellaria subulata Boeber ex Schlecht., petaloid transformation of leaves of S. polymorphum; Ti-Sb (48004’27.9’’N; 37058’27.6’’E) – teratological syncotyly of Atriplex mircantha C.A.Mey., folding of the leaf blade of Fumaria schleicheri Soy.-Willem, proliferation of flowers of Convolvulus arvensis L.; Fe-Cs (48002’28.5’’N; 38006’53.0’’E) – hypergenesis of leaves and hypogenesis of shoots of Glaucium corniculatum (L.) Rudolph; Co-Eu (48003’00.7’’N; 38009’56.1’’E) – teratological schizocotyly of C. intybus; matrix heterospermy of Gipsophila paniculata L., change in the characteristic shape of the leaf blade of Cirsium arvense (L.) Scop.; Cu-Sr-W (48001’24.0’’N; 38010’15.8’’E) – choriza of flower organs and disturbance of the branching pattern of the shoot of Tanacetum vulgare L., fasciation of the gametophyte axes of Brachythecium campestre (Müll.Hal.) Bruch et al.; – Hg-Sb-Cd (48004’05.9’’N; 38015’09.1’’E) – proliferation of flowers and inflorescences of P. major, proliferation of inflorescences of Moehringia trinervia (L.) Clairv.; Dy-Yb-Cd (48001’36.2’’N; 38015’39.7’’E) – dystopia of gametophyte elements in the general architecture of the growth of Ceratodon purpureus (Hedw.) Brid, choriza of various parts of the Chenopodium album L. flower, fasciation of inflorescence axes of Cyclachaena xanthiifolia (Nutt.) Fresen.; Ni (48000’49.5’’N; 38016’15.8’’E) – teratological syncotyly of Dianthus campestris M. Bieb, false branching of inflorescences, habitual terata of C. intybus; Fe-Hf (48002’56.6’’N; 38028’28.8’’E) – oligomerization of the leaf blade of Sagina procumbens L.; flower proliferation of Nigella arvensis L.; Cu-Yb (48001’17.0’’N; 38038’29.2’’E) – fasciation of leaf blades of Portulaca oleracea L., dystopia of the gametophyte Chamberlainia salebrosa (Hoffm. ex F. Weber & D. Mohr) H. Rob.; – Hg-Sc-Zr (48002’18.9’’N; 38046’02.3’’E) – dystopia of leaf arrangement of Alsine media L., hypogenesis of the shoot of Chelidonium majus L.

There may be many reasons for the manifestation of atypical heterogeneity, however, particular examples of indication confirm the presence of information correlations of several signs of a structural-functional nature or in accordance with macroclimatic trends, for example, when stating a general tendency in the manifestation of xeromorphic characters. In field studies to establish the structural and functional heterogeneity of plants, technogenic ecotopes are ranked in descending order of impact toxicity: from metallurgical and coke-chemical enterprises, through mining and processing complexes, as well as ruderal polygons to urban landscapes and residential areas in the Donbass.

An important step in the experiment to calculate the overall teratogenicity of a territory was to identify the most significant part (more mobile) in the statistical difference, therefore the general TT criterion was divided into vegetative and generative components. The results of a reverse divergent experiment on isolating data on atypical morphogenesis for vegetative and generative structures (expedi-

tion collections 2022) make it possible to trace not only the specific territorial localization of anomalies in different functional spheres, but also to identify the most dynamic features based on the plastic characteristics of indicator plants. The main zone of a significant and reliable increase in the TT indicator (total teratogenicity) is the "red line" of the military conflict that began in 2014 and continues to this day - the profile line ("red line") connects the western parts of the cities of Donetsk (and agglomerations in contact with Avdeevka), Yasinovataya and Gorlovka. This line is characterized by a width of 5–7 (up to 8) km. The territory following it deeper into the survey zone can be conditionally called the "gray zone".

Atypical morphogenesis of vegetative organs was characterized by a scale with an equal step change of 4 units, and for the generative sphere, observing the same principle of 4-interval equal degrees throughout heterogeneity, the step of the interval value is 10. This difference indicates the determining contribution of signs of atypical plant polymorphism from plasticity of discrete generative structures (structure and quality of pollen grains, embryonic, conformational and integumentary histological formations, also in carpological terms, features of the relative arrangement of parts in flowers and inflorescences, atypical architectonics of the entire generative part of plants (upper formations), as well as other signs of atypical morphogenesis of plant organisms). The used characteristics in the structure of plants according to the vegetative criterion were associated with frequent somatic manifestations at the level of morphological pathology according to the microstructures of surfaces (sculpture, ornamentation, pubescence, general morphology and architectonics of organs) and internal tissues of the leaf apparatus and shoot system (excluding inflorescences) of indicator plants .

At the analyzed points, signs of the general teratogenicity of the generative sphere of the structure and functional activity of the plant are subject to greater transformation, which largely indicates changes in heritable traits (compared to somatic ones) and the possibility of implementing the program of adaptive mutagenesis at a higher speed, compared to the expected evolutionary norm, which also noted in previous publications. Some features in the structure of indicator plants associated with the unfavorable tendency of militarization of the Donbass region have been identified; plant teratomorphs are a criterion of anthropotolerance; they have been identified as variants of adaptation genesis of some species to polemostress factors.

The structural and functional norms of plant indicators in natural environments recorded in the pre-war period for certain significant characteristics differ significantly from the indicators in conditions of active hostilities. Associated with the anthropogenic load on natural environments, the ability of plants to show more of their heterogeneity in terms of recorded teratomorphs reflects the specificity of the adverse impact on ecotopes, due to which monitoring and quantification

experiments were implemented in the work to prove environmental tension in specific territorial positions. Two leading reasons for multidirectional background fluctuations in the occurrence and manifestation of deformities in indicator plants in the Donbass have been identified: 1) the conduct of military operations - recording data on teratogenic indicator polymorphism along the line of confrontation; 2) stagnation of heavy industry in the region - the process is established along the vector of positive dynamics in reducing the teratogenicity of the territories of the rear areas. The results provide an information base for the implementation of environmental monitoring in the Northern Azov region, assessment of damage from military operations in specific territories, and the development of methods for optimizing disturbed landscapes.

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CALCULATION OF FORMULAS OF HOMOLOGOUS SERIES OF CHEMICAL COMPOUNDS (IN GENERALIZED FORM): THREE–COMPONENT SYSTEMS ($A^{a+} – B^{b+} – C^{c–}$) AND ($Na^{+} – TI^{4+} – O^{2-}$), ($Li^{+} – Ti^{4+} – O^{2–}$), ($K^{+} – V^{5+} – O^{2–}$), ($Ba^{2+} – Cu^{2+} – O^{2–}$)

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Abstract. *For the first time, a method for calculating formulas of homologous series of chemical compounds of the system ($A^{a+} – B^{b+} – C^{c–}$) and {Li^{+}-Fe^{2+}-$(PO_4)^{3-}$} in a generalized form is presented. The calculation is confirmed by the literature experimentally obtained compounds: thirteen compounds of the system ($Na^{+} – Ti^{4+} – O^{2–}$), seven – systems ($Li^{+} – Ti^{4+} – O^{2–}$), five – systems ($K^{+} – V^{5+} – O^{2–}$), eight – systems ($Ba^{2+} – Cu^{2+} – O^{2–}$). Homological series have the following generalized form: $A_{\{t-k\cdot r+(n-1)r\}bc}B_{rac}C_{\{t+r-k\cdot r+(n-1)r\}ab}$ and $A_{tbc}B_{\{r-k\cdot t+(n-1)t\}ac}C_{\{t+r-k\cdot t+(n-1)t\}ab}$, which can be used for any systems of chemical elements.*

Keywords: *homological series, chemical compounds, charged clusters, calculation method, three-component systems.*

1. Introduction

The search for new chemical compounds **(XC)** in multicomponent systems of chemical elements **(ХЭ)** is a difficult task. The great variety of properties of a set of three-component chemical compounds **(TXC)** is of great interest in solving a number of scientific and applied studies. There are known works in the literature that use the mathematical apparatus for predicting phases in multicomponent systems. Thus, semiempirical quantum-chemical methods, such as Hartree-Fock-Rutaan and Hartree-Fock-Slater methods [1-3], are used to calculate the formulae of hypothetical multicomponent XC. When using these methods to describe a chemical system, many physical and chemical phenomena must be taken into account. The exact solution of the basic laws leads to overcomplicated calculations. Therefore, for practically all ХЭ systems, the solution of the corresponding electronic equations used in quantum-chemical calculations is only possible approximately. Well-known quantum-chemical methods of calculation, allowing to calculate the formula of any XC, are rather complicated and require special knowledge in the field of mathematical programming.

According to the works [4-7], knowledge of the laws of formation of homological series **(ГС)** of chemical compounds can be included in the process of searching for new XC. Thus, the author of the work [8, p. 190] believes that "...the activated complex theory consists in the fact that in the course of any chemical reaction the initial configuration of atoms passes to the final one as a result of continuous change of interatomic distances", which is characterized by the formation of various critical intermediate configurations, i.e. activated complexes". On the basis of this idea, in the works [4-7] the method of calculation of formulae of HS of chemical compounds of three-component systems of ХЭ ions was developed.

It is known [9, 10] that multicomponent ХЭ systems include XC, which are combined into different HS. As the HS develops, the fundamental properties of its members change in a regular way, which is determined by a regular change in the crystal structure of homologues [9, 10]. In turn, the regular change in the crystal structure of homologues is determined by the regular change in their composition, which contributes to the search for new XC in [4-7]. In the works [9-11], the structural homology of inorganic XC of different systems of ХЭ is discussed in detail. Thus, structural homologues are observed, for example, as derivative structures at ordered substitution of atoms in the initial structure with tetrahedral coordination of atoms: C (diamond) – ZnS (sphalerite) – $CuFeS_2$ (chalcopyrite) – Cu_2FeSnS_4 (stannite) [9].

N.A. Goryunova and C.H.L. Goodman in their works [12-14] drew attention to the fact that the similarity of properties of chemical elements C (diamond), Si and Ge, located in the same 4b-subgroup of the Periodic System, is determined by the number of valence electrons. In the case of chemical compounds $A^{III}B^{V}$ (GaAs, InP, etc.), the similarity of properties is the similarity of chemical interatomic bonding. Thus, in [13, 14] the "octet rule" for diamond-like whole-valence compounds was formulated. In turn, in three-component chemical compounds $A^{II}B^{IV}C^{V}_2$ ($ZnGeP_2$, $CdGeP_2$, $CdSnAs_2$, $CdGeAs_2$, etc.), which are the closest electronic and crystal-chemical analogues of compounds $A^{III}B^{V}$,both signs of similarity of properties, the number of valence electrons and the "octet rule" are preserved. Considering the so-called defective diamond-like semiconductors, N.A. Goryunova pointed out the connection of the pattern of formation of compounds with the position of ХЭ in the Periodic System. Then the author of works [13, 14] had a question: is it possible to unite compounds of different groups into a single system? In particular, one of the answers to it is the regularity of formation of ГС of chemical compounds in different multicomponent systems.

So far, judging from the literature, the formulas of ГС are known, which were obtained **only empirically.**

For example, there are known ГС systems with different set of ХЭ: C (diamond), Si, Ge (diamond structure) – $A^{III}B^{V}$ (sphalerite structure) – $A^{II}B^{IV}C^{V}_2$

(chalcopyrite structure) [12-14]; or NaCl – MgO – PbS – SrSb (NaCl structure); or TiO_2 – MgF_2 – Zn_2SiO_4 – Li_2BeF_4 – $CaMgSi_2O_6$ – – $NaLiBe_2F_6$, or the disulfide group: FeS_2 (pyrite) – CoAsS (cobaltine) – NiSbS (ullmannite) [9].

In the literature, there are known ГС of systems with a single set of chemical elements: $Ba_mCu^{2+}_{m+n}O$ [15]; or $La_nNi_nO_{3n-1}$ [16]; $La_{n+1}Ni_nO_{3n+1}$, n = 1-5 [17]; $La_{n+1}Ni_nO_{3n-1}$, n = 7, 9, 13 and 30 [18]; $La_{2n-4}Ni_2O_{4n-5}$, n = 5-8 [19]; or $Fe^{2+}_nFe^{3+}_{2m}O_{n+3m}$ [20] or $Sr_{n+1}Ti_nO_{3n+1}$ [21]. Thus, in the (Ba^{2+} – Cu^{2+} – O^{2-}) system, the homologous series of XC is described by the formula $Ba_mCu_{m+n}O_{3n-1}$, where 2m = 2n – 1 [15], and in [20] it is reported that a series of XC belonging to the ГС were obtained, described by the formula $nFeO{\cdot}mFe_2O_3 = Fe^{2+}_nFe^{3+}_{2m}O^{2-}_{n+3m}$.

Additionally, experimentally obtained inorganic XC described by formulas that exhibit regular changes in composition are known in the literature: M_nO_{3n-1} (M = Mo, W) [27], M_nO_{2n-1} (M = = Ti, V) (n = 4-10) [22-24], W_nO_{3n-2} (n = 20, 38-40) [25].

However, in the case of Magnéli phases in the (M – O) systems, where M ≡ Mo, W, V, Ti, [22-25] and in the (La – Ni – O) system [16-19] all these formulas, without taking into account the existence of a divalent metal atom of the same name, in our opinion, cannot be considered correct. Following the electron neutrality of XC formulas, in all crystal lattices of XC belonging to the Magnéli phases described by formulas from [22-25], two divalent metal ions of the same name should be present: for example, M^{5+} and M^{6+} in Me_nO_{3n-1} or in W_nO_{3n-2} (M ≡ Mo, W), or M^{3+} and M^{4+} in M_nO_{2n-1} (M ≡ Ti, V). In the formulas described in [16-19] two divalent ions Ni^{2+} and Ni^{3+} should be present as equal chemical entities, determining the existence of the crystal lattice of XC. That is why the formulas of Magnéli phases from [22-25], in our opinion, should be attributed not to two-component, but to three-component ХЭ systems. In turn, the formulas related to the (La – Ni — O) system [16-19] belong not to a three-component system but to a four-component ХЭ system, (La^{3+} – Ni^{2+} – Ni^{3+}). For this reason, the formulas from [16-19], in our opinion, could be written as follows:

$Me_nO_{3n-1} \equiv Me^{5+}_2Me^{6+}_{n-2}O_{3n-1}$, where (Me ≡ Mo, W) and n = 8–12, 14 [22]; or $Me_nO_{2n-1} \equiv Me^{3+}_2Me^{4+}_{n-2}O_{2n-1}$, where (Me ≡ Ti, V) and n = 4-10 [23, 24]; or $W_nO_{3n-2} \equiv W^{5+}_4W^{6+}_{n-4}O_{3n-2}$, where n = 20, 38-40 [25], and the formulas from [16-19] are suggested to be written as follows: $La_nNi_nO_{3n-1}$ [16] ≡ $La_nNi^{2+}_2Ni^{3+}_{n-2}O_{3n-1}$, $La_{n+1}Ni_nO_{3n+1}$ [17] ≡ $La_{n+1}Ni^{2+}Ni^{3+}_{n-1}O_{3n+1}$, $La_{n+1}Ni_nO_{3n-1}$ [18] ≡ ≡ $La_{n+1}Ni^{2+}Ni^{3+}_{n-1}O_{3n-1}$ and $La_{2n-4}Ni_nO_{4n-5}$ [19] ≡ $La_{2n-4}Ni^{2+}_{n-2}Ni^{3+}_2O_{4n-5}$.

In the literature, for the system (M^+ – Ti^{4+} – O^{2-}), where $M^+ \equiv Li^+$, Na^+, K^+, Rb^+, Cs^+, a series of formulas for experimentally obtained TXC is known, generalized for n = 1-9 in the form of $M^+_4Ti^{4+}_nO_{2(n+1)}$ [26]. This formula for ГС is confirmed both here and in work [7] by the proposed calculation method.

In conclusion, it should be noted that in work [27], based on crystallographic analysis of structural data, predictions were made for new TXC of the ABX_6 type,

where A represents metal atoms, and X represents O and Cl atoms. Unfortunately, the results obtained by the author were not linked to the formation of ГС.

The aim of this study is to develop a method for calculating the formulas of homologous series of three-component systems of chemical elements in a generalized form using the geometric features of the triangle representing the system of chemical element ions.

2. Justification of the Method for Calculating Homologous Series of Chemical Compounds

The method for calculating ГС of three-component systems developed in [4-7] allows, in our opinion, for the generalized determination of ГС formulas. This conclusion is drawn from the findings presented in [6, 7], which provide numerous confirmations of the accuracy of the ГС calculation method for a range of three-component systems through experimental results taken from the literature. It should be noted, however, that the laws governing the formation of individual ХС and the laws governing the formation of ГС are different. Before the publications of [4-7], there was no possibility in the literature to predict the formation scheme of ГС. In some cases, ГС formulas were **only experimentally** determined in works [15-26].

Based on the works [4-7], the justification for the generalized method of calculating ГС can be formulated as follows:

1) In our view, the rule (or scheme) for forming ГС of chemical compounds can be formulated by considering all possible directions of chemical interactions between the components of the system, as allowed by the combination of the valence electron count of chemical elements and the composition of complex atomic clusters in the system. In reality, only ions of elementary substances and "certain intermediate atom configurations critical for a given reaction" participate in chemical interactions [8, 28]. In our case, these are activated ХС and charge clusters (**ЗК**). It is clear that determining the formula of ГС is possible if, among the many presumed directions of chemical interaction between the components of the ХЭ system, we can select those responsible for the formation of ГС. Therefore, to solve this problem, the ХЭ system must be represented as ions, as only ions can chemically interact with each other, producing intermediate, more complex, compositionally charge clusters and activated multi-component ХС. To do this, the system is represented as a triangle (Figure 1), with ХЭ ions placed at its vertices.

2) It was found that the **geometric features of the triangle** representing the system of ХЭ ions consist of representing the reaction of interaction between any pair of reacting system components as a line segment, where each pair of reactants and the product of their interaction lie on a line segment unique to them. In cases where line segments connecting different pairs of chemically interacting system components intersect at a single point, the common product of the interaction, ЗК

or activated XC, must be located at that point. This feature is explained by the difference in the laws governing the interaction of different pairs of reactants, which are determined by the different combinations of valence ions of XЭ and the composition of interacting pairs of reactants represented by different line segments: at the point of intersection of these line segments, different laws of chemical interaction of different pairs of chemical entities cannot coexist simultaneously.

Thus, the calculation of ГС formulas, i.e., the search for new HS-homologs, is based on the premise that homologs are located within a triangle at the intersection of line segments connecting different pairs of chemically interacting components of the system, including ions, XC, and activated charge clusters.

3) Next, we will consider that homologs enriched with the A_cC_a cluster belong to the *p*-groups of ГС, while homologs enriched with the B_cC_b cluster belong to the *m*-groups of ГС. ГС are formed depending on the direction of development through a chain of sequentially occurring interactions of ТХС with cation A^{a+} – the development direction of *p*-groups of ГС is A_cC_a. When ТХС interacts with cation B^{b+} – the *m*-groups of ГС develop towards B_cC_b.

The formation of ГС involves three-component charge clusters (**ТЗК$_n$**) through interaction with anion C^{c-} (Figure 1).

The formation of ГС is described by the following scheme:

$$ЗК_n + C^{c-} \rightarrow \mathbf{XC_n},\ XC_n + A^{a+}\ (\text{or } B^{b+}) \rightarrow \mathbf{ЗК_{n+1}},\ ЗК_{n+1} + C^{c-} \rightarrow \mathbf{XC_{n+1}},$$
$$XC_{n+1} + A^{a+}\ (\text{or } B^{b+}) \rightarrow \mathbf{ЗК_{n+2}},\ ЗК_{n+2} + C^{c-} \rightarrow \mathbf{XC_{n+2}}. \quad \text{.....(1)}$$

The value of **n** is determined experimentally, where **n** represents the position of the homolog in ГС ($1 \leq n$).

4) Activated TXC_n are located on line segments (A_cC_a – B_cC_b) – see Figure 1. In works [4-6], the nature of the connection of the same TXC_n, which simultaneously belongs to both the *p*-groups and *m*-groups of ГС, is described. Following the conditions outlined in point 3 regarding the membership of ТХС in *p*-groups and *m*-groups of ГС, it can be concluded that in the case of *p*-groups of ГС, its first homologs, $TXC_{n=1}$, are located on the line segment (point 2 – B_cC_b), excluding B_cC_b, and the clusters $TXC_{n>1}$ are located on the line segment (point 2 – A_cC_a), excluding point 2 and A_cC_a.

In the case where the same TXC_n cluster belongs to the *m*-group of ГС, its first homologs, $TXC_{n=1}$, are located on the line segment (point 2 – A_cC_a), excluding A_cC_a. The clusters $TXC_{n>1}$ are located on the line segment (point 2 – B_cC_b), excluding point 2 and B_cC_b – see Figure 1.2.

5) Clusters $T3K_{n=1}$, belonging to *p*-groups of ГС, are located on the line segment (point 1 – B^{b+}), excluding B^{b+}, and clusters $T3K_{n>1}$ are located on the line segment (point 1 – A_cC_a), excluding point 1 and A_cC_a.

In the case where the $T3K_n$ cluster belongs to the *m*-group of ГС, its first homologs, $T3K_{n=1}$, are located on the line segment (point 1 – A^{a+}), excluding A^{a+}, and

clusters $ТЗК_{n>1}$ are located on the line segment (point 1 – B_cC_b), excluding point 1 and B_cC_b – see Figure 1.2.

6) XC_n and $ЗК_n$, occupying the same position in the same ГС, are linked by the reaction:

$$ЗК_n + C^{c-} \rightarrow XC_n \quad \text{.....(2)}$$

7) Any known XC is necessarily a member of some HSs.

8) Any ГС consists of an XC branch and a ЗК branch, the members of which are linked by reaction (2). Each branch of the same ГС develops towards enrichment with only one two-component XC (**ДХС**), either A_cC_a or B_cC_b.

9) The geometric features of the triangle, if following scheme (1), ensure a systematic and periodic change in the composition of homologs in ГС.

10) The difference in compositions, Δ, of any adjacent homologs in the same ГС is constant:

$$\Delta = XC_{n+1} - XC_n = ЗК_{n+1} - ЗК_n \quad \text{.....(3)}$$

11) The charges of all ЗК in the same ГС are identical.

12) In the case of determining the formulas of ГС to which some known (basic) $TXC_{n(bas)}$ belongs, the calculation of ГС formulas is carried out as follows: first, the formulas of $ТЗК_{n(bas)}$, $TXC_{n(bas)+1}$, and $ТЗК_{n(bas)+1}$ are calculated, then the formulas of Δ and the first terms, $TXC_{n=1}$ and $ТЗК_{n=1}$, of the considered ГС are determined. Formulas $TXC_{n=1}$ and $ТЗК_{n=1}$ are calculated by subtracting the **maximum** number of times the formula Δ from the formulas of basic clusters while retaining the **minimum** number of the cation contained in the formula Δ in their composition:

$$TXC_{n(bas)} - k\cdot\Delta = \mathbf{TXC_{n=1}} \quad \text{.....(4)}$$

$$ТЗК_{n(bas)} - k\cdot\Delta = \mathbf{ТЗК_{n=1}} \quad \text{.....(5)}$$

where ($0 \le k$). If $k = 0$, then n(bas) = 1.

13) The formula of any homolog in the same ГС, i.e., the formula of the ГС, is determined as follows:

XC branch: $TXC_{n=1} + (n-1)\cdot\Delta = \mathbf{TXC_n}$ .....(6)

ЗК branch: $ТЗК_{n=1} + (n-1)\cdot\Delta = \mathbf{ТЗК_n}$ .....(7)

14) When calculating ГС, it should be taken into account that one of the ХЭ may have different valencies, being not only a component that does not introduce impurities into the crystalline lattice of TXC but also one of the main ХЭ in the crystalline lattice.

In practice, researchers often need to determine the formulas of ГС to which a known TXC already belongs. In the formation of these ГС, any TXC_n can participate, including $TXC_{n=1}$ and $TXC_{n>1}$.

3. Calculation of Homologous Series (ГС) in the ($A^{a+} – B^{b+} – C^{c-}$) System

Let's examine the sequentially occurring chemical reactions in a three-component system. The formation of ГС occurs according to scheme (1). The system ($A^{a+} – B^{b+} – C^{c-}$) is **initially** in a state where the interaction of a positively charged ion with an anion will lead to the formation of **activated** ДХС, A_cC_a and B_cC_b.

Activated ДХС, A_cC_a and B_cC_b can interact with each other to form $ТХС_n$ based on the ratios of ions A^{a+}, B^{b+} and C^{c-} in $ТЗК_n$, which participate in reaction (2).

Furthermore, according to the initial ratios of ions in $ТХС_n$ and $ТЗК_n$, the interaction of **cations with each other** leads to the formation of two-component charged clusters (**ДЗК$_n$**), which are connected to $ТХС_n$ and $ТЗК_n$ by reaction (2), where ($1 \leq n$).

As seen in Figure 1, clusters A_cC_a and B_cC_b can interact with the missing ion B^{b+} or A^{a+} in their composition, respectively, forming clusters $ТЗК_{n \geq 1}$. Clusters $ТЗК_n$, when reacting with anions according to (2), form $ТХС_n$. In turn, clusters $ТХС_n$ interact with cation A^{a+}, forming $ТЗК_{n+1}$, and thus participate in the formation of the *p*-group of ГС. In the case where the cluster $ТЗК_n$ reacts with cation B^{b+}, these interactions also form $ТЗК_{n+1}$, but they participate in the formation of the *m*-group of ГС. Clusters $ТЗК_{n+1}$, belonging to each ГС group, when reacting with anions according to (2), form clusters $ТХС_{n+1}$, which belong to the corresponding ГС group.

Moreover, according to scheme (1) and Figure 1, clusters ($ТЗК_{n=1}$ = p. 1), formed as a result of the interaction between A_cC_a and B^{b+} and B_cC_b and A^{a+}, when reacting with anions, form a cluster ($ТХС_{n=1}$ = p. 2), starting the formation of the *αm*-group of ГС, characterized by the intersection of segments {($ТХС_{n=1}$ = p. 2) – B^{b+}} and ($A^{a+} – B_cC_b$) at point ($ТЗК_{n=2}$ = p. 4).

Simultaneously, cluster ($ТХС_{n=1}$ = p. 2) can also interact with cation A^{a+}, forming ($ТЗК_{n+1}$ = p. 7), starting the formation of the *αp*-group of ГС, characterized by the intersection of segments {($ТХС_{n=1}$ = p. 2) – A^{a+}} and ($B^{b+} – A_cC_a$) at point ($ТЗК_{n=2}$ = p. 7) – see Figure 1.

According to (2), clusters $ТЗК_{n+1}$ of each ГС group can interact with anions to form $ТХС_{n+1}$. Homologs of the *p*-group of ГС become enriched with the AcCa cluster as ГС develops, while those of the *m*-group of ГС become enriched with the B_cC_b cluster.

The interactions mentioned are characterized by the intersection of segments corresponding to the reacting components of the ХЭ system. Thus, the formation of cluster ($ТЗК_{n=1}$ = p. 1) is characterized by the intersection of segments ($A_cC_a – B^{b+}$) and ($B_cC_b – A^{a+}$), and the formation of cluster ($ТХС_{n=1}$ = p. 2) is characterized by the intersection of segments {($ТЗК_{n=1}$ = p. 1) – C^{c-}} and ($A_cC_a – B_cC_b$) – Figure 1, which is described by the following reaction equations:

$bA_cC_a + acB^{b+} = aB_cC_b + bcA^{a+} = (\mathbf{[A_{bc}B_{ac}C_{ab}]^{abc+} = ТЗК_{n=1} = p.\ 1})$…..(8)

$([A_{bc}B_{ac}C_{ab}]^{abc+} = ТЗК_{n=1} = p.\ 1) + abC^{c-} = \{bcA^{a+} + acB^{b+} = (\mathbf{ДЗК_{n=1} = [A_{bc}B_{ac}]^{2abc+} = p.\ 3})\} + 2abC^{c-} = bA_cC_a + aB_cC_b = \mathbf{(A_{bc}B_{ac}C_{2ab} = ТХС_{n=1} = p.\ 2})$……..(9)

P.S. *In the text and on Figure 1, the following notations are used: p. 1 ≡ point 1, p. 2 ≡ point 2, p. 3 ≡ point 3, and so on. In the text, the determined formulas of ХС and ЗК as reactants and products of their interaction are highlighted in bold.*

Therefore, cluster ($ТХС_{n=1}$ = p. 2), when interacting with different ДХС, simultaneously belongs to both *αm*-ГС and αp-ГС [4]. Since $ТХС_{n=1}$ and $Т3К_{n=1}$ are linked by reaction (2), ($Т3К_{n=1}$ = p. 1) also belongs to *αm*-ГС and *αp*-ГС, just like $ТХС_{n=1}$ – Figure 1.

3. 1. Calculation of the Formula for *αp*-ГС Developing Towards A_cC_a

The continuous nature of chemical interaction in the ($A^{a+} – B^{b+} – C^{c–}$) system during the formation of ГС implies that any $ТХС_n$ cluster, starting from ($A_{bc}B_{ac}C_{2ab}$= $ТХС_{n=1}$ = p. 2), can interact with A^{a+} to form the $Т3К_{n+1}$ cluster. The clusters $ДЗК_{n+1}$ and $Т3К_{n+1}$, when interacting with anions, form the $ТХС_{n+1}$ cluster. These interactions begin to form *αp*-ГС, the members of which become enriched with the component A_cC_a as this ГС develops – see Figure 1.

In works [4-6], it is reported that in three-component systems, besides *αp*-ГС, there exist other ГС groups that also develop towards A_cC_a and belong to the *p*-group of ГС.

The formation of *p*-group ГС is characterized by the intersection of segments ($ТХС_n – A^{a+}$) and ($B^{b+} – A_cC_a$) at the point corresponding to $Т3К_{n+1}$ and the intersection of segments ($Т3К_{n+1}$–$C^{c–}$) and ($ДЗК_{n+1}$ – – $C^{c–}$) with the segment ($A_cC_a – B_cC_b$) at the point corresponding to $ТХС_{n+1}$. For *αp*-ГС, starting from ($ТХС_{n=1}$ = p. 2), this is described by the reaction equations:

($A_{bc}B_{ac}C_{2ab}$= $ТХС_{n=1}$ = p. 2) + bcA^{a+} = acB^{b+} + $2bA_cC_a$ = (**$[A_{2bc}B_{ac}C_{2ab}]^{abc+}$ = = $Т3К_{n=2}$ = p. 4**)……...(10)

Following the dependency (2), clusters ($[A_{2bc}B_{ac}C_{2ab}]^{abc+}$= $Т3К_{n=2}$ = p. 4) and $ДЗК_{n=2}$, represented as p. 6, can only interact with anions, characterized by the intersection of segments {($Т3К_{n=2}$ = p. 4) – $C^{c–}$} and {($ДЗК_{n=2}$ = p. 6) – $C^{c–}$} with the segment ($A_cC_a – B_cC_b$) at point (p. 5 = $ТХС_{n=2}$), and is described by the reaction equations:

($[A_{2bc}B_{ac}C_{2ab}]^{abc+}$=$Т3К_{n=2}$ = p. 4) + $abC^{c–}$ =$2bA_cC_a$ + aB_cC_b= {2bcA^{a+} + acB^{b+} = = (**$ДЗК_{n=2}$ = $[A_{2bc}B_{ac}]^{3abc+}$ = p. 6**)} + $3abC^{c–}$ = (**$A_{2bc}B_{ac}C_{3ab}$ = $ТХС_{n=2}$ = p. 5**)..(11)

According to (3), the formula Δ is determined as follows:

Δ = ($A_{2bc}B_{ac}C_{3ab}$ = $ТХС_{n=2}$ = p. 5) – ($A_{bc}B_{ac}C_{2ab}$ = $ТХС_{n=1}$ = p. 2) = $[A_{2bc}B_{ac}C_{2ab}]^{abc+}$= = $Т3К_{n=2}$ = p. 4) – ($[A_{bc}B_{ac}C_{ab}]^{abc+}$ = $Т3К_{n=1}$ = p. 1) = $A_{bc}C_{ab}$……(12)

Knowledge of the formulas of the first homologs ($ТХС_{n=1}$ = p. 2), ($Т3К_{n=1}$ = p. 1) and Δ allows us to determine the formulas of both branches of *αp*-ГС according to (6) and (7):

ХС branch: ($A_{bc}B_{ac}C_{2ab}$= $ТХС_{n=1}$ = p. 2) + (n – 1)$A_{bc}C_{ab}$ = $A_{nbc}B_{ac}C_{(n+1)ab}$ ….(13)

ЗК branch: ($[A_{bc}B_{ac}C_{ab}]^{abc+}$ = $Т3К_{n=1}$ = p. 1) + (n – 1)$A_{bc}C_{ab}$ = $[A_{nbc}B_{ac}C_{nab}]^{abc+}$.……(14)

The formulas for both branches of ГС in other *p*-group ГС are determined in accordance with dependencies (4)-(7).

3. 2. Calculation of the Formula for *αm*-ГС Developing Towards B_cC_b

Following the continuous nature of chemical interaction in the ($A^{a+} – B^{b+} – C^{c–}$) system during the formation of ГС, the $Т3К_n$ cluster, starting from ($A_{bc}B_{ac}C_{2ab}$=

$ТХС_{n=1}$ = p. 2), can interact with B^{b+} to form the $ТЗК_{n+1}$ cluster. The $ДЗК_{n+1}$ and $ТЗК_{n+1}$ clusters, when interacting with anions, form the $ТХС_{n+1}$ cluster. These interactions begin to form *αm*-ГС, the members of which become enriched with the component B_cC_b as this ГС develops.

As shown in works [4-6], in three-component systems, besides *αm*-ГС, there exist other ГС groups that also develop towards B_cC_b. All these ГС groups belong to the *m*-group of ГС.

The formation of *m*-group ГС is characterized by the intersection of segments ($ТХС_n – B^{b+}$) and ($A^{a+} – B_cC_b$) at the point corresponding to $ТЗК_{n+1}$ and the intersection of segments ($ТЗК_{n+1} – C^{c-}$) and ($ДЗК_{n+1} – C^{c-}$) with the segment ($A_cC_a – B_cC_b$) at the point corresponding to $ТХС_{n+1}$. For *αm*-ГС, this is described by the reaction equations, starting from ($ТХС_{n=1}$ = p. 2) – see Figure 1:

$(A_{bc}B_{ac}C_{2ab} = ТХС_{n=1} = p.2) + acB^{b+} = bcA^{a+} + 2aB_cC_b = (\mathbf{[A_{bc}B_{2ac}C_{2ab}]^{abc+} = ТЗК_{n=2} = p.7})$…(15)

$([A_{bc}B_{2ac}C_{2ab}]^{abc+} = ТЗК_{n=2} = p.7) + abC^{c-} = bA_cC_a + 2aB_cC_b = \{bcA^{a+} + 2acB^{b+} =$

$= (\mathbf{ДЗК_{n=2} = [A_{bc}B_{2ac}]^{3abc+} = p.9})\} + 3abC^{c-} = (\mathbf{A_{bc}B_{2ac}C_{3ab} = ТХС_{n=2} = p.8})$..(16)

According to (3), the formula Δ is determined as follows:

$\Delta = (A_{bc}B_{2ac}C_{3ab} = ТХС_{n=2} = p.8) – (A_{bc}B_{ac}C_{2ab} = ТХС_{n=1} = p.2) = [A_{bc}B_{2ac}C_{2ab}]^{abc+} =$

$= ТЗК_{n=2} = p.7) – ([A_{bc}B_{ac}C_{ab}]^{abc+} = ТЗК_{n=1} = p.1) = \mathbf{B_{ac}C_{ab}}$.....(17)

Knowledge of the formulas of the first homologs $ТХС_{n=1}$, $ТЗК_{n=1}$, and Δ allows us to determine the formulas of both branches of ***αm*-ГС** according to (6) and (7):

ХС branch: $(A_{bc}B_{ac}C_{2ab} = ТХС_{n=1} = т.2) + (n-1)B_{ac}C_{ab} = \mathbf{A_{bc}B_{nac}C_{(n+1)ab}}$……(18)

ЗК branch: $([A_{bc}B_{ac}C_{ab}]^{abc+} = ТЗК_{n=1} = т.1) + (n-1)B_{ac}C_{ab} = \mathbf{[A_{bc}B_{nac}C_{nab}]^{abc+}}$……(19)

The formulas for both branches of ГС in other *m*-group ГС are determined in accordance with dependencies (4)-(7).

3. 3. Calculation of the Generalized Formula for Homologous Series (ГС) to Which a Known (Basic) $ТХС_{n(bas)}$ Belongs

In the process of designing various devices, researchers often face the task of determining the formulas of ТХС that would possess more suitable properties compared to the currently used ТХС in the device. In situations where the composition of the utilized ТХС is known and experimentally confirmed, we will consider this cluster as **the basic one, $ТХС_{n(bas)}$.** The problem of finding new $ТХС_{n \neq n(bas)}$ can be solved by identifying the formulas of ГС to which the basic $ТХС_{n(bas)}$ belongs. In the desired ГС, the fundamental properties of homologs, including $ТХС_{n(bas)}$, change periodically and systematically.

To determine the regularity of ГС formation in a **generalized** form, it is necessary to represent the formula of $ТХС_{n(bas)}$ appropriately. Thus, the formula of any ТХС, including $ТХС_{n(bas)}$, can be expressed in a **generalized** form as follows:

$tA_cC_a + rB_cC_b = \mathbf{A_{tbc}B_{rac}C_{(t+r)ab}}$……..……..(20)

where ($0 \leq t, r$).

3. 3. 1. Calculation of the Generalized Formula for the *p*-Group of ГС to Which a Known (Basic) ($\mathbf{ТХС_{n(bas)} = A_{\mathit{t}bc}B_{\mathit{r}ac}C_{(\mathit{t}+\mathit{r})ab}}$) Belongs

In accordance with points 3-5, the basic cluster, represented in a generalized form as ($A_{tbc}B_{rac}C_{(t+r)ab} = ТХС_{n(bas)}$), begins to form the *p*-group of ГС by interacting with A^{a+}. In this case, the formulas of $ТЗК_{n(bas)}$ and $ДЗК_{n(bas)}$, associated with $ТХС_{n(bas)}$ by reaction (2), are determined by the composition of the cluster ($A_{tbc}B_{rac}C_{(t+r)ab} = ТХС_{n(bas)}$), which is described by the reaction equation:

$(tbcA^{a+} + racB^{b+} = \mathbf{[A_{tbc}B_{rac}]^{(t+r)abc+} = ДЗК_{n(bas)}}) + (t + r)abC^{c-} = (racB^{b+} + tbA_cC_a =$
$= \mathbf{[A_{tbc}B_{rac}C_{tab}]^{rabc+} = ТЗК_{n(bas)}}) + rabC^{c-} = (A_{tbc}B_{rac}C_{(t+r)ab} = ТХС_{n(bas)}$……..(21)

The initiation of the formation of the *p*-group of ГС based on ($A_{tbc}B_{rac}C_{(t+r)ab} = ТХС_{n(bas)}$) is characterized by the intersection of segments ($ТХС_{n(bas)} – A^{a+}$) and ($B^{b+} – A_cC_a$) at a point corresponding to $ТЗК_{n(bas)+1}$, as well as the intersection of segments ($ТЗК_{n(bas)+1} – C^{c-}$) and ($ДЗК_{n(bas)+1} – C^{c-}$) with the segment ($A_cC_a – B_cC_b$) at a point corresponding to $ТХС_{n(bas)+1}$, which is described by the reaction equations:

$(A_{tbc}B_{rac}C_{(t+r)ab} = ТХС_{n(bas)=1}) + rbcA^{a+} = racB^{b+} + (t+r)bA_cC_a = \mathbf{([A_{(t+r)bc}B_{rac}C_{(t+r)ab}]^{rabc+} =}$
$\mathbf{= ТЗК_{n(bas)+1}})$……(22)

$([A_{(t+r)bc}B_{rac}C_{(t+r)ab}]^{rabc+} = ТЗК_{n(bas)+1}) + rabC^{c-} = (t + r)bA_cC_a + raB_cC_b =$
$= (t + r)bcA^{a+} + racB^{b+} = (\mathbf{ДЗК_{n(bas)+1} = [A_{(t+r)bc}B_{rac}]^{(t+2r)abc+}}) + (t + 2r)abC^{c-} =$
$= (\mathbf{A_{(t+r)bc}B_{rac}C_{(t+2r)ab} = ТХС_{n(bas)+1}})$……..(23)

The formula Δ for the *p*-group of ГС is determined according to (3):

$\Delta = (A_{(t+r)bc}B_{rac}C_{(t+2r)ab} = ТХС_{n(bas)+1}) – (A_{tbc}B_{rac}C_{(t+r)ab} = ТХС_{n(bas)}) =$
$([A_{(t+r)bc}B_{rac}C_{(t+r)ab}]^{rabc+} = = ТЗК_{n(bas)+1}) – ([A_{tbc}B_{rac}C_{rab}]^{tabc+} = ТЗК_{n(bas)}) = \mathbf{A_{rbc}C_{rab}}$ ……..(24)

The formulas of the first homologs of the sought *p*-group of ГС, with the basic cluster represented as ($A_{tbc}B_{rac}C_{(t+r)ab} = ТХС_{n(bas)}$), are determined according to (4) and (5):

$\mathbf{ТХС_{n=1}} = (A_{tbc}B_{rac}C_{(t+r)ab} = ТХС_{n(bas)}) – k{\cdot}A_{rbc}C_{rab} = \mathbf{A_{(t-k\cdot r)bc}B_{rac}C_{(t+r-k\cdot r))ab}}$……..…(25)

$\mathbf{ТЗК_{n=1}} = ([A_{tbc}B_{rac}C_{tab}]^{rabc+} = ТЗК_{n(bas)}) – k{\cdot}A_{rbc}C_{rab} = \mathbf{[A_{(t-k\cdot r)bc}B_{rac}C_{(t-k\cdot r)ab}[^{rabc+}}$……(26)

where *k* characterizes the positioning of $ТХС_{n(bas)}$ in ГС, and for this ГС, any $ТХС_n$ corresponds to ($0 \le k$).

As can be seen, the determination of the composition of the first homologs and the formulas of both branches of the sought *p*-group of ГС according to the formulas (25), (26), (6), and (7) depends on the relationship between the values *t* and $k{\cdot}r$. In this case, two variants are possible:

1) Inequality ($\boldsymbol{t \le k{\cdot}r}$) when ($t, r, k > 0$) **does not allow** obtaining formulas for $ТХС_{n=1}$ and $ТЗК_{n=1}$ according to (25) and (26) **by subtracting** the product ($k{\cdot}\Delta \equiv$ $\equiv k{\cdot}A_{rbc}C_{rab}$) from the formulas ($A_{tbc}B_{rac}C_{(t+r)ab} = ТХС_{n(bas)}$) and ($[A_{tbc}B_{rac}C_{tab}]^{rabc+} =$ $= ТЗК_{nbas)}$). It follows that ($k = 0$). This fast indicates that when ($t \le k{\cdot}r$), the basic cluster is the first homolog ($A_{tbc}B_{rac}C_{(t+r)ab} = ТХС_{n(bas)=1}$) in this *p*-group of ГС. Therefore, both branches of the *p*-group of ГС will be determined according to (6) and (7):

ХС branch of *p*-group of ГС – $(A_{tbc}B_{rac}C_{(t+r)ab} = ТХС_{n(bas)=1}) + (n-1)A_{rbc}C_{rab} =$
$= \mathbf{A}_{\{t+r(n-1)\}bc}\mathbf{B}_{rac}\mathbf{C}_{\{t+rn\}ab}$.....(27)

ЗК branch of *p*-group of ГС – $([A_{tbc}B_{rac}C_{tab}]^{rabc+} = ТЗК_{n(bas)=1}) +$
$+ (n-1)A_{rbc}C_{rab} = [\mathbf{A}_{\{t+r(n-1)\}bc}\mathbf{B}_{rac}\mathbf{C}_{\{t+r(n-1)\}ab}]^{rabc+}$.....(28)

In the case where $\{t \le k{\cdot}r\}$, according to Figure 2, for the *p*-group of ГС, we obtain formulas for the following homologs: ($A_{tbc}B_{rac}C_{(t+r)ab} = ТХС_{n(bas)=1}$ = p. 10), ($[A_{rbc}B_{rac}C_{tab}]^{rabc+} = = ТЗК_{n(bas)=1}$ = p. 11), ($[A_{tbc}B_{rac}]^{(t+r)abc+} = ДЗК_{n(bas)=1}$ = p. 12), ($[A_{(t+r)bc}B_{rac}C_{(t+r)ab}]^{rabc+} = ТЗК_{n(bas)+1=2}$ = p. 13), ($A_{(t+r)bc}B_{rac}C_{(t+2r)ab} = ТХС_{n(bas)+1=2}$ = p. 14), ($[A_{(t+r)bc}B_{rac}]^{(t+2r)abc+} = ДЗК_{n(bas)+1=2}$ = p. 15), ($[A_{(t+2r)bc}B_{rac}C_{(t+2r)ab}]^{rabc+} = ТЗК_{n(bas)+2=3}$ = p. 16), ($A_{(t+2r)bc}B_{rac}C_{(t+3r)ab} = ТХС_{n(bas)+2=3}$ = p. 17), ($[A_{(t+2r)bc}B_{rac}]^{(t+3r)abc+} = ДЗК_{n(bas)+2=3}$ = p. 18), ($[A_{(t+3r)bc}B_{rac}C_{(t+3r)ab}]^{rabc+} = ТЗК_{n(bas)+3=4}$ = p. 19), ($A_{(t+3r)bc}B_{rac}C_{(t+4r)ab} = ТХС_{n(bas)+3=4}$ = p. 20), ($[A_{(t+3r)bc}B_{rac}]^{(t+4r)abc+} = ДЗК_{n(bas)+3=4}$ = p. 21), ($[A_{(t+4r)bc}B_{rac}C_{(t+4r)ab}]^{rabc+} = ТЗК_{n(bas)+4=5}$ = p. 22), ($A_{(t+4r)bc}B_{rac}C_{(t+5r)ab} = ТХС_{n(bas)+4=5}$ = p. 23) и ($[A_{(t+4r)bc}B_{rac}]^{(t+5r)abc+} = ДЗК_{n(bas)+4=5}$ = p. 24).

2) In the case when the inequality ($\boldsymbol{k{\cdot}r < t}$) holds, to determine the composition of the first homologs, it is **possible to subtract** the product ($k{\cdot}\Delta \equiv k{\cdot}A_{rbc}C_{rab}$) from the formulas of the basic clusters ($A_{tbc}B_{rac}C_{(t+r)ab} = ТХС_{n(bas)}$) and ($[A_{tbc}B_{rac}C_{tab}]^{rabc+} = ТЗК_{n(bas)}$), i.e., ($0 < k$). Then the first members of $ТХС_{n=1}$ and $ТЗК_{n=1}$ of the sought *p*-group of ГС will be determined by expressions (25) and (26). Both branches of the *p*-group of ГС will be determined according to (6), (7), (24), (25), and (26):

ХС branch of *p*-group of ГС – $(A_{(t-k{\cdot}r)bc}B_{rac}C_{(t+r-k{\cdot}r))ab} = ТХС_{n=1}) +$
$+ (n-1)A_{rbc}C_{rab} = \mathbf{A}_{\{t-k{\cdot}r+(n-1)r\}bc}\mathbf{B}_{rac}\mathbf{C}_{\{t-k{\cdot}r+nr\}ab}$.....(29)

ЗК branch of *p*-group of ГС – $([A_{(t-k{\cdot}r)bc}B_{rac}C_{(t-k{\cdot}r)ab}]^{rabc+} = ТЗК_{n=1}) +$
$+ (n-1)A_{rbc}C_{rab} = [\mathbf{A}_{\{t-k{\cdot}r+(n-1)r\}bc}\mathbf{B}_{rac}\mathbf{C}_{\{t-k{\cdot}r+(n-1)r\}ab}]^{rabc+}$.....(30)

It should be noted that for the sake of brevity, in both cases ($t \le k{\cdot}r$) and ($k{\cdot}r < t$), the same formula ($A_{tbc}B_{rac}C_{(t+r)ab} = ТХС_{n(bas)}$) in a generalized form is assigned to the basic clusters for the same *p*-group of ГС depicted in Figure 2. However, these formulas correspond to different points ($A_{tbc}B_{rac}C_{(t+r)ab} = ТХС_{n(bas)}$ = p. 10) and ($A_{tbc}B_{rac}C_{(t+r)ab} = ТХС_{n(bas)}$ = p. 20), respectively, on Figure 2.

In the case where ($k{\cdot}r < t$) and ($\Delta = A_{rbc}C_{rab}$) for the *p*-group of ГС, where the basic cluster is ($A_{tbc}B_{rac}C_{(t+r)ab} = ТХС_{n(bas)>1}$ = p. 20) – Figure 2, according to (29), we do the following conclusion:

($ТХС_{n(bas)>1}$ = p. 20 = $A_{tbc}B_{rac}C_{(t+r)ab}$) ≡ $A_{\{t-k{\cdot}r+\{n(bas)-1\}r\}bc}B_{rac}C_{\{t-k{\cdot}r+r{\cdot}n(bas)\}ab}$.....(31)

Comparing the concentration coefficients of A^{a+} in the left and right sides of equation (31), it can be noticed that the equality $\{r{\cdot}n(bas) - r - k{\cdot}r\} = 0$ holds. Then, for ($r \ne 0$), we obtain:

$k = \{n(bas) - 1\}$.....(32)

In reality, when ($k{\cdot}r < t$), the value of k is determined during the calculation of the ГС in accordance with the possibility of subtracting the product ($k{\cdot}\Delta \equiv k{\cdot}A_{rbc}C_{rab}$) from the formula ($A_{tbc}B_{rac}C_{(t+r)ab} = ТХС_{n(bas)>1}$). Determining the value of k according to (32) establishes the value of n(bas).

According to Figure 2, for a cluster in the form of ($ТХС_{n(bas)>1}$ = p. 20) when $k = 3$, the value of n(bas) = 4. Therefore, according to (25), (29), and Figure 2, in this case, when ($k \cdot r < t$), we obtain the formulas for the homologs of the *p*-group of ГС: ($A_{tbc}B_{rac}C_{(t+r)ab} = ТХС_{n(bas)=4}$ = p. 20), ($[A_{tbc}B_{rac}C_{tab}]^{rabc+} = = ТЗК_{n(bas)=4}$ = p. 19), ($[A_{tbc}B_{rac}]^{(t+r)abc+} = ДЗК_{n(bas)=4}$ = p. 21), ($[A_{(t+r)bc}B_{rac}C_{(t+r)ab}]^{rabc+} = ТЗК_{n(bas)+1=5}$ = p. 22), ($A_{(t+r)bc}B_{rac}C_{(t+2r)ab} = ТХС_{n(bas)+1=5}$ = p. 23), ($[A_{(t+r)bc}B_{rac}]^{(t+2r)abc+} = ДЗК_{n(bas)+1=5}$ = p. 24) and ($[A_{(t-r)bc}B_{rac}]^{rabc+} = ДЗК_{n=3}$ = т. 18), ($A_{(t-r)bc}B_{rac}C_{tab} = ТХС_{n=3}$ = p. 17), ($[A_{(t+2r)bc}B_{rac}C_{(t+2r)ab}]^{rabc+} = ТЗК_{n=3}$ = p. 16), ($[A_{(t-2r)bc}B_{rac}]^{(t-r)abc+} = ДЗК_{n=2}$ = p. 15), ($ТХС_{n=2}$ = p. 14 = $A_{(t-2r)bc}B_{rac}C_{(t-r)ab}$), ($[A_{(t-2r)bc}B_{rac}C_{(t-2r)ab}]^{rabc+} = ТЗК_{n=2}$ = p. 13), ($[A_{(t-3r)bc}B_{rac}]^{(t-2r)abc+} = = ДЗК_{n=1}$ = p. 12), ($[A_{(t-3r)bc}B_{rac}C_{(t-3r)ab}]^{rabc+} = ТЗК_{n=1}$ = p. 11), ($ТХС_{n=1}$ = p. 10 = $A_{(t-3r)bc}B_{rac}C_{(t-2r)ab}$).

3. 3. 2. Calculation of the Generalized Formula for the *m*-group of ГС to Which the Known (basic) ($ТХС_{n(bas)} = A_{tbc}B_{rac}C_{(t+r)ab}$) Belongs

Let the cluster $ТХС_{n(bas)}$, the formula of which is represented in a generalized form as ($A_{tbc}B_{rac}C_{(t+r)ab} = ТХС_{n(bas)}$), interact with B^{b+} to start forming the ГС, which in this case will belong to the *m*-group of ГС. In this process, the formulas for $ТЗК_{n(bas)}$ and $ДЗК_{n(bas)}$ related to $ТХС_{n(bas)}$ by reaction (2) are determined by the composition of $ТХС_{n(bas)}$, which is described by the reaction equation:

$(tbcA^{a+} + racB^{b+} = \mathbf{[A_{tbc}B_{rac}]^{(t+r)abc+} = ДЗК_{n(bas)}}) + (t+r)abC^{c-} = (tbcA^{a+} + raB_cC_b =$

$= \mathbf{[A_{tbc}B_{rac}C_{rab}]^{tabc+} = ТЗК_{n(bas)}}) + tabC^{c-} = (A_{tbc}B_{rac}C_{(t+r)ab} = ТХС_{n(bas)})$……...(33)

The formation of the *m*-group of ГС based on ($A_{tbc}B_{rac}C_{(t+r)ab} = ТХС_{n(bas)}$) is characterized by the intersection of the segments ($ТХС_{n(bas)} - B^{b+}$) and ($A^{a+} - B_cC_b$) at the point corresponding to $ТЗК_{n(bas)+1}$, as well as the intersection of the segments ($ТЗК_{n(bas)+1} - C^{c-}$) and ($ДЗК_{n(bas)+1} - C^{c-}$) with the segment ($A_cC_a - B_cC_b$) at the point corresponding to $ТХС_{n(bas)+1}$ – Figure 3, which is described by the following reaction equations:

$(A_{tbc}B_{rac}C_{(t+r)ab} = ТХС_{n(bas)=1}) + tacB^{b+} = tbcA^{a+} + (t+r)aB_cC_b =$

$= (\mathbf{[A_{tbc}B_{(t+r)ac}C_{(t+r)ab}]^{tabc+} = ТЗК_{n(bas)+1}})$……...(34)

$([A_{tbc}B_{(t+r)ac}C_{(t+r)ab}]^{tabc+} = ТЗК_{n(bas)+1}) + tabC^{c-} = tbA_cC_a + (t+r)aB_cC_b =$

$= tbcA^{a+} + (t+r)acB^{b+} = (\mathbf{ДЗК_{n(bas)+1} = [A_{tbc}B_{(t+r)ac}]^{(2t+r)abc+}}) + (t+r)abC^{c-} =$

$= (\mathbf{A_{tbc}B_{(t+r)ac}C_{(2t+r)ab} = ТХС_{n(bas)+1}})$……...(35)

The formula Δ is determined according to (3):

$\Delta = (A_{tbc}B_{(t+r)ac}C_{(2t+r)ab} = ТХС_{n(bas)+1}) - (A_{tbc}B_{rac}C_{(t+r)ab} = ТХС_{n(bas)}) =$

$= ([A_{tbc}B_{(t+r)ac}C_{(t+r)ab}]^{tabc+} = ТЗК_{n(bas)+1} = ТЗК_{n=2}) - ([A_{tbc}B_{rac}C_{rab}]^{tabc+} = ТЗК_{n(bas)}) =$

$= \mathbf{B_{tac}C_{tab}}$……(36)

The formulas for the first homologs of the sought *m*-group of ГС, whose basic cluster is in the form of ($A_{tbc}B_{rac}C_{(t+r)ab} = ТХС_{n(bas)}$), are determined according to (4) and (5):

$\mathbf{ТХС_{n=1}} = (A_{tbc}B_{rac}C_{(t+r)ab} = ТХС_{n(bas)}) - k \cdot B_{tac}C_{tab} = \mathbf{A_{tbc}B_{(r-k\cdot t)ac}C_{(t+r-k\cdot t))ab}}$……..(37)

$\mathbf{ТЗК_{n=1}} = ([A_{tbc}B_{rac}C_{rab}]^{tabc+} = ТЗК_{nbas}) - k \cdot B_{tac}C_{tab} = \mathbf{[A_{tbc}B_{(r-k\cdot t)ac}C_{(r-k\cdot t)ab}]^{tabc+}}$…….(38)

As can be seen from equations (37) and (38), determining the composition of the first homologs and formulas of both branches of the sought *m*-group of ГС depends on the relationship between the values of *r* and $k \cdot t$. In this regard, two variants are possible:

1) In the case of the inequality ($\boldsymbol{r \le k \cdot t}$) with $\{0 < t, r, k\}$, **it is not possible** to obtain the compositions of $ТХС_{n=1}$ and $ТЗК_{n=1}$ according to (4) and (5) **by subtracting** the formula ($\Delta \equiv B_{tac}C_{tab}$) from the formulas ($A_{tbc}B_{rac}C_{(t+r)ab} = ТХС_{n(bas)}$) and ($[A_{tbc}B_{rac}C_{rab}]^{tabc+} = ТЗК_{nbas)}$). In this scenario, it implies that ($k = 0$), and the basic clusters are the first homologs themselves ($A_{tbc}B_{rac}C_{(t+r)ab} = ТХС_{n(bas)=1}$) and ($[A_{tbc}B_{rac}C_{rab}]^{tabc+} = ТЗК_{n(bas)=1}$) in the *m*-group of ГС. Consequently, both branches of the *m*-group of ГС can be determined according to (6), (7), and (35)-(38):

ХС branch of *m*-group of ГС – $(A_{tbc}B_{rac}C_{(t+r)ab} = ТХС_{n(bas)=1}) + (n-1)B_{tac}C_{tab} =$

$= \mathbf{A_{tbc}B_{\{r+t(n-1)\}ac}C_{\{r+tn\}ab}}$ .....(39)

ЗК branch of *m*-group of ГС – $([A_{tbc}B_{rac}C_{rab}]^{tabc+} = ТЗК_{n(bas)=1}) + (n-1)B_{tac}C_{tab} =$

$= \mathbf{[A_{tbc}B_{\{r+t(n-1)\}ac}C_{\{r+t(n-1)\}ab}]^{tabc+}}$ .....(40)

In this case, according to (39), (40) and Figure 3, we will obtain:

$(A_{tbc}B_{rac}C_{(t+r)ab} = ТХС_{n(bas)=1}$ = p. 25), $([A_{tbc}B_{rac}C_{rab}]^{tabc+} = ТЗК_{n(bas)=1}$ = p. 26), $([A_{tbc}B_{rac}]^{(t+r)abc+} = ДЗК_{n(bas)=1}$ = p. 27), $([A_{tbc}B_{(t+r)ac}C_{(t+r)ab}]^{tabc+} = ТЗК_{n(bas)+1=2}$ = p. 28), $(A_{tbc}B_{(t+r)ac}C_{(2t+r)ab} = ТХС_{n(bas)+1=2}$ = p. 29) and $([A_{tbc}B_{(t+r)ac}]^{(2t+r)abc+} = ДЗК_{n(bas)+1=2}$ = p. 30), $([A_{tbc}B_{(2t+r)ac}C_{(2t+r)ab}]^{tabc+} = ТЗК_{n(bas)+2=3}$ = p. 31), $(A_{tbc}B_{(2t+r)ac}C_{(3t+r)ab} = ТХС_{n(bas)+2=3}$ = p. 32) and $([A_{tbc}B_{(2t+r)ac}]^{(3t+r)abc+} = ДЗК_{n(bas)+2=3}$ = p. 33), $([A_{tbc}B_{(3t+r)ac}C_{(3t+r)ab}]^{tabc+} = ТЗК_{n(bas)+3=4}$ = p. 34), $(A_{tbc}B_{(3t+r)ac}C_{(4t+r)ab} = ТХС_{n(bas)+3=4}$ = p. 35) and $([A_{tbc}B_{(3t+r)ac}]^{(4t+r)abc+} = ДЗК_{n(bas)+3=4}$ = p. 36).

2) In the case of the inequality ($\boldsymbol{k \cdot t < r}$), to determine the formulas of the first homologs, it is possible to subtract the product ($k \cdot \Delta \equiv k \cdot B_{tac}C_{tab}$) from the composition of the basic clusters ($A_{tbc}B_{rac}C_{(t+r)ab} = ТХС_{n(bas)}$) and ($[A_{tbc}B_{rac}C_{rab}]^{tabc+} = ТЗК_{n(bas)=1}$), i.e., ($0 < k$). In this scenario, the first members of the sought *m*-group of ГС, where the basic cluster is ($A_{tbc}B_{rac}C_{(t+r)ab} = ТХС_{n(bas)}$), will be determined by equations (37) and (38). Both branches of the *m*-group of ГС will be determined according to (6), (7), (36), (37), and (38):

ХС branch of *m*-group of ГС –$(A_{tbc}B_{\{r-k\cdot t\}ac}C_{\{t+r-k\cdot t\}ab} = ТХС_{n=1}) +$

$+ (n-1)B_{tac}C_{tab} = \mathbf{A_{tbc}B_{\{r-kt+(n-1)t\}ac}C_{\{r-k\cdot t+nt\}ab}}$ .....(41)

ЗК branch of *m*-group of ГС – $([A_{tbc}B_{(r-k\cdot t)ac}C_{(r-k\cdot t)ab}]^{tabc+} = ТЗК_{n=1}) + (n-1)B_{tac}C_{tab} =$

$= [\mathbf{A_{tbc}B_{\{r-k\cdot t+(n-1)t\}ac}C_{\{r-k\cdot t+(n-1)t\}ab}}]^{tabc+}$ .....(42)

Similar to the case of *p*-groups in ГС, for brevity, we assign the same basic cluster formula ($A_{tbc}B_{rac}C_{(t+r)ab} = ТХС_{n(bas)}$) in its generalized form to both scenarios when ($k \cdot t < r$) and ($r \le k \cdot t$). However, it should be noted that in Figure 3, this formula corresponds to different points ($A_{tbc}B_{rac}C_{(t+r)ab} = ТХС_{n(bas)}$ = p. 25) and ($A_{tbc}B_{rac}C_{(t+r)ab} = ТХС_{n(bas)}$ = p. 32), respectively.

In the case where ($k \cdot t < r$) and ($\Delta = B_{tbc}C_{tab}$), for the *m*-group of ГС, when the basic cluster is ($A_{tbc}B_{rac}C_{(t+r)ab} = TXC_{n(bas)>1}$ = p. 32) – Figure 3, according to (41), we can conclude:

($TXC_{n(bas)>1}$ = p. 32 = $A_{tbc}B_{rac}C_{(t+r)ab} = A_{tbc}B_{\{r-k\cdot t+\{n(bas)-1\}t\}ac}C_{\{r-k\cdot t+t\cdot n(bas)\}ab}$……(43)

Comparing the concentration coefficients at B^{b+} in the left and right sides of equation (43), it can be observed that the equality $\{t \cdot n(bas) - t - k \cdot t\} = 0$ holds. Then, for ($t \neq 0$), we obtain:

$\{k = n(bas) - 1\}$……..(44)

The value of k is determined during the calculation of ГС when determining the condition for subtracting the product ($k \cdot \Delta \equiv k \cdot B_{tbc}C_{tab}$) from the formula ($A_{tbc}B_{rac}C_{(t+r)ab} = TXC_{n(bas)>1}$). After determining the value of k in the case of ($k \cdot t < r$) according to (44), the value of n(bas) can be determined.

According to Figure 3, for a cluster in the form ($TXC_{n(bas)>1}$ = p. 32) when ($k = 2$), the value of n(bas) = 3. Therefore, according to (41), (42), and Figure 3, for this scenario, when ($k \cdot t < r$), we obtain formulas for the homologs of the *m*-group of ГС: ($A_{tbc}B_{(r-2t)ac}C_{(r-t)ab} = TXC_{n(bas)-2=1}$ = p. 25), ($[A_{tbc}B_{(r-2t)ac}C_{(r-2t)ab}]^{tabc+} = ТЗК_{n(bas)-2=1}$ = p. 26), ($[A_{tbc}B_{(r-2t)ac}]^{(r-t)abc+} = ДЗК_{n(bas)-2=1}$ = p. 27), ($[A_{tbc}B_{(r-t)ac}C_{(r-t)ab}]^{tabc+} = ТЗК_{n(bas)-1=2}$ = p. 28), ($A_{tbc}B_{(r-t)ac}C_{rab} = TXC_{n(bas)-1=2}$ = p. 29), ($[A_{tbc}B_{(r-t)ac}]^{rabc+} = ДЗК_{n(bas)-1=2}$ = p. 30), ($[A_{tbc}B_{rac}C_{rab}]^{tabc+} = ТЗК_{n(bas)=3}$ = p. 31), ($A_{tbc}B_{rac}C_{(t+r)ab} = TXC_{n(bas)=3}$ = p. 32), ($[A_{tbc}B_{rac}]^{(t+r)abc+} = ДЗК_{n(bas)=3}$ = p. 33), ($[A_{tbc}B_{(t+r)ac}C_{(t+r)ab}]^{tabc+} = ТЗК_{n(bas)+1=4}$ = p. 34), ($A_{tbc}B_{(t+r)ac}C_{(2t+r)ab} = TXC_{n(bas)+1=4}$ = p. 35) and ($[A_{tbc}B_{(t+r)ac}]^{(2t+r)abc+} = ДЗК_{n(bas)+1=4}$ = p. 36).

4. Calculation of the *m*-group of ГС in the $\{Li^+ – Fe^{2+} – (PO_4)^{3-}\}$ System Based on $LiFe^{2+}(PO_4)$

As an example of practical application of the generalized formulas obtained earlier, we will calculate the formulas for the *m*- and *p*-groups of ГС to which the known (basic) XC $\{TXC_{n(bas)} = LiFe^{2+}(PO_4) \equiv A_{tbc}B_{rac}C_{(t+r)ab}\}$ [29] belongs. In solving this problem, we will assume that the homologs that enrich with the cluster $\{Li_3(PO_4) \equiv A_cC_a\}$as the ГС develops belong to the *p*-group of ГС, while the homologs that enrich with the cluster $\{Fe_3(PO_4)_2 \equiv B_cC_b\}$ belong to the *m*-group of ГС.

For $\{TXC_{n(bas)} = LiFe^{2+}(PO_4) \equiv A_{tbc}B_{rac}C_{(t+r)ab}\}$, we obtain: $A^{a+} \equiv Li^+$, $B^{b+} \equiv Fe^{2+}$, $C^{c-} \equiv (PO_4)^{3-}$, bc = 6, ac = 3, ab = 2, abc = 6, *t*bc = 1, $t = 1/6$, *r*ac = 1, $r = 1/3$, $(t + r)ab = 1$, $(t + r) = 1/2$. Then, we have the following:

$\{TXC_{n(bas)} = A_{tbc}B_{rac}C_{(t+r)ab}\} \equiv LiFe^{2+}(PO_4) \equiv \mathbf{Li_{6t}Fe^{2+}_{3r}(PO_4)_{2(t+r)}} \equiv \mathbf{Li_{6/6}Fe^{2+}_{6/6}(PO_4)_{6/6}}$…….(45)

To determine the position of the basic cluster in the *m*- and *p*-groups of ГС, we need to calculate the formula Δ for each ГС group and compare the formula Δ with the formula of the basic cluster.

For instance, the cluster $\{TXC_{n(bas)} = LiFe^{2+}(PO_4) \equiv A_{tbc}B_{rac}C_{(t+r)ab}\}$ can interact with lithium to begin forming the *p*-group of ГС $\{Li_3(PO_4)$ *direction*$\}$. In this

case, according to (24), we determine the value ($\Delta = A_{rbc}C_{rab} = Li_{6/3}(PO_4)_{2/3}$). The inequality ($r = 1/3$) > ($t = 1/6$) corresponds to the basic cluster becoming the first homolog in *p*-group of ГС, $\{LiFe^{2+}(PO_4) \equiv A_{tbc}B_{rac}C_{(t+r)ab} = TXC_{n(bas)=1}\}$. Then, according to (27), the formula for the XC branch of this *p*-group of ГС is as follows:

XC branch *p*-group of ГС – $A_{\{t+(n-1)r\}bc}B_{rac}C_{\{t+r\cdot n\}ab} \equiv \mathbf{Li_{3(2n-1)}Fe^{2+}{}_3(PO_4)_{(2n+1)}}$…(46)

For the *m*-group $\{Fe_3(PO_4)_2$ *direction*$\}$ according to (36), we obtain:

$\Delta = B_{tac}C_{tab} = \mathbf{Fe^{2+}{}_{3t}(PO_4)_{2t} \equiv Fe^{2+}{}_{3/6}(PO_4)_{2/6}}$……..……..(47)

Comparing the formula ($\Delta = Fe^{2+}{}_{3/6}(PO_4)_{2/6}$) from (47) with the formula $\{TXC_{n(bas)} \equiv A_{tbc}B_{rac}C_{(t+r)ab} \equiv Li_{6/6}Fe^{2+}{}_{6/6}(PO_4)_{6/6}\}$ from (45) it can be seen that (**$r = 1/3$**) > (**$t = 1/6$**). Therefore, we can subtract the formula $\{\Delta = Fe^{2+}{}_{3/6}(PO_4)_{2/6}\}$ from the formula $\{TXC_{n(bas)} \equiv LiFe^{2+}(PO_4) \equiv Li_{6t}Fe^{2+}{}_{3r}(PO_4)_{2(t+r)} \equiv Li_{6/6}Fe^{2+}{}_{6/6}(PO_4)_{6/6}\}$. In this case, ($k = 1$) and {n(bas*)* = 2}. Then, according to (39), the formula for the XC branch of the *m*-group of ГС can be presented as follows:

XC branch *m*-group of ГС – $A_{tbc}B_{\{r-t\cdot k+(n-1)t\}ac}C_{\{r-t\cdot k+t\cdot n\}ab} \equiv$

$\equiv \mathbf{Li_{6t}Fe^{2+}{}_{3\{(n-1)t+r-t\cdot k\}}(PO_4)_{2\{(n-1)t+t+r-t\cdot k\}}} \equiv \mathbf{Li_{6/6}Fe^{2+}{}_{3n/6}(PO_4)_{2(n+1)/6}} \equiv$

$\equiv \mathbf{Li_6Fe^{2+}{}_{3n}(PO_4)_{2(n+1)}}$……..….(48)

For (n = 1) and ($k = 0$) according to (35) we obtain: $(TXC_{n=1} = Li_6Fe^{2+}{}_3(PO_4)_4)$, and for (n = 2) and ($k = 1$) we obtain: $\mathbf{Li_6Fe^{2+}{}_6(PO_4)_6 \equiv LiFe^{2+}(PO_4) = TXC_{n(bas)=2}}$.

Since experimentally obtained in [29] $\{TXC_{n=2} = LiFe^{2+}(PO_4) \equiv Li_6Fe^{2+}{}_6(PO_4)_6\}$ is the second member in the *m*-group of ГС, it implies that considering the continuity of ГС, the cluster $\{Li_6Fe^{2+}{}_3(PO_4)_4 = TXC_{n=1}\}$ must exist. As observed, the cluster $\{Li_6Fe^{2+}{}_3(PO_4)_4 = TXC_{n=1}\}$ contains more lithium than $\{TXC_{n=2} = LiFe^{2+}(PO_4) \equiv Li_6Fe^{2+}{}_6(PO_4)_6\}$, which can offer certain advantages compared to $LiFe^{2+}(PO_4)$ when used in Li-ion energy sources.

In the $\{Li^+ – Fe^{2+} – (PO_4)^{3-}\}$ system, the formula for the first homolog $TXC_{n=1}$ in the *αm*-ГС, obtained according to equation (9), is as follows: $\{TXC_{n=1} = A_{bc}B_{ac}C_{2ab} = Li_6Fe^{2+}{}_3(PO_4)_4\}$, indicating that the formula (48) belongs to the XC branch of the *αm*-ГС, and the basic cluster $\{LiFe^{2+}(PO_4) = TXC_{n(bas)=2}\}$ belongs to the *αm*-ГС.

5. Comparison of Experiments (known from the Literature) with the Results of ГС Calculations

The effectiveness of the ГС calculation method presented here and in references [4-7] has been **confirmed by numerous experiments taken from the literature** [11]. If we substitute $A^{a+} \equiv Li^+$, Na^+, K^+, Rb^+, etc., $B^{b+} \equiv Ti^{4+}$, $C^{c-} \equiv O^{2-}$ into formula (17), $A_{bc}B_{nac}C_{(n+1)ab}$, for the systems $(Na^+ – Ti^{4+} – O^{2-})$ and $(Li^+ – Ti^{4+} – O^{2-})$, we can obtain the following:

1) **Thirteen** experimentally obtained compounds in the $(Na^+ – Ti^{4+} – O^{2-})$ system.

2) **Seven** compounds in the $(Li^+ – Ti^{4+} – O^{2-})$ system adhere to the calculated formula (17) (ГС development direction – TiO_2) – $\mathbf{Li_4Ti^{4+}{}_nO_{2(n+1)}}$: **n = 1, 2** [35], **n = 3, 5, 12** [36], n = **n = 4, 7, 8** [37].

Based on the calculations for the ($Li^+ – Ti^{4+} – O^{2–}$) and ($Na^+ – Ti^{4+} – O^{2–}$) systems, the following formula (18) can be written for the ($M^+ – Ti^{4+} – O^{2–}$) system, where $\mathbf{M^+ \equiv Li^+, Na^+, K^+, Rb^+}$:

$$\mathbf{M^+_4Ti^{4+}_nO_{2(n+1)}} \quad \text{.....(49)}$$

The obtained formula (49) completely coincides with the formula obtained in the study [26] based on experiments.

3) When substituting $A^{a+} \equiv K^+$, $B^{b+} \equiv V^{5+}$, and $C^{c-} \equiv O^{2-}$, **five** compounds in the ($K^+ – V^{5+} – O^{2–}$) system adhere to the calculated formula (17) (ГС development direction – V_2O_5): $\mathbf{K_{10}V^{5+}_{2n}O_{5(n+1)}}$: **n = 3, 5, 15, 20, 25** [38-40].

4) When substituting $A^{a+} \equiv Ba^{2+}$, $B^{b+} \equiv Cu^{2+}$, and $C^{c-} \equiv O^{2-}$, **five** compounds in the ($Ba^{2+} – Cu^{2+} – O^{2–}$) system adhere to the calculated formula (17) (ГС development direction – CuO): $\mathbf{BaCu^{2+}_nO_{n+1}}$: **n = 1** [15, 41-44], **n = 2** [43]; **n = 3, 7** [44]; **n = 4** [15].

5) When substituting $A^{a+} \equiv Ba^{2+}$, $B^{b+} \equiv Cu^{2+}$, and $C^{c-} \equiv O^{2-}$, **three** compounds in the ($Ba^{2+} – Cu^{2+} – O^{2–}$) system adhere to the calculated formula (22) (ГС development direction – BaO): $\mathbf{Ba_nCu^{2+}O_{n+1}}$: **n = 1** [15, 41–44], **n = 2** [41, 42]; **n = 3** [44].

It should be noted that the literature crystallographic data for XC in the ($Na^+ – Ti^{4+} – O^{2–}$) and ($Ba^{2+} – Cu^{2+} – O^{2–}$) systems correspond to the calculated ГС. However, this topic is rather complex and requires separate analysis by a crystallographer and is not considered here.

6) When substituting $A^{a+} \equiv Fe^{2+}$, $B^{b+} \equiv Fe^{3+}$, and $C^{c-} \equiv O^{2-}$, **five** compounds in the ($Fe^{2+} – Fe^{3+} – O^{2–}$) system adhere to the calculated formula (17) (ГС development direction – Fe_2O_3): $Fe^{2+}_3Fe^{3+}_{2n}O_{3(n+1)}$: **n = 1-4, 6** [20].

6. Conclusion

Before the works [4-7], there was no scheme for the formation of ГС that would allow determining the formulas of homologs without conducting experiments. In this study, on the example of the system ($A^{a+} – B^{b+} – C^{c-}$), it has been shown **for the first time in a generalized form** that the formation of ГС occurs due to a chain of alternating chemical interactions of XC with cations and ЗК with anions. It has been demonstrated that ГС of three-component XC develop towards enrichment with members of two-component compounds A_cC_a or B_cC_b. It is known that any existing ТХС is a member of ГС that develop both towards A_cC_a and B_cC_b. The existing ГС is continuous but limited ($1 \leq n$). The extent of the ГС is determined experimentally. According to the continuous nature of the ГС, homologs with a smaller value of **n** than the experimentally obtained $ТХС_n$ should exist.

As it was found out, the geometric features of the triangle representing the system of ХЭ ions reflect the periodic and regular change in the composition of XC and ЗК in the form of the ГС formula. As a result, it became possible to determine the scheme for the formation of ГС and calculate its formula. The basis of the calculation method is as follows: homologs, XC, and ЗК, in such a triangle are

located at the intersection of segments that connect different pairs of chemically interacting components of the system, ions, XC, and ЗК.

The calculation method developed here for ГС in a generalized form **simplifies** the process of obtaining ГС formulas, one of which is a known (base) $ТХС_{n(bas)}$. This is demonstrated using the example of the known $LiFe^{2+}(PO_4) \equiv Li_6Fe^{2+}{}_6(PO_4)_6$ cluster, which is used in Li-ion energy sources.

For existing chemical compounds $ХС_{n(bas)}$, when substituting A^{a+}, B^{b+}, and C^{c-} ions in the formulas $\Delta = (ТХС_{n+1} - ТХС_n) = (ТЗК_{n+1} - ТЗК_n)$, as well as in the formulas of XC and ЗК branches to which this $ХС_{n(bas)}$ belongs, it is possible to determine the formulas of previously unknown XC-homologs in order to obtain materials with more suitable properties compared to $ХС_{n(bas)}$.

By using well-studied three-component ХЭ systems, it was possible to find such systems as $(Na^+ - Ti^{4+} - O^{2-})$, $(Li^+ - Ti^{4+} - O^{2-})$, $(K^+ - V^{5+} - O^{2-})$, and $(Ba^{2+} - Cu^{2+} - O^{2-})$, numerous ТХС formulas of which adhere to the calculated ГС formulas using the method proposed here.

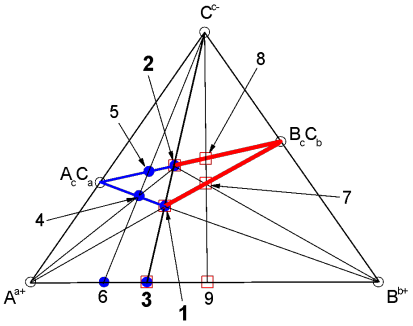

Figure 1. *($A^{a+} - B^{b+} - C^{c-}$) system: αm-ГС and αp-ГС are formed based on the cluster (p. 2 = $ТХС_{n(bas)=1} = A_{bc}B_{ac}C_{2ab}$) and (p. 1 = $ТЗК_{n(bas)=1} = [A_{bc}B_{ac}C_{ab}]^{abc+}$); clusters represented as p. 1 – p. 6 belong to αp-ГС; clusters represented as p. 1, p. 2, p. 3, p. 7, p. 8, and p. 9 belong to αm-ГС;*

Formulas of clusters $ТХС_n$, $ТЗК_n$, and $ДЗК_n$ represented as p. 1 – p. 9 are presented in chapters 3.1. and 3.2.

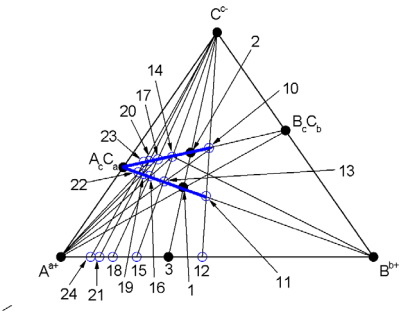

Figure 2. *($A^{a+} – B^{b+} – C^{c–}$) system: p-group of ГС is calculated based on the basic cluster (p. 10 = $A_{tbc}B_{rac}C_{(t+r)ab}$ = $TXC_{n(bas)}$). Formulas of clusters TXC_n, $ТЗК_n$, and $ДЗК_n$ represented as p. 10 – p. 24 are presented in chapter 3.3.1, section 1.*

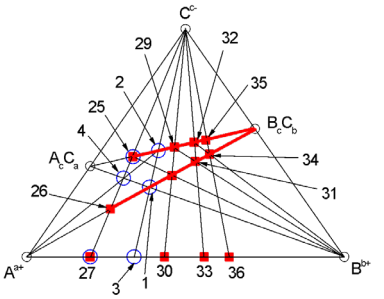

Figure 3. *($A^{a+} – B^{b+} – C^{c–}$) system: m-group of ГС is calculated based on the basic cluster (p. 20 = $A_{tbc}B_{rac}C_{(t+r)ab}$ = $TXC_{n(bas)}$). Formulas of clusters TXC_n, $ТЗК_n$, and $ДЗК_n$ represented as p. 25 – p. 36 are presented in chapter 3.3.1., section 2.*

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CALCULATION OF FORMULAS OF HOMOLOGOUS SERIES OF CHEMICAL COMPOUNDS(IN GENERAL): FOUR-COMPONENT SYSTEMS ($A^{a+} – B^{b+} – D^{d+} – C^{c-}$) AND ($La^{3+} – Ni^{2+} – Ni^{3+} – O^{2-}$)

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Abstract. *The paper presents for the first time a method for calculating formulas of homologous series of chemical compounds of four-component systems (A^{a+}-B^{b+}-D^{d+}-C^{c-}) and (La^{3+}--Ni^{2+}-Ni^{3+}-O^{2-}) in a generalized form. The reliability of the calculation method of the three-component system (A^{a+}-B^{b+}-C^{c-}) is confirmed by experimentally obtained three-component compounds of five systems of chemical elements taken from the literature. Taking into account the analogy of the geometric features of a triangle and a triangular pyramid, which allow us to calculate the formulas of homological series of chemical compounds, the method of calculating a three-component system is extended to a four-component system (A^{a+}-B^{b+}-D^{d+}-C^{c-}) and (La^{3+}--Ni^{2+}-Ni^{3+}-O^{2-}). The formulas of homological series of chemical compounds of the four–component system, which are calculated in a generalized form for the three directions of their development towards A_cC_a, B_cC_b and D_cC_d, have the following form, respectively:*
$A_{\{(r+w)(n-1-k)+t\}bdc}B_{radc}D_{wabc}C_{\{(r+w)(n-k)+t\}abd}$, $A_{tbdc}B_{\{(t+w)(n-1-k)+r\}adc}D_{wabc}C_{\{(t+w)(n-k)+r\}abd}$ *and* $A_{tbdc}B_{radc}D_{\{(t+r)(n-1-k)+w\}abc}C_{\{(t+r)(n-k)+w\}abd}$.

Keywords: *homologous series, chemical compounds, charged clusters, calculation method, four-component systems, ions of chemical elements.*

1. Introduction

In multicomponent systems of chemical elements **(ХЭ)**, chemical compounds **(ХС)** are combined into homological series **(ГС)** [1, 2]. It should be noted that multicomponent systems are understood as systems and ХС containing three, four or five ХЭ that form the basis of the crystal lattice of the ХС. The composition, crystal structure and fundamental properties of homologues in ГС change periodically and in a regular way [1, 2]. Knowledge of the laws of ГС formation makes it possible to predict the existence of formulas of new multicomponent ХС. Thus, for example, knowing these laws, on the basis of a known, i.e. experimentally

obtained XC, it is possible to determine the formula of the ГС to which this XC belongs. Consequently, the formula of this ГС can be used to determine the formulae of other unknown XC - homologues. At the same time, given the continuity of the ГС, it is especially important to keep in mind that the homologues of this ГС, which in order precede the known XC, must also exist [3-9].

As shown, the method developed in [3-5, 8] for calculating the formulae of three-component ГС has been confirmed by numerous experimental results taken from the literature.

From [3-9], it was found that the same geometrical features of the triangle and triangular pyramid representing three-, four-, and five-component ХЭ systems allow the developed method of calculating the ГС formulae to be used for all these ХЭ systems.

Moreover, the works [3-9] show the relative simplicity of the calculation of the formulae of XC-homologues in comparison, for example, with the semiempirical quantum-chemical methods of Hartree-Fock-Rutaan and Hartree_Fock-Slater [10-12].

The author of [13] presents the results of crystal-chemical analysis of structures in $ABCX_6$ compounds (A, B, C – cations, X – anion) – author's designations. The prediction of new compounds with the structure of K_2PtCl_6, $RbNiCrF_6$ (pyrochlore), gagarinite and $KHoBeF_6$ types is presented. Thus, the number of compounds with the structure of K_2PtCl_6 which were known by 1992 was 181, and the number of predicted compounds was 1169. The number of known compounds with the pyrochlore type structure was 95 and the number of predicted compounds was 481. For example, in compounds $A^+B^{2+}C^{3+}F_6$ (space group C^5_h - F_d3_m)the following ХЭ are possible: A^+ = Li, K, Rb, Cs, etc.; B^{2+} = Mg, Ca, Ti, V, Fe, Ni; C^{3+} = Ni, Co, Fe, Mn, Ti, Al, Cu, and in compounds $A^+B^{5+}C^{6+}O^{2-}_6$ – A^+ = K, Rb, Cs, etc., B^{5+} = Nb, Ta, Bi; C^{6+} = Mo, W, Te [14].

Judging from the literature, due to its complexity of study and the probable existence of many unknown XC in four-component systems, the latter is much less studied compared to three-component systems. For this reason, it is currently not possible to confirm experimentally the validity of the calculation of four-component ГС, as demonstrated for three-component ХЭ systems [8]. However, as shown in [6, 9], taking into account the same geometrical features of a triangle and a triangular pyramid, the experimentally confirmed method of calculation of three-component ХЭ systems can be extended to a four-component system.

However, for example, in [15-18] the authors, investigating the (La – Ni – O) system, stated about the existence of ГС: $La_nNi_nO_{3n-1}$ [15]; $La_{n+1}Ni_nO_{3n+1}$, n = 1-5 [16]; $La_{n+1}Ni_nO_{3n-1}$, n = 7, 9, 13 and 30 [17]; $La_{2n-4}Ni_2O_{4n-5}$, n = 5-8 [18]. However, following electroneutrality, in the ГС formulas given in [15-18], two different valence nickel ions, Ni^{2+}andNi^{3+}, should be present. Consequently, on

this basis, all the formulas of these ГС should refer not to three-component, but to four-component ion systems and look as follows:
$La_nNi_nO_{3n-1}$ [15] ≡ $La_nNi^{2+}_2Ni^{3+}_{n-2}O_{3n-1}$, $La_{n+1}Ni_nO_{3n+1}$ [16] ≡ $La_{n+1}Ni^{2+}Ni^{3+}_{n-1}O_{3n+1}$, $La_{n+1}Ni_nO_{3n-1}$ [17] ≡ $La_{n+1}Ni^{2+}_5Ni^{3+}_{n-5}O_{3n-1}$ and $La_{2n-4}Ni_nO_{4n-5}$ [18] ≡ ≡ $La_{2n-4}Ni^{2+}_{n-2}Ni^{3+}_2O_{4n-5}$.

In [19], a series of samples of the (La - Cu - O) system were obtained, whose compositions obey the formula ГС $La_{n+1}Cu_nO_{3n+1}$. The authors of [19] on the basis of X-ray-phase analysis believe that the samples of this ГС, possessing the structure of perovskite K2FeF4, can be represented by alternating layers of $La_2Cu^{2+}O_4$ and $LaCu^{3+}O_3$. That is, these samples contain Cu^{2+} and Cu^{3+}. In this case, in our opinion, the authors of [19] should have adopted the ГС formula as follows: $La_{n+1}Cu_nO_{3n+1}$[19] ≡ $La_{n+1}Cu^{2+}Cu^{3+}_{n-1}O_{3n+1}$, which was not done.

Purpose of work: using geometrical features of a triangle and a triangular pyramid representing the system of ХЭ ions, to develop a method of calculation of ГС formulae of four-component ХЭ systems **in generalised form.**

2. Description of the four-component system of ХЭ ions and justification of the method of calculation of the ГС of chemical compounds

As it was found out in [3-9], due to the same geometrical features of a triangle and a triangular pyramid, it is possible to extend in a **generalised form** the method of calculating the ГС of three-component systems to a four-component system (A^{a+} – B^{b+} – D^{d+} – C^{c-}).

Based on the works [3-9], the method of ГС calculation can be justified as follows:

The rule (or scheme) for the formation of ГС chemical compounds can be to formulate, if we consider all possible directions of chemical interaction of the system components, which the combination of the number of valence electrons of ХЭ and the composition of complex atomic clusters of the system, activated ХС and charged clusters **(ЗК)** allows. The geometrical features of the triangle and triangular pyramid, representing the systems of ions of chemical elements, allow us to choose from a set of chemical interactions those responsible for the formation of ГС. For this purpose, the ХЭ system is represented by a triangular pyramid with ХЭ ions in its corners.

2) Geometrical features of the triangle and triangular pyramid consist in the graphical representation of the interaction reaction of any pair of reacting components of the system by a line segment, when each pair of reactants and products of their interaction are located on one line segment belonging only to them. At the point of intersection of line segments linking different pairs of reactants, there is a common product of interaction, ЗК or ХС, for these pairs. This feature is due to the difference in the laws of interaction of different pairs of reagents, which, in turn, is due to a different combination of valence of ХЭ ions and the composition

of pairs of reagents. Consequently, the search for new XC is based on the fact that homologues are arranged in a triangle and in a triangular pyramid at the intersection of segments that connect different pairs of reagents.

3) ГС are formed depending on the direction of development by means of a chain of successive interactions of four-component XC **(ЧХС)** with the ion A^{a+}– the direction of ГС development – A_cC_a, or with B^{b+} – the direction of ГС development – B_cC_b, or with D^{d+} – the direction of ГС development – D_cC_d. At the same time, interactions with anion of four-component ЗК **(ЧЗК)** and three-component ЗК (ТЗК) participate in the formation of ГС. This is described by the following scheme - Fig. 1:

$ТЗК_n + C^{c-} \rightarrow \mathbf{ЧЗК_n}$, $ЧЗК_n + C^{c-} \rightarrow \mathbf{ЧХС_n}$, $ЧХС_n + A^{a+}$ (or B^{b+}, or D^{d+}) $\rightarrow \mathbf{ЧЗК_{n+1}}$, $ТЗК_{n+1} + C^{c-} \rightarrow ЧЗК_{n+1}$, $ЧЗК_{n+1} + C^{c-} \rightarrow \mathbf{ЧХС_{n+1}}$, $ЧХС_{n+1} + A^{a+}$ (or B^{b+}, or D^{d+}) $\rightarrow$ $\rightarrow \mathbf{ЧЗК_{n+2}}$, $ТЗК_{n+2} + C^{c-} \rightarrow ЧЗК_{n+2} + C^{c-} \rightarrow \mathbf{ЧХС_{n+2}}$, etc. ……(1)

The maximum value of n for the considered ГС is determined experimentally, where n is the position of the homologue in the ГС and ($1 \leq n$).

4) XC_n and $ЗК_n$, occupying the same position in the same ГС are linked by the following reaction:

$ЗК_n + C^{c-} \rightarrow XC_n$……..……(2)

5) The homologues $ЧХС_n$, $ЧЗК_n$ and $ТЗК_n$, which occupy the same position in the same ГС, are in the same plane - Figures 1-5.

6) The ГС consists of a XC branch and a ЗК branch, which are linked by reaction (2). Both branches of the same ГС develop towards the same two-component XC (ДХС), A_cC_a, or B_cC_b, or D_cC_d, i.e., as the ГС develops, its members are enriched with the corresponding ДХС.

7) The compositions of the nearest members of the same ГС differ by the same formula in the form of Δ:

$\Delta = XC_{n+1} - XC_n = ЗК_{n+1} - ЗК_n$…….…....(3)

8) The charges of all ЧЗКof the same ГС are the same.

9) The activated ЧХС are located in the ($A_cC_a - B_cC_b - D_cC_d$) plane – – fig. 4. Moreover, the homologues belonging to the ГС, which develops towards A_cC_a, are located on the segment ($A_cC_a - TXC_n$), where TXC_n belongs to the system ($B^{b+} - - D^{d+} - C^{c-}$) – Figs. 1-3.

Homologues belonging to ГС that develops towards B_cC_b, are on the segment ($B_cC_b - TXC_n$), where TXC_n belongs to the system ($A^{a+} - D^{d+} - C^{c-}$) – Figs. 1, 3, 4.

In the case of ГС, which develops towards D_cC_d, its homologues are on the segment ($D_cC_d - TXC_n$), where TXC_n belongs to the system ($A^{a+} - B^{b} - C^{c-}$)–Figs. 1, 3.

10) The ЧЗК-homologues, belonging to the ГС that develops towards A_cC_a, are located on the segment (A_cC_a – ДЗК$_n$), where ДЗК$_n$ belongs to the system ($B^{b+} - D^{d+}$) – Figs. 1-3.

At the same time, the ЧЗК-homologues, belonging to the ГС, which develops towards B_cC_b, are located on the segment ($A^{a+} – D^{d+}$) – Figs. 1, 3, 4.

The ЧЗК-homologues belonging to the ГС that develops towards D_cC_d, are located in the segment ($A^{a+} – B^{b+}$) – Figs. 1, 3.

11) The four-component ГС that develops towards A_cC_a are formed in the plane of the triangle ($A^{a+} – ДЗК_n – C^{c-}$), where $ДЗК_n$ belongs to the system ($B^{b+} – D^{d+}$) - Fig. 1-3.

At the same time, the ГС that develops towards B_cC_b are formed in the plane of the triangle ($B^{b+} – ДЗК_n – C^{c-}$), where $ДЗК_n$ belongs to the system ($A^{a+} – D^{d+}$) - Figs. 1, 3, 4.

ГС, which develops towards D_cC_d, are formed in the plane of the triangle ($D^{d+} – ДЗК_n – C^{c-}$), where $ДЗК_n$ belongs to the system ($A^{a+} – B^{b+}$) - Fig. 1, 3.

12) In the case when a ГС formula is determined to which some known (basic) $ЧХС_{n(bas)}$ belongs (in this case the value of n(bas) is unknown), the calculation of the ГС formula is performed as follows: first the formulas $ЧЗК_{n(bas)}$, $ЧХС_{n(bas)+1}$ and $ЧЗК_{n(bas)+1}$ are determined, then the formula Δ is calculated according to dependence (3). The formulas $ЧХС_{n=1}$ and $ЧЗК_{n=1}$ are calculated by subtracting the maximum number of times of the formula Δ from the formulas $ЧХС_{n(bas)}$ and $ЧЗК_{n(bas)}$, provided that the minimum amount of the cation contained in the formula Δ is maintained in the compound of $ЧХС_{n=1}$ and $ЧЗК_{n=1}$:

$$ХС_{n(bas)} – k\cdot\Delta = \mathbf{ХС_{n=1}} \quad (4)$$

$$ЗК_{n(bas)} – k\cdot\Delta = \mathbf{ЗК_{n=1}} \quad (5)$$

where $k \geq 0$. In case, if $k = 0$, then n(bas) = 1.

13) The formula of any homologue in the same ГС is determined according to [6]:

ХС branch: $$ХС_{n=1} + (n – 1)\cdot\Delta = \mathbf{ХС_n} \quad (6)$$

ЗК branch: $$ЗК_{n=1} + (n – 1)\cdot\Delta = \mathbf{ЗК_n} \quad (7)$$

14) When calculating the ГС, one should take into account the variant when one of the chemical elements may be different valent, being in the crystal lattice of the XC not an alloying component, but one of the main chemical elements of the crystal lattice.

Basically, researchers need to determine the formulas of ГС, which belong to some already known XC. In the formation of these ГС can take part a combination of any $ХС_n$ including $ТХС_{n=1}$ and $ТХС_{n>1}$.

3. Formation of ГС of four-component XC in the system ($A^{a+} – B^{b+} – D^{d+} – C^{c–}$) with the participation of $ТХС_{n=1} = A_{bc}B_{ac}C_{2ab}$, $A_{dc}D_{ac}C_{2ad}$ and $B_{dc}D_{bc}C_{2bd}$

The formation of ГС-1, ГС-2 and ГС-3 four-component XC in the system ($A^{a+} – – B^{b+} – D^{d+} – C^{c–}$) begins with the participation in this process of the first homologues of all three-component systems

($A^{a+} – B^{b+} – C^{c–}$), ($B^{b+} – D^{d+} – C^{c–}$) and ($A^{a+} – D^{d+} – C^{c–}$), i.e., clusters ($ТХС_{n=1}$ = = $A_{bc}B_{ac}C_{2ab}$ = p. 2), ($ТХС_{n=1}$ = $B_{dc}D_{bc}C_{2bd}$ = p. 5), ($ТХС_{n=1}$ = $A_{dc}D_{ac}C_{2ad}$ = p. 8), ($ТЗК_{n=1}$ = $[A_{bc}B_{ac}C_{ab}]^{abc+}$ = p. 1), ($[B_{dc}D_{bc}C_{bd}]^{bdc+}$ = p. 4), ($[A_{dc}D_{ac}C_{ad}]^{adc+}$ = p. 7) and ($ДЗК_{n=1}$ = $[A_bB_a]^{2ab+}$ = p. 3), ($ДЗК_{n=1}$ = $[B_dD_b]^{2bd+}$ = p. 6), ($ДЗК_{n=1}$ = $[A_dD_a]^{2ad+}$ = = p.9) – fig. 1. Thus, in the four-component system, ГС-1 evolves towards A_cC_a – fig. 2, ГС-2 – towards B_cC_b,andГС-3 – towards D_cC_d – fig. 1. The homologues are enriched with the corresponding ДХС, A_cC_a, B_cC_b and D_cC_d. As it turned out [3-9], in this case, due to the same geometrical features of the triangle and triangular pyramid, the first homologues ($ЧХС_{n=1}$ = p. 11), ($ЧЗК_{n=1}$ = p. 10) and ($ТЗК_{n=1}$ = p. 12) for all three triangles (p. 6 – $A^{a+} – C^{c-}$), (p. 9 – $B^{b+} – C^{c-}$) and (p. 3 – $D^{d+} – C^{c-}$), in which ГС-1, ГС-2andГС-3, are formed, respectively, are common and thus confirm this geometrically: in **p. 12** intersect the segments (p. 6 – – A^{a+}), (p. 9 – – B^{b+}) and (p. 3 – D^{d+}); in **p. 10** intersect the segments (p. 6 – A_cC_a), (p. 9 – B_cC_b), (p. 3 – D_cC_d), (p. 4 – A^{a+}), (p. 7 – B^{b+}) and (p. 1 – D^{d+}); in **p. 11** the segments (p. 5 – A_cC_a), (p. 8 – B_cC_b) and (p. 2 – D_cC_d) intersect – Fig. 1, which is described by the following reaction equations:

$ac([B_dD_b]^{2bd+}$ =$ДЗК_{n=1}$ = p. 6) + $bdcA^{a+}$ = $bc([A_dD_a]^{2ad+}$ = $ДЗК_{n=1}$ = p. 9) + + $adcB^{b+}$=$dc([A_bB_a]^{2ab+}$ = $ДЗК_{n=1}$ =p. 3) + $abcD^{d+}$ = (**$c[A_{bd}B_{ad}D_{ab}]^{3abd+}$=$ТЗК_{n=1}$ = = p. 12**)……..(8)

$ac([B_dD_b]^{2bd+}$ = p. 6) + bdA_cC_a = $bc([A_dD_a]^{2dd+}$ = p. 9) + adB_cC_b = $dc([A_bB_a]^{2ab+}$ = = p. 3) + abD_cC_d = $a([B_{dc}D_{bc}C_{bd}]^{bdc+}$ = $ТЗК_{n=1}$ = p. 4) + $bdcA^{a+}$ = $b([A_{dc}D_{ac}C_{ad}]^{adc+}$ = = $ТЗК_{n=1}$ = p. 7) + $adcB^{b+}$) = $d([A_{bc}B_{ac}C_{ab}]^{abc+}$ = $ТЗК_{n=1}$ = p. 1) + $abcD^{d+}$ = = (**$[A_{bdc}B_{adc}D_{abc}C_{abd}]^{2abdc+}$ = $ЧЗК_{n=1}$ = p. 10**)……..(9)

$a(B_{dc}D_{bc}C_{2bd}$ = $ТХС_{n=1}$ = p. 5)+ bdA_cC_a = $b(A_{dc}D_{ac}C_{2ad}$ = $ТХС_{n=1}$ = p. 8} + adB_cC_b = = $d(A_{bc}B_{ac}C_{2ab}$ = $ТХС_{n=1}$ = p. 2) + abD_cC_d = $(c[A_{bd}B_{ad}D_{ab}]^{3abd+}$ = $ТЗК_{n=1}$ = p. 12) + + $3abdC^{c-}$ = ($[A_{bdc}B_{adc}D_{abc}C_{abd}]^{2abdc+}$ = $ЧЗК_{n=1}$ = p. 10)+$2abdC^{c-}$= (**$A_{bdc}B_{adc}D_{abc}C_{3abd}$ = =$ЧХС_{n=1}$ = p.11**)..……(10)

As can be seen from the reaction equations (8), (9) and (10), the ЧЗК and ТЗК clusters located at the intervals (p. 6 - A_cC_a) and (p. 6 – A^{a+}), respectively, are linked by reaction (2) with the ЧХС clusters located at the interval (p. 5 – A_cC_a) - Figs. 1, 2, while the clusters located at the intervals (p. 9 – B_cC_b) and (p. 9 – B^{b+}) are linked by reaction (2) to the ЧХС clusters that are located at the interval (p. 8 – B_cC_b) - Fig. 1. In turn, the clusters located at the intervals (p. 3 – D_cC_d) and (p. 3 – D^{d+}) are linked by reaction (2) with the ЧХС clusters that are located on the interval(p. 2 – D_cC_d) - Fig. 1. Consequently, the clusters as p. 10 and p. 12 are also connected to the cluster as p. 11 by reaction (2) - Fig. 1.

3. 1. Calculation of ГС-1 formula that evolves towards A_cC_a

The formation of ГС-1, which develops towards A_cC_a, occurs in the triangle (p. 6– – $A^{a+} – C^{c-}$) – Fig. 1, 2. The intersection of the segments (p. 11 – A^{a+}) and (p. 6 – A_cC_a) determines the location and formula of the cluster $ЧЗК_{n=2}$ as p. 13, and the

intersection of the segments (p. 13 – C^{c-}) and (p. 5 – A_cC_a) determines the location and formula of the cluster ($ЧХС_{n=2}$ = p. 14). Cluster ($ДЗК_{n=2}$ = p. 15) is located at the intersection of the continuation of segment (p. 15 – p. 14) with segment (p. 6 – A^{a+}), which is described by the following equations - Fig. 1, 2:

$(A_{bdc}B_{adc}D_{abc}C_{3abd} = ЧХС_{n=1}$ = p. 11) + $2bdcA^{a+}$ = (c[$B_{ad}D_{ab}]^{2abd+} = ДЗК_{n=1}$ = p. 6) + + $3bdA_cC_a$ = $([\mathbf{A_{3bdc}B_{adc}D_{abc}C_{3abd}}]^{\mathbf{2abdc+}} = \mathbf{ЧЗК_{n=2}}$ **= p. 13)**……(11)

$([A_{3bdc}B_{adc}D_{abc}C_{3abd}]^{2abdc+} = ЧЗК_{n=2}$ = p. 13) + $2abdC^{c-}$ = $d(B_{dc}D_{bc}C_{2bd} = ТХС_{n=1}$ = = p. 5) + $3bdA_cC_a$ = {(c[$B_{ad}D_{ab}]^{2abd+}$ =$ДЗК_{n=1}$ = p. 6)+$3bdcA^{a+}$= $\mathbf{c[A_{3bd}B_{ad}D_{ab}]^{5abd+}}$ = **= ТЗК$_{n=2}$ = p. 15**} + $5abdC^{c-}$ = $(\mathbf{A_{3bdc}B_{adc}D_{abc}C_{5abd} = ЧХС_{n=2}}$ **= p. 14)**…..(12)

The formula Δ will be determined according to expression (3):

Δ = ($A_{3bdc}B_{adc}D_{abc}C_{5abd} = ЧХС_{n=2}$ = p. 14) – ($A_{bdc}B_{adc}D_{abc}C_{3abd} = ЧХС_{n=1}$ = p. 11) = $([A_{3bdc}B_{adc}D_{abc}C_{3abd}]^{2abdc+} = ЧЗК_{n=2}$ = p. 13) – $([A_{bdc}B_{adc}D_{abc}C_{abd}]^{2abdc+} = ЧЗК_{n=1}$ = = p. 10) = $\mathbf{A_{2bdc}C_{2abd}}$ ……..…(13)

Since the first homologues for ГС-1 are known, the formulae for both branches of ГС-1 will be determined according to (6) and (7):

branch ХС – ($A_{bdc}B_{adc}D_{abc}C_{3abd} = ЧХС_{n=1}$ = p. 11) + (n – 1)$A_{2bdc}C_{2abd}$ = = $\mathbf{A_{(2n-1)bdc}B_{adc}D_{abc}C_{(2n+1)abd}}$……..(14)

branch ЗК – ($[A_{bdc}B_{adc}D_{abc}C_{abd}]^{2abdc+} = ЧЗК_{n=1}$ = p. 10) + (n – 1)$A_{2bdc}C_{2abd}$ = = $\mathbf{[A_{(2n-1)bdc}B_{adc}D_{abc}C_{(2n-1)abd}]^{2abdc+}}$ ……..……...(15)

3. 2. Calculation of ГС-2 and ГС-3 formulae that evolve towards B_cC_b and D_cC_d

Formation of ГС-2, which develops towards B_cC_b, occurs in the triangle (p. 9 – B^{b+} - C^{c-}). ГС-2 belongs to clusters in the form ($ЧЗК_{n=1}$ = p. 10), ($ЧХС_{n=1}$ = p. 11), ($ТЗК_{n=1}$ = p. 12), ($ЧХС_{n=2}$ = p. 17), ($ЧЗК_{n=2}$ = = p. 16) and ($ТЗК_{n=2}$ = p. 18) – fig. 1. Calculation of the formulae of both branches of ГС-2 is done similarly to ГС-1. Here are the final results of the calculation:

Δ = $\mathbf{B_{2adc}C_{2abd}}$……..…..(16)

branch ХС – $\mathbf{A_{bdc}B_{(2n-1)adc}D_{abc}C_{(2n+1)abd}}$……...(17)

branch ЗК – $\mathbf{[A_{bdc}B_{(2n-1)adc}D_{abc}C_{(2n-1)abd}]^{2abdc+}}$ ……..…..(18)

The formation of ГС-3, which develops towards D_cC_d, occurs in the triangle (p. 3 – D^{d+} – C^{c-}).The clusters involved in the formation of ГС-3 are ($ЧЗК_{n=1}$ = p. 10), ($ЧХС_{n=1}$ = p. 11), ($ТЗК_{n=1}$ = p. 12), ($ЧХС_{n=2}$ = p. 20), ($ЧЗК_{n=2}$ = p. 19) and ($ТЗК_{n=2}$ = p. 21) – fig. 1. The calculation of ГС-3 is calculated in the same way as ГС-1. Here are the final results of the calculation:

Δ = $\mathbf{D_{2abc}C_{2abd}}$……..……..(19)

branch ХС – $\mathbf{A_{bdc}B_{adc}D_{(2n-1)abc}C_{(2n+1)abd}}$……..……..(20)

branch ЗК – $\mathbf{[A_{bdc}B_{adc}D_{(2n-1)abc}C_{(2n-1)abd}]^{2abdc+}}$ ……..……...(21)

4. Calculation of formulae of four-component homological series, ГС-4, ГС-5 and ГС-6, to which belongs the known (basic) $ЧХС_{n(bas)}$

In order to determine the pattern of ГС formation in **generalised** form, it is necessary to represent the formula of $ТХС_{n(bas)}$ in an appropriate way. Thus, the formula of any ТХС including $ТХС_{n(bas)}$ can be **generalised** as follows:

$$tA_cC_a + rB_cC_b + wD_cC_d = \mathbf{A_{tbdc}B_{radc}D_{wabc}C_{(t+r+w)abd}} \quad \text{.....(22)}$$

where $(0 < t, r, w)$,i.e., it can be written down: $(ЧХС_{n(bas)} = \text{p. } 22 = A_{tbdc}B_{radc}D_{wabc}C_{(t+r+w)abd})$.

The intersection of the segments (p. 23 – A_cC_a), (p. 24 – B_cC_b) and (p. 25 – D_cC_d) at the point $(ЧХС_{n(bas)} = \text{p. } 22 = A_{tbdc}B_{radc}D_{wabc}C_{(t+r+w)abd})$ will determine the location and formulas of the clusters as p. 23, p. 24 and p. 25 according to the following equation (Fig. 3):

$$(rad\mathrm{B}_c\mathrm{C}_b + wab\mathrm{D}_c\mathrm{C}_d = a\mathbf{B_{rdc}D_{wbc}C_{(r+w)bd}} = \mathbf{p.\ 23}) + tbd\mathrm{A}_c\mathrm{C}_a =$$
$$= (tbd\mathrm{A}_c\mathrm{C}_a + wab\mathrm{D}_c\mathrm{C}_d = b\mathbf{A_{tdc}D_{wac}C_{(t+w)ad}} = \mathbf{p.\ 24}) + rad\mathrm{B}_c\mathrm{C}_b =$$
$$= (tbd\mathrm{A}_c\mathrm{C}_a + rad\mathrm{B}_c\mathrm{C}_b = d\mathbf{A_{tbc}B_{rac}C_{(t+r)ab}} = \mathbf{p.\ 25}) + wab\mathrm{D}_c\mathrm{C}_d =$$
$$= (A_{tbdc}B_{radc}D_{wabc}C_{(t+r+w)abd} = ЧХС_{n(bas)} = \text{p. } 22) \quad \text{.....(23)}$$

Clusters in the form of p. 26 and p. 23, p. 27 and p. 24, as well as p. 28 and p. 25 are linked by reaction (2), which allows us to determine the formulae of clusters as p. 26, p. 27 and p. 28 c using the following equations (Fig. 3):

$$c(r\mathrm{dB}^{b+} + w\mathrm{bD}^{d+} = \mathbf{[B_{rd}D_{wb}]^{(r+w)bd+} = p.\ 26}) + (r+w)\mathrm{bdC}^{c-} = (B_{rdc}D_{wbc}C_{(r+w)bd} = \text{p. } 23) \quad \text{..(24)}$$

$$c(t\mathrm{dA}^{a+} + w\mathrm{aD}^{d+} = \mathbf{[A_{td}D_{wa}]^{(t+w)ad+} = p.\ 27}) + (t+w)\mathrm{adC}^{c-} = (A_{tdc}D_{wac}C_{(t+w)ad} = \text{p. } 24) \quad \text{...(25)}$$

$$c(t\mathrm{bA}^{a+} + r\mathrm{aB}^{b+} = \mathbf{[A_{tb}B_{ra}]^{(t+r)ab+} = p.\ 28}) + (t+r)\mathrm{abC}^{c-} = (A_{tbc}B_{rac}C_{(t+r)ab} = \text{p. } 25) \quad \text{.....(26)}$$

The intersection of the segments (p. 26 – A^{a+}), (p. 27 – B^{b+}) and (p.28 – D^{d+}) will determine the location and formula of the cluster as $(\text{p. } 29 = ТЗК_{n(bas)})$, which is related to the base cluster $(A_{tbdc}B_{radc}D_{wabc}C_{(t+r+w)abd} = ЧХС_{n(bas)} = \text{p. } 22)$ by reaction (2). The above is described by the following equations:

$$\{(c[B_{rd}D_{wb}]^{(r+w)bd+} = \text{p. } 26) + tbdcA^{a+} = (c[A_{td}D_{wa}]^{(t+w)ad+} = \text{p. } 27) + radcB^{b+} =$$
$$= (c[A_{tb}B_{ra}]^{(t+r)ab+} = \text{p. } 28) + wabcD^{d+} = (c\mathbf{[(A_{tbd}B_{rad}D_{wab}]^{(t+r+w)abd+} = ТЗК_{n(bas)} =}$$
$$\mathbf{= p.\ 29}\}) + (t+r+w)\mathrm{abdC}^{c-} = (A_{tbdc}B_{radc}D_{wabc}C_{(t+r+w)abd} = ЧХС_{n(bas)} = \text{p. } 22) \quad \text{.....(27)}$$

Knowing the formula $(ТЗК_{n(bas)} = \text{p. } 29)$ it becomes possible to determine the location and formulas of the clusters $ЧЗК_{n(bas)}$, which are associated with $(ЧХС_{n(bas)} = \text{p. } 22)$ by reaction (2). Excluding the case of ГС-1, ГС-2 and ГС-3, when for them the $ЧЗК_{n(bas)}$ cluster is the same, in all other cases the formulas of $ЧЗК_{n(bas)}$ may be different depending on the direction of ГС development.

So, for ГС-4 (development direction of A_cC_a) the intersection of the segments (p. 29 – C^{c-}), (p. 26 –A_cC_a) and (p. 23 – A_cC_a) will determine the location and the formula $(ЧЗК_{n(bas)} = \text{p. } 30)$ – fig. 3:

$$(c[(A_{tbd}B_{rad}D_{wab}]^{(t+r+w)abd+} = ТЗК_{n(bas)} = \text{p. } 29) + tabdC^{c-} = (ac[B_{rd}D_{wb}]^{(r+w)bd+} =$$
$$= \text{p. } 26) + tbdA_cC_a = (\mathbf{[(A_{tbdc}B_{radc}D_{wabc}C_{tabd}]^{(r+w)abdc+} = ЧЗК_{n(bas)} = p.\ 30}) \quad \text{.....(28)}$$

For ГС-5 (development direction of B_cC_b) he intersection of segments (p. 29 – C^{c-}), (p. 27 – B_cC_b) and (p. 24 – B_cC_b) will determine the location and the formula $(ЧЗК_{n(bas)} = \text{p. } 31)$ – fig. 3:

$(c[(A_{tbd}B_{rad}D_{wab}]^{(t+r+w)abd+} = ТЗК_{n(bas)} = p.\ 29) + rabdC^{c-} = (bc[A_{td}D_{wa}]^{(t+w)ad+} =$
$= p.\ 27) + radB_cC_b = = (\mathbf{[(A_{tbdc}B_{radc}D_{wabc}C_{rabd}]^{(t+w)abdc+} = ЧЗК_{n(bas)} = p.\ 31})$…….(29)

For ГС-6 (development direction of D_cC_d) the intersection of the segments (p. 29 – C^{c-}), (p. 27 – D_cC_d) and (p. 24 – D_cC_d) will determine the location and the formula (ЧЗК$_{n(bas)}$ = p. 31) – fig. 3:

$(c[(A_{tbd}B_{rad}D_{wab}]^{(t+r+w)abd+} = ТЗК_{n(bas)} = p.\ 29) + wabdC^{c-} = (dc[A_{tb}B_{ra}]^{(t+r)ab+} =$
$= p.\ 28) + wabD_cC_d = = (\mathbf{[(A_{tbdc}B_{radc}D_{wabc}C_{wabd}]^{(t+r)abdc+} = ЧЗК_{n(bas)} = p.\ 32})$…..(30)
$(c[(A_{tbd}B_{rad}D_{wab}]^{(t+r+w)abd+} = ТЗК_{n(bas)} = p.\ 29) + (t+r+w)abdC^{c-} =$
$= ([(A_{tbdc}B_{radc}D_{wabc}C_{tabd}]^{(r+w)abdc+} = ЧЗК_{n(bas)} = p.\ 30) + (r+w)abdC^{c-} =$
$= ([(A_{tbdc}B_{radc}D_{wabc}C_{rabd}]^{(t+w)abdc+} = ЧЗК_{n(bas)} = p.\ 31) + (t+w)abdC^{c-} =$
$= ([(A_{tbdc}B_{radc}D_{wabc}C_{wabd}]^{(t+r)abdc+} = ЧЗК_{n(bas)} = p.\ 32) + (t+r)abdC^{c-} =$
$= (A_{tbdc}B_{radc}D_{wabc}C_{(t+r+w)abd} = ЧХС_{n(bas)} = p.\ 22)$……..……(31)

4. 1. Calculation of the formula of the homological series ГС-4, to which belongs the known (base) ЧХС$_{n(bas)}$

The base cluster in the form of p. 22, interacting with A^{a+},begins to form ГС-4. The intersection of the segments (p. 22 – A^{a+}) and (p. 26 – A_cC_a) at the point (p. 33 = ЧЗК$_{n(bas)+1}$), the intersection of the segments (p. 33 – C^{c-}) and (p. 23 – A_cC_a) at the point (p. 34 = ЧХС$_{n(bas)+1}$), as well as the intersection of the continuation of the segment (p. 34 – p. 33) with the segment (p. 26 – A^{a+}) at the point (p. 35 = ТЗК$_{n(bas)+1}$) will determine the location and formulas of the clusters (p. 33 = ЧЗК$_{n(bas)+1}$), (p. 35 = ТЗК$_{n(bas)+1}$) and (p. 34 = ЧХС$_{n(bas)+1}$) – Fig. 3, which is described by the following equations:

$(A_{tbdc}B_{radc}D_{wabc}C_{(t+r+w)abd} = ЧХС_{n(bas)} = p.\ 22) + (r+w)A^{a+} = (ac[B_{rd}D_{wb}]^{(r+w)bd+} =$
$= p.\ 26) + (t+r+w)bdA_cC_a = (\mathbf{[(A_{(t+r+w)bdc}B_{radc}D_{wabc}C_{(t+r+w)abd}]^{(r+w)abdc+} =}$
$\mathbf{= ЧЗК_{n(bas)+1} = p.\ 33})$……..…(32)
$(ac[B_{rd}D_{wb}]^{(r+w)bd+} = p.\ 26) + (t+r+w)bdcA^{a+} = (\mathbf{[(A_{(t+r+w)bdc}B_{radc}D_{wabc}]^{(t+r)abdc+} =}$
$\mathbf{= p.\ 35}) + \{t+2(r+w)\}abdC^{c-} = ([(A_{(t+r+w)bdc}B_{radc}D_{wabc}C_{(t+r+w)abd}]^{(r+w)abdc+} = p.\ 33) +$
$+ (r+w)abdC^{c-} = a(B_{rdc}D_{wbc}C_{(r+w)bd} = p.\ 23) + (t+r+w)bdA_cC_a =$
$= (\mathbf{A_{(t+r+w)bdc}B_{radc}D_{wabc}C_{\{t+2(r+w)\}abd} = ЧХС_{n(bas)+1} = p.\ 34})$……..(33)

According to (3), (22)and(33) will determine the formulae Δ:

$\Delta = (A_{(t+r+w)bdc}B_{radc}D_{wabc}C_{\{t+2(r+w)\}abd} = ЧХС_{n(bas)+1} = p.\ 34) – (A_{tbdc}B_{radc}D_{wabc}C_{(t+r+w)abd} =$
$= ЧХС_{n(bas)} = p.\ 22) = ([(A_{(t+r+w)bdc}B_{radc}D_{wabc}C_{(t+r+w)abd}]^{(r+w)abdc+} = ЧЗК_{n(bas)+1} =$
$= p.\ 33) – ([(A_{tbdc}B_{radc}D_{wabc}C_{tabd}]^{(r+w)abdc+} = ЧЗК_{n(bas)} = p.\ 30) = \mathbf{A_{(r+w)bdc}C_{(r+w)abd}}$..(34)

Expressions (4), (5), (22), (30) and (34) will define the formulae ЧХС$_{n=1}$ and ЧЗК$_{n=1}$:

$(A_{tbdc}B_{radc}D_{wabc}C_{(t+r+w)abd} = ЧХС_{n(bas)} = p.\ 22) – kA_{(r+w)bdc}C_{(r+w)abd} = (\mathbf{ЧХС_{n=1} =}$
$\mathbf{= A_{\{t-k(r+w)\}bdc}B_{radc}D_{wabc}C_{\{t+(1-k)(r+w)\}abd}})$……..(35)
$([(A_{tbdc}B_{radc}D_{wabc}C_{tabd}]^{(r+w)abdc+} = ЧЗК_{n(bas)} = p.\ 30) – kA_{(r+w)bdc}C_{(r+w)abd} = (\mathbf{ЧЗК_{n=1} =}$
$\mathbf{= [A_{\{t-k(r+w)\}bdc}B_{radc}D_{wabc}C_{\{t-k(r+w)\}abd}]^{(r+w)abdc+}})$……..(36)

According to (6), (7), (35) and (36) the formulae of both branches ГС-4 are defined:

branch ХС – $(A_{\{t-k(r+w)\}bdc}B_{radc}D_{wabc}C_{\{t+(1-k)(r+w)abd} = ЧХС_{n=1}) + (n-1)A_{(r+w)bdc}C_{(r+w)abd} =$
$= \mathbf{A_{\{(r+w)(n-1-k)+t\}bdc}B_{radc}D_{wabc}C_{\{(r+w)(n-k)+t\}abd}}$ ……..(37)
branch ЗК – $(A_{\{t-k(r+w)\}bdc}B_{radc}D_{wabc}C_{\{t-k(r+w)\}abd}]^{(r+w)abdc+}) + (n-1)A_{(r+w)bdc}C_{(r+w)abd} =$
$=\mathbf{[A_{\{(r+w)(n-1-k)+t\}bdc}B_{radc}D_{wabc}C_{\{(r+w)(n-1-k)+t\}abd}]^{(r+w)abdc+}}$ ……..….(38)

There are two possibilities: first, when $\{t \le (r+w)\}$, then {n(bas) = 1} and ($k = 0$); second, when $(r+w) < t$, then $\{1 < n(bas)\}$ and $(0 < k)$.

4. 2. Calculation of the formulae of the homological series ГС-5 and ГС-6, to which belongs the known (basic) $ЧХС_{n(bas)}$

The formation of ГС-5, which develops towards B_cC_b, occurs in a triangle (p. 27 – B^{b+} – C^{c-}). Calculation of the formulas ($ЧХС_{n=2}$ = p. 37), ($ЧЗК_{n=2}$ = p. 36), ($ТЗК_{n=2}$ = p. 38) and both branches of ГС-5 is carried out similarly to the calculation of ГС-4 . As can be seen from Figs. 3, 4, the clusters ($ЧЗК_{n=1}$ = p. 31), ($ЧХС_{n=1}$ = p. 22), ($ТЗК_{n=1}$ = p. 29), ($ЧХС_{n=2}$ = p. 37), ($ЧЗК_{n=2}$ = p. 36) and ($ТЗК_{n=2}$ = p. 38) belong to ГС-5. Here are the final results of the ГС-5 calculation:

$\Delta = \mathbf{B_{(t+w)adc}C_{(t+w)abd}}$ ……..(39)
branch ХС – $\mathbf{A_{tbdc}B_{\{(t+w)(n-1-k)+r\}adc}D_{wabc}C_{\{(t+w)(n-k)+r\}abd}}$ ……..….(40)
branch ЗК – $[\mathbf{A_{tbdc}B_{\{(t+w)(n-1-k)+r\}adc}D_{wabc}C_{\{(t+w)(n-1-k)+r\}abd}}]^{(t+w)abdc+}$ ……...(41)

There are two variants: first, when $\{r \le (t+w)\}$, then {n(bas) = 1} and ($k = 0$); second, when $(t+w) < r$, then $\{1 < n(bas)\}$ and $(0 < k)$.

The formation of ГС-6, which evolves towards D_cC_d, occurs in a triangle (p. 28 – D^{d+} – C^{c-}). The calculation of the formulae ($ЧХС_{n=2}$ = p. 40), ($ЧЗК_{n=2}$ = p. 39), ($ТЗК_{n=2}$ = p. 41) and both branches of ГС-6 is carried out similarly to the calculation of ГС-4 . As can be seen from Fig. 3 Clusters ($ЧЗК_{n=1}$ = p. 32), ($ЧХС_{n=1}$ = p. 22), ($ТЗК_{n=1}$ = p. 29), ($ЧХС_{n=2}$ = p. 40), ($ЧЗК_{n=2}$ = p. 39) and ($ТЗК_{n=2}$ = p. 41) belong to ГС-6. Here are the final results of the ГС-6 calculation:

$\Delta = \mathbf{D_{(t+r)adc}C_{(t+r)abd}}$ ……..(42)
branch ХС – $\mathbf{A_{tbdc}B_{radc}D_{\{(t+r)(n-1-k)+w\}abc}C_{\{(t+r)(n-k)+w\}abd}}$ ……..(43)
branch ЗК – $[\mathbf{A_{tbdc}B_{radc}D_{\{(t+r)(n-1-k)+w\}abc}C_{\{(t+r)(n-1-k)+w\}abd}}]^{(t+r)abdc+}$ ……..(44)

There are two possibilities: first, when $\{w \le (t+r)\}$, then {n(bas) = 1} and ($k = 0$); second, when $(t+r) < w$, then $\{1 < n(bas)\}$ and $(0 < k)$.

5. Calculation of homological series of the system (La^{3+} – Ni^{2+} – Ni^{3+} – O^{2-}) based on the compounds $La_2Ni^{2+}{}_3Ni^{3+}{}_2O_9$, $La_8Ni^{2+}{}_6Ni^{3+}{}_6O_{27}$ and $La_4Ni^{2+}{}_3Ni^{3+}{}_6O_{18}$,

On the example of the system (La^{3+} – Ni^{2+} – Ni^{3+} – O^{2-}) we will demonstrate the calculation of ГС using the formulas (33), (36)-(43) of both branches of ГС obtained above in **generalised** form. The compound $La_2Ni^{2+}{}_3Ni^{3+}{}_2O_9$, is used below as a base cluster for the calculation of ГС-7, ГС-8 and ГС-9.

Preliminary ГС calculations of the (La^{3+} – Ni^{2+} – Ni^{3+} – O^{2-}) system showed that the compounds ($La_3Ni_2O_7$ [16] ≡ $La_6Ni^{2+}{}_2Ni^{3+}{}_2O_{14}$) and ($La_4Ni_3O_{10}$ [16] ≡ ≡ $La_4Ni^{2+}Ni^{3+}{}_2O_{10}$ (fig. 5) known from the work [16] turned out to be the second members of ГС-13 and ГС-10, which were calculated on the basis of ($ЧХС_{n(bas)=1}$ =

$=La_8Ni^{2+}_6Ni^{3+}_6O_{27}$) and ($ЧХС_{n(bas)=1} = La_4Ni^{2+}_3Ni^{3+}_6O_{18}$), respectively. For this reason, we will present the calculation of ГС-10, ГС-11 and ГС-12 based on

($La_8Ni^{2+}_6Ni^{3+}_6O_{27} = ЧХС_{n(bas)=1}$) and ГС-13, ГС-14 and ГС-15 on the basis of ($La_4Ni^{2+}_3Ni^{3+}_6O_{18} = ЧХС_{n(bas)=1}$).

For the system ($La^{3+} – Ni^{2+} – Ni^{3+} – O^{2-}$) we obtain: $A^{a+} ≡ La^{3+}$, $B^{b+} ≡ Ni^{2+}$, $D^{d+} ≡ ≡ Ni^{3+}$, $C^{c-} ≡ O^{2-}$, a = 3, b = 2, d = 3, c = 2, bdc = 12, adc = 18, abc = 12, abd = 18.

5. 1. The calculation of ГС-7, ГС-8 and ГС-9 on the basis of the compound $La_2Ni^{2+}_3Ni^{3+}_2O_9$, in the formation of which clusters $ТХС_{n=1} = La_2Ni^{2+}_3O_6$, $ТХС_{n=1} = La_2Ni^{3+}_2O_6$ and $ТХС_{n=1} = Ni^{2+}_3Ni^{3+}_2O_6$ take part

For the system ($La_2O_3 – NiO – Ni_2O_3$) can be written – fig. 5:

$La_2O_3 + (Ni^{2+}_3Ni^{3+}_2O_6 ≡ ТХС_{n=1}) = 3NiO + (La_2Ni^{3+}_2O_6 ≡ ТХС_{n=1}) = Ni_2O_3 +$
$+ (La_2Ni^{2+}_3O_6 ≡ ТХС_{n=1}) = \mathbf{La_2Ni^{2+}_3Ni^{3+}_2O_9}$……..……..…(45)

5. 1. 1. Development direction ГС-7 – La_2O_3

According to (14) we can write:

branch XC in ГС-7 – $A_{(2n-1)bdc}B_{adc}D_{abc}C_{(2n+1)abd} = La_{(2n-1)bdc}Ni^{2+}_{adc}Ni^{3+}_{abc}O_{(2n+1)abd} =$
$= \mathbf{La_{4n-2}Ni^{2+}_3Ni^{3+}_2O_{6n+3}}$……..…(46)

5. 1. 2. Development direction ГС-8 – NiO

According to (17) we can write:

branch XC in ГС-8 – $A_{bdc}B_{(2n-1)adc}D_{abc}C_{(2n+1)abd} = La_{bdc}Ni^{2+}_{(2n-1)adc}Ni^{3+}_{abc}O_{(2n+1)abd} =$
$=\mathbf{La_2Ni^{2+}_{6n-3}Ni^{3+}_2O_{6n+3}}$……..…(47)

In ГС-8 – ($ЧХС_{n=1} = La_2Ni^{2+}_3Ni^{3+}_2O_9$).

5. 1. 3. Development direction ГС-9 – Ni_2O_3

According to (19) we can write:

branch XC in ГС-9 – $A_{bdc}B_{adc}D_{(2n-1)abc}C_{(2n+1)abd} = La_{bdc}Ni^{2+}_{adc}Ni^{3+}_{(2n-1)abc}O_{(2n+1)abd} =$
$=\mathbf{La_2Ni^{2+}_3Ni^{3+}_{4n-2}O_{6n+3}}$……..…(48)

As can be seen, in all ГС-7, ГС-8 and ГС-9 the cluster $La_2Ni^{2+}_3Ni^{3+}_2O_9$ is the first homologue..

5. 2. Calculation of ГС-10 (direction La_2O_3), ГС-11 (direction NiO) and ГС-12 (direction Ni_2O_3) on the basis of the compound $La_4Ni^{2+}_3Ni^{3+}_6O_{18}$

For ($ЧХС_{n(bas)} ≡ A_{t bdc}B_{r adc}D_{w abc}C_{(t+r+w)abd} ≡ La_4Ni^{2+}_3Ni^{3+}_6O_{18}$) can be written the following: $t$bdc = 4, t = 12/36, $r$adc = 3, r = 6/36, $w$abc = 6, w = 18/36, (t + r) = =18/36, (t + w) = 30/36, (r + w) = 24/36, (t + r)abc = 216/36, (t +r)abd = 324/36, (r + w)bdc = 288/36, (r + w)abd = 432/36, (t + w)adc = 540/36 and (t + w)abd = = 540/36.

Then according to (34) the following is true for **ГС-10** (direction La_2O_3):

$\Delta = A_{(r+w)bdc}C_{(r+w)abd} = La_{96/36}O_{144/36}$ and (t = 12/36) < (r + w = 24/36), Consequently, k = 0 and n(bas) = 1. Then according to (37) at k = 0 the formula of the XC branch of this ГС-10 will be as follows:

branch XC ГС-10 – $A_{\{(r+w)(n-1-k)+t\}bdc}B_{radc}D_{wabc}C_{\{(r+w)(n-k)+t\}abd} ≡$
$≡ La_{\{(r+w)(n-1)+t\}bdc}Ni^{2+}_{radc}Ni^{3+}_{wabc}O_{\{(r+w)n+t\}abd} ≡ \mathbf{La_{8n-4}Ni^{2+}_3Ni^{3+}_6O_{12n+6}}$…….....(49)

From (49) we obtain: ($ЧХС_{n=1} = La_4Ni^{2+}{}_3Ni^{3+}{}_6O_{18}$), (**$ЧХС_{n=2} = La_{12}Ni^{2+}{}_3Ni^{3+}{}_6O_{30} \equiv$**
$\equiv La_4Ni^{2+}Ni^{3+}{}_2O_{10} \equiv La_4Ni_3O_{10}$ [13]) and ($ЧХС_{n=3} = La_{20}Ni^{2+}{}_3Ni^{3+}{}_6O_{42}$).

Then according to (39) the following is true for **ГС-11** (NiO direction):

$\Delta = B_{(t+w)adc}C_{(t+w)abd} = Ni^{2+}{}_{540/36}O_{540/36}$ and ($r = 6/36$) < ($t + w = 30/36$),Consequently, $k = 0$ and n(bas) = 1. Then according to (40) at $k = 0$ the formula of the XC branch of this ГС-11 will be as follows:

branch XC ГС-11 – $A_{t bdc}B_{\{(t+w)(n-1)+r\}adc}D_{w abc}C_{\{(t+w)n+r\}abd} \equiv$
$\equiv$ **$La_4Ni^{2+}{}_{15n-12}Ni^{3+}{}_6O_{15n+3}$**.....(50)

From (50) we obtain: ($ЧХС_{n=1} = La_4Ni^{2+}{}_3Ni^{3+}{}_6O_{18}$), ($ЧХС_{n=2} = La_4Ni^{2+}{}_{18}Ni^{3+}{}_6O_{33}$) and ($ЧХС_{n=3} = La_4Ni^{2+}{}_{33}Ni^{3+}{}_6O_{48}$).

Then according to (42) the following is true for **ГС-12** (Ni_2O_3 direction):

$\Delta = D_{(t+r)abc}C_{(t+r)abd} = Ni^{3+}{}_{216/36}O_{324/36}$ and ($w = 18/36$) < ($t + r = 18/36$), Consequently, $k = 0$ and n(bas) = 1. Then according to (43) at $k = 0$ the formula of the XC branch of this ГС-12 will be as follows:

branch XC ГС-12 – $A_{t bdc}B_{r adc}D_{\{(t+r)(n-1)+w\}abc}C_{\{(t+r)n+w\}abd} \equiv$ **$La_43i^{2+}{}_3Ni^{3+}{}_{6n}O_{9n+9}$**.....(51)

From (51) we obtain: ($ЧХС_{n=1} = La_4Ni^{2+}{}_3Ni^{3+}{}_6O_{18}$), ($ЧХС_{n=2} = La_4Ni^{2+}{}_3Ni^{3+}{}_{12}O_{27}$) and ($ЧХС_{n=3} = La_4Ni^{2+}{}_3Ni^{3+}{}_{18}O_{36}$).

5. 3. Calculation of ГС-13 (La_2O_3 direction), ГС-14 (NiO direction) and ГС-15 (Ni_2O_3 direction) on the basis of the compound $La_8Ni^{2+}{}_6Ni^{3+}{}_6O_{27}$

For ($ЧХС_{n(bas)} \equiv A_{t bdc}B_{r adc}D_{w abc}C_{(t+r+w)abd} \equiv La_8Ni^{2+}{}_6Ni^{3+}{}_6O_{27}$) can be written as follows: $t$bdc = 8, t = 24/36, $r$adc = 6, r = 12/36, $w$abc = 6, w = 18/36, ($t + r$) = = 36/36, ($t + w$) = 42/36, ($r + w$) = 30/36, ($t + r$)abc = 432/36, ($t + r$)abd = 648/36, ($r + w$)bdc = 360/36, ($r + w$)abd = 540/36, ($t + w$)adc = 756/36 and ($t + w$)abd = = 756/36.

Then according to (34) the following is true for **ГС-13** (direction La_2O_3):

$\Delta = A_{(r+w)bdc}C_{(r+w)abd} = La_{360/36}O_{540/36}$ and ($t = 24/36$) < ($r + w = 30/36$), Consequently, k = 0 and n(bas) = 1. Then according to (37) at $k = 0$ the formula of the XC branch of this ГС-13 will be as follows:

branch XC ГС-13–$A_{\{(r+w)(n-1-k)+t\}bdc}B_{r adc}D_{w abc}C_{\{(r+w)(n-k)+t\}abd} \equiv$
$\equiv$ **$La_{10n-2}Ni^{2+}{}_6Ni^{3+}{}_6O_{15n+12}$**.....(52)

From (52) we obtain: ($ЧХС_{n=1} = La_8Ni^{2+}{}_6Ni^{3+}{}_6O_{27}$), (**$ЧХС_{n=2} = La_{18}Ni^{2+}{}_6Ni^{3+}{}_6O_{42} \equiv$**
$\equiv La_6Ni^{2+}{}_2Ni^{3+}{}_2O_{14} \equiv La_3Ni_2O_7$ [16]) and ($ЧХС_{n=3} = La_{28}Ni^{2+}{}_6Ni^{3+}{}_6O_{57}$).

Then according to (39) the following is true for **ГС-14** (direction NiO):

$\Delta = B_{(t+w)adc}C_{(t+w)abd} = Ni^{2+}{}_{540/36}O_{540/36}$ and ($r = 12/36$) < ($t + w = 42/36$), Consequently, k = 0 and n(bas) = 1. Then according to (40) at $k = 0$ the formula of the XC branch of this ГС-14 will be as follows:

branch XC ГС-14 – $A_{t bdc}B_{\{(t+w)(n-1)+r\}adc}D_{w abc}C_{\{(t+w)n+r\}abd} \equiv$
$\equiv$ **$La_8Ni^{2+}{}_{21n-15}Ni^{3+}{}_6O_{21n+6}$**.....(53)

From (53) we obtain: ($ЧХС_{n=1} = La_8Ni^{2+}{}_6Ni^{3+}{}_6O_{27}$), ($ЧХС_{n=2} = La_8Ni^{2+}{}_{27}Ni^{3+}{}_6O_{48}$) and ($ЧХС_{n=3} = La_8Ni^{2+}{}_{48}Ni^{3+}{}_6O_{69}$).

Then according to (42) the following is true for **ГС-15** (direction Ni_2O_3):

$\Delta = D_{(t+r)abc}C_{(t+r)abd} = Ni^{3+}_{432/36}O_{648/36}$ and $(w = 18/36) < (t + r = 36/36)$, Consequently, k = 0 and n(bas) = 1. Then according to (43) at $k = 0$ the formula of the XC branch of this ГС-15 will be as follows:

branch XC ГС-15 – $A_{tbdc}B_{radc}D_{\{(t+r)(n-1)+w\}abc}C_{\{(t+r)n+w\}abd} \equiv$

$\equiv \mathbf{La_8Ni^{2+}_6Ni^{3+}_{12n-6}O_{18n+9}}$……(54)

From (54) we obtain: ($ЧХС_{n=1} = La_8Ni^{2+}_6Ni^{3+}_6O_{27}$), ($ЧХС_{n=2} = La_8Ni^{2+}_6Ni^{3+}_{18}O_{45}$) and ($ЧХС_{n=3} = La_8Ni^{2+}_6Ni^{3+}_{30}O_{63}$).

6. Conclusion

The method developed in [3-5] for calculating the ГС of three-component XC has been confirmed by numerous experiments [8]. This was possible due to the geometrical features of the triangle representing the three-component system of ХЭ ions, which made it possible to identify and determine the regularities of changes in the composition of XC-homologues forming the ГС. Taking into account the identical geometrical features of the triangle and the triangular pyramid representing the four-component system of ХЭ ions, the method of calculating the ГС of the three-component system was extended to the four-component system in [6, 9].

The formation of ГС in the system ($A^{a+} – B^{b+} – D^{d+} – C^{c–}$) occurs due to the chain of alternating chemical interactions of XC with cations and ЗК with anion. Homological series of XC evolve towards enrichment of their members with two-component chemical compounds A_cC_a, or B_cC_b, or D_cC_d. The existing ГС is continuous but bounded ($n \geq 1$). The extent of ГС is determined experimentally. According to the continuous character of ГС homologues with smaller values of **n** than those corresponding to experimentally obtained XC_n must exist.

For really existing chemical compounds $XC_{n(bas)}$ by substituting ions A^{a+}, B^{b+}, D^{d+} and C^c in the formulas of the XC_n branch and the $ЗК_n$ branch, to which this $XC_{n(bas)}$ belongs, it is possible to determine the formulas of unknown XC-homologues. This may help to realise plans to search for new XC-homologues of the sought ГС to obtain more suitable material properties for use in certain devices in comparison with $XC_{n(bas)}$.

This paper presents **for the first time** a method for calculating the ГС of four-component systems of ХЭ ions in a **generalised form**, which makes it possible to use it for specific ХЭ systems more effectively. A well-studied system ($La^{3+} – Ni^{2+} – Ni^{3+} – O^{2-}$) is used as an example of application of the results of the **generalised** version of the ГС calculation.

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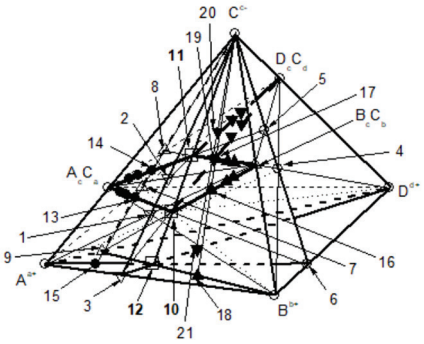

Figure 1. *System* ($A^{a+} – B^{b+} – D^{d+} – C^{c-}$).

($ЧХС_{n=1}$ = p. 11 = $A^{a+}_{bdc}B^{b+}_{adc}D^{d+}_{abc}C^{c-}_{3abd}$) and ($ЧЗК_{n=1}$ = p. 10 = $=[A^{a+}_{bdc}B^{b+}_{adc}D^{d+}_{abc}C^{c-}_{abd}]^{2abdc+}$) in ГС-1, ГС-2 and ГС-3:

ГС-1: $ЧЗК_{n=2}$ = p. 13, $ЧХС_{n=2}$ = p. 14; **ГС-2**: $ЧЗК_{n=2}$ = p. 16, $ЧХС_{n=2}$ = p. 17;

ГС-3: $ЧЗК_{n=2}$ = p. 19, $ЧХС_{n=2}$ = p. 20.

$ТЗК_{n=1}$ = p. 1, p. 4, p. 7, p. 12; $ТЗК_{n=2}$ = p. 15, p. 18, p. 21; $ТХС_{n=1}$ = p. 2, p. 5, p. 8;

$ДЗК_{n=1}$ = p. 3, p. 6, p. 9.

The formulas of clusters in the form of p. 1 - p. 21 are given in Chapter 3.

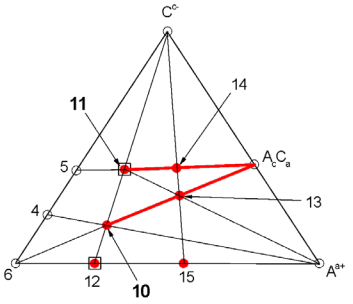

Figure 2. *System{(p. 6 =* $[B_dD_b]^{2bd+}$*) –* A^{a+}*–* C^{c-}*}.*

ГС-1: ЧЗК$_{n=1}$ = p. 10, ЧЗК$_{n=2}$ = p. 13, ЧХС$_{n=1}$ = p. 11, ЧХС$_{n=2}$ = p. 14; ТЗК$_{n=1}$ = p. 4, ДЗК$_{n=1}$ = p. 6, ТХС$_{n=1}$ = p. 5, ТЗК$_{n=1}$ = p. 12, ТЗК$_{n=2}$ = p. 15. Cluster formulas as p. 4 - t. 6 and p. 10 - t. 15 are given in Chapter 3.

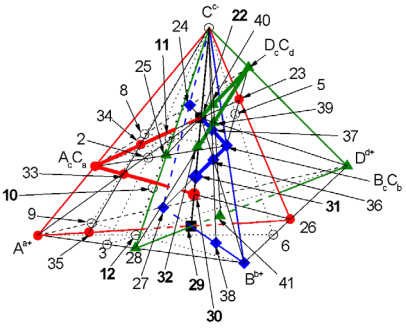

Figure 3. *System* ($A^{a+} – B^{b+} – D^{d+} – C^{c-}$).

(ЧХС$_{n(bas)=1}$ = p. 22 = $A_{tbdc}B_{radc}D_{wabc}C_{(t+r+w)abd}$) in ГС-4, ГС-5 and ГС-6:
ГС-4: ЧЗК$_{n=1}$ = p. 30, ЧЗК$_{n=2}$ = p. 33, ЧХС$_{n=2}$ = p. 34;
ГС-5: ЧЗК$_{n=1}$ = p. 31, ЧЗК$_{n=2}$ = p. 36, ЧХС$_{n=2}$ = p. 37;
ГС-6: ЧЗК$_{n=1}$ = p. 32, ЧЗК$_{n=2}$ = p. 39, ЧХС$_{n=2}$ = p. 40.
ТХС$_{n=1}$ = p. 2, p. 5, p. 8; ТЗК = p. 12, p. 23, p. 24, p. 25, p. 29; ДЗК = p. 3, p. 6, p. 9, p. 26, p. 27, p. 28.

Cluster formulas as p. 2, p. 3, p. 5, p. 6, p. 8 - 12 are given in chapter 3, and in the form of p. 22 - p. 41 are given in Chapter 4.

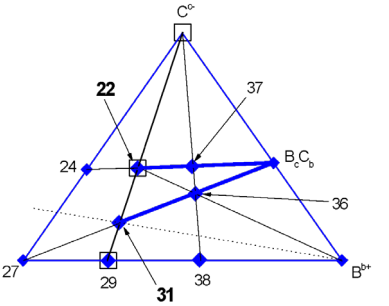

Figure 4. *System {(p. 27 -* B^{b+} C^{c-}*}.*

ГС-5: ЧЗК$_{n=1}$ = p. 31, ЧЗК$_{n=2}$ = p. 36, ЧХС$_{n=1}$ = p. 22, ЧХС$_{n=2}$ = p. 37;
ТЗК= p. 24, ДЗК = p. 27, ТХС$_{n=1}$ = p. 5, ТЗК = p. 29, p. 38.

Cluster formulas as p. 22, p. 24, p. 27, p. 29, p. 31, p. 36, p. 37, p. 38 are given in chapter 4.

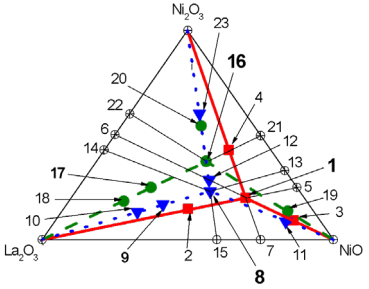

Figure 5. *System (La_2O_3 – NiO - Ni_2O_3).*

(ЧХС$_{n(bas)=1}$ = p. 1 = $La_2Ni^{2+}_3Ni^{3+}_2O_9$) in ГС-7, ГС-8 and ГС-9:
ГС-7 – (p. 2 = ЧХС$_{n=2}$ = $La_6Ni^{2+}_3Ni^{3+}_2O_{15}$);
ГС-8 – (p. 3 = ЧХС$_{n=2}$ = $La_2Ni^{2+}_9Ni^{3+}_2O_{15}$);
ГС-9 – (p. 4 = ЧХС$_{n=2}$ = $La_2Ni^{2+}_3Ni^{3+}_6O_{15}$).
(p. 5 = $Ni^{2+}_3Ni^{3+}_2O_6$), (p. 6 = $La_2Ni^{3+}_2O_6$), (p. 7 = $La_2Ni^{2+}_3O_6$).
(ЧХС$_{n(bas)=1}$ = p. 8 = $La_8Ni^{2+}_6Ni^{3+}_6O_{27}$) in ГС-13, ГС-14 and ГС-15:
ГС-13 – (p. 9 = ЧХС$_{n=2}$ = $La_{18}Ni^{2+}_6Ni^{3+}_6O_{42} \equiv La_3Ni_2O_7$ [15]), (p. 10 = ЧХС$_{n=3}$ = = $La_{28}Ni^{2+}_6Ni^{3+}_6O_{57}$;
ГС-14 – (p. 11 = ЧХС$_{n=2}$ = $La_8Ni^{2+}_{27}Ni^{3+}_6O_{48}$);
ГС-15 – (p. 12 = ЧХС$_{n=2}$ = $La_8Ni^{2+}_6Ni^{3+}_{18}O_{45}$), (p. 23 = ЧХС$_{n=3}$ = = $La_8Ni^{2+}_6Ni^{3+}_{30}O_{63}$).
(p. 13 = $Ni^{2+}_6Ni^{3+}_6O_{15}$), (p. 14 = $La_8Ni^{3+}_6O_{21}$), (p. 15 = $La_4Ni^{2+}_3O_{18}$).
(ЧХС$_{n(bas)=1}$ = p. 16 = $La_4Ni^{2+}_3Ni^{3+}_6O_{18}$) in ГС-10, ГС-11 and ГС-12:
ГС-10 – (p. 17 = ЧХС$_{n=2}$ = $La_{12}Ni^{2+}_3Ni^{3+}_6O_{30} \equiv La_4Ni_3O_{10}$ [15]), (p. 18 = ЧХС$_{n=3}$ = = $La_{20}Ni^{2+}_3Ni^{3+}_6O_{42}$;
ГС-11 – (p. 19 = ЧХС$_{n=2}$ = $La_4Ni^{2+}_{18}Ni^{3+}_6O_{33}$);
ГС-12 – (p. 20 = ЧХС$_{n=2}$ = $La_4Ni^{2+}_3Ni^{3+}_{12}O_{27}$).
(p. 15 = $La_4Ni^{2+}_3O_{18}$). (p. 21 = $Ni^{2+}_3Ni^{3+}_6O_{12}$), (p. 22 = $La_4Ni^{3+}_6O_{15}$).

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CALCULATION OF FORMULAS OF HOMOLOGOUS SERIES OF CHEMICAL COMPOUNDS (IN A GENERALIZED FORM): FIVE-COMPONENT SYSTEMS ($A^{a+} – F^{f+} – [B_{rd}D_{wb}]^{(r+w)bd+} – C^{c–}$) AND ($Li^{+} – Fe^{4+} – [Sr_3La_2]^{12+} – O^{2–}$)

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Abstract. *The paper presents a method for calculating formulas of homologous series of chemical compounds of five-component systems of ions of chemical elements (A^{a+} - B^{b+} - D^{d+}- F^{f+}- $C^{c–}$) in a generalized form. Geometric features of a triangular pyramid that represents a subsystem (A^{a+} - F^{f+} - $[B_{rd}D_{wb}]^{(r+w)bd+}$ - $C^{c–}$), makes it possible to determine that the observed changes in the composition of the members of each particular homological series occur naturally, which is described by the formula. The results of the calculation of homological series of systems (A^{a+} - B^{b+} - -D^{d+}- F^{f+}- $C^{c–}$), presented in a generalized form, make it possible to use them fairly easily and quickly in the case of specific five-component systems of chemical elements. As an example of the application of the calculation of homological series in a generalized form, the calculations of the homological series of the system (Li^{+} - Sr^{2+}- La^{3+} - Fe^{4+} - $O^{2–}$) are given. In the homologous series $Li_6Sr_6La_{14n-10}Fe^{4+}{}_6O_{21n+6}$, the known compound ($Li_{0.5}Sr_{0.5}La_{1.5}Fe^{4+}{}_{0.5}O_4 \equiv Li_6Sr_6La_{18}Fe^{4+}{}_6O_{48}$) turned out to be the second member.*

Keywords: *five-component systems, homologous series, chemical compounds, calculation, generalized version of calculation.*

1. Introduction

When representing single-anion three-component systems by a triangle and four-component systems by a triangular pyramid, in the corners of which ions of chemical elements **(ХЭ)** are placed, homological series **(ГС)** of chemical compounds **(ХС)** are formed by a chain of successive chemical interactions of simple and more complex chemical components of the system [1-7]. The geometrical features of the triangle and triangular pyramid make it possible to choose from these reactions those that are responsible for the formation of ГС, i.e., to choose those that obey the laws of ГС formation rather than the laws of formation of

separately taken XC. **The calculation of ГС formulas is based on the fact that XC-homologues and charged clusters (ЗК)-homologues are arranged in a triangle or in a triangular pyramid at the intersection of segments that connect different pairs of chemically interacting components of the system, ions, XC and ЗК [1-7].**

In the case of five-component ХЭ systems, as shown in [5], it is impossible to calculate the ГС formulae when the system is represented by a quadrangular pyramid, since in this case the basic principle of the arrangement of XC-homologues and ЗК-homologues in the pyramid is not observed: according to [1-7], XC-homologues and ЗК-homologues in a triangle or in a triangular pyramid can be located **only** at the intersection of segments that connect different pairs of interacting chemical individuals, ions, XC and ЗК.

The problem of determining the method of calculating the ГС formulae of five-component systems is solved if the system is represented by a triangular pyramid **with only two positively charged ХЭ ions in two corners of the base, and a positively charged two-component ЗК (ДЗК) consisting of two missing up to four cations in the third corner** [5], where ДЗК ≡ $[D_{wf}F_{vd}]^{(w+v)df+}$, or $[B_{rf}F_{vb}]^{(r+v)bf+}$, or $[B_{rd}D_{wb}]^{(r+w)bd+}$, or $[A_{tf}F_{va}]^{(t+v)af+}$, or $[A_{td}D_{wa}]^{(t+w)ad+}$, or $[A_{tb}B_{ra}]^{(t+r)ab+}$, where ($0 < t, r, w, v$). Determination of the formulae of the ДЗК, which is located in one of the corners of the base of the pyramid, will be shown below. In this case, to calculate the formulas of all ГС of the same five-component system ($A^{a+} – B^{b+} – D^{d+} – F^{f+} – C^{c–}$) six subsystems need to be considered [5]: ($A^{a+} – B^{b+} – [D_{wf}F_{vd}]^{(w+v)df+} – C^{c–}$), ($A^{a+} – D^{d+} – [B_{rf}F_{vb}]^{(r+v)bf+} – C^{c–}$), ($A^{a+} – F^{f+} – [B_{rd}D_{wb}]^{(r+w)bd+} – C^{c–}$), ($B^{b+} – D^{d+} – [A_{tf}F_{va}]^{(t+v)af+} – C^{c–}$), ($B^{b+} – F^{f+} – [A_{td}D_{wa}]^{(t+w)ad+} – C^{c–}$) and ($D^{d+} – F^{f+} – [A_{tb}B_{ra}]^{(t+r)ab+} – C^{c–}$). In [1-7], it is accepted that ГС develop towards two-component XC (**ДХС**), A_cC_a, B_cC_b, D_cC_d and F_cC_f, i.e., as the ГС develops, the homologues are enriched with these ДХС.

If it is necessary to change the properties of $ПХС_{n(bas)}$ of known composition used, for example, in some device, it is possible to calculate the formula of ГС, to which this $ПХС_{n(bas)}$ belongs, and experimentally select a suitable homologue of another composition for this purpose. In this case, the ГС calculation will be made on the basis of the basic five-component **$ПХС_{n(bas)}$** cluster.

Here, the basic five-component $ПХС_{n(bas)}$ cluster will also be represented in a generalised form to calculate the ГС (Fig. 1):

$t$bdfA_cC_a + $r$adfB_cC_b + $w$abfD_cC_d + $v$abdF_cC_f = (**$A_{tbdfc}B_{radfc}D_{wabfc}F_{vabdc}C_{(t+r+w+v)abdf}$ = $ПХС_{n(bas)}$ = p. 1**)……(1)

where n – position of the homologue in the ГС. Here, the value of n(bas) and the values of the concentration parameters *t, r, w, v* are unknown and arbitrary ($0 < t, r, w, v$) provided that the formulae of the activated XC are electrically neutral. However, in practice, a cluster with a known formula ($ПХС_{n(bas)}$ =

$= A_{t\text{bdfc}}B_{r\text{adfc}}D_{w\text{abfc}}F_{v\text{abdc}}C_{(t\,+\,r\,+\,w\,+\,v)\text{abdf}}$) can be used. In this case, as will be shown below, the parameters *t, r, w* and *v* are easily determined.

The determinable formula of the product of chemical interaction between the reactants of the system, as well as the determinable formula of an unknown reactant, when another reactant and the product of interaction between these reactants are known, are highlighted in bold in the reaction equations.

Homological series in the system (A^{a+} – $B^{и+}$ – D^{d+} – F^{f+} – C^{c-}) are formed depending on the direction of development with the help of a chain of successive interactions of $ПХС_n$ clusters with the cation A^{a+} the direction of ГС development – A_cC_a, or with B^{b+} – the direction of B_cC_b,or with D^{d+} - the direction of D_cC_d, or with F^{f+} – the direction of F_cC_f, and five-component ЗК (**ПЗК$_n$**) – with the anion. The formation of ГС occurs according to the scheme [1-7]:

$ПЗК_{n=1} + C^{c-} \rightarrow$ **ПХС$_{n=1}$**, $ПХС_{n=1} + A^{a+}$(or B^{b+}, or D^{d+}, or F^{f+}) $\rightarrow$ **ПЗК$_{n=2}$**,

$ПЗК_{n=2} + C^{c-} \rightarrow$ **ПХС$_{n=2}$**, $ПХС_{n=2} + A^{a+}$(or B^{b+}, or D^{d+}, or F^{f+}) $\rightarrow$ **ПЗК$_{n=3}$**,

$ПЗК_{n=3} + C^{c-} \rightarrow$ **ПХС$_{n=4}$**, etc. ……..……..…(2)

The difference in composition of the closest homologues in the same ГС is invariable:

$\Delta = ХС_{n+1} - ХС_n = ЗК_{n+1} - ЗК_n =$ **constant**……...…..(3)

The formula of any homologue in the same ГС is determined according to [1-7]:

branch ХС: $ПХС_{n=1} + (n-1)\cdot\Delta =$ **ПХС$_n$** ……(4)

branch ЗК: $ПЗК_{n=1} + (n-1)\cdot\Delta =$ **ПЗК$_n$** ……..……..(5)

The formulas of the first members of the considered ГС, $ПХС_{n=1}$ and $ПЗК_{n=1}$, are calculated by subtracting the **maximum** number of times of the formula Δ from the formulas of the initial (base) clusters $ПХС_{n(bas)}$ and $ПЗК_{n(bas)}$ while keeping in their composition the **minimum** amount of that cation contained in the formula Δ [1-7], i.e., keeping the homologues five-component:

$ПХС_{n(bas)} - k\cdot\Delta =$ **ПХС$_{n=1}$**……..……..……(6)

$ПЗК_{n(bas)} - k\cdot\Delta =$ **ПЗК$_{n=1}$**……..……..(7)

where k – is an integer and $0 \le k$. In the case when $k = 0$, then n(bas) = 1.

It should be noted that all $ЗК_n$ and $ХС_n$ occupying the same position in the same ГС are linked by the following reaction:

$ЗК_n + C^{c-} = ХС_n$……..……..……..…….(8)

Due to the difficulty of studying five-component ХЭ systems in the literature, compared, for example, with three-component systems, it is practically impossible to find a sufficient number of specific five-component ХЭ systems, which would allow us to compare them with the calculated by the presented method ГС. However, the well-studied system (Y – Ba – Cu –O) can help to some extent.

Thus, numerous studies of the (Y – Ba – Cu –O) element system stimulated by the discovery of high-temperature superconductivity (**HTSC)** in $YBa_2Cu_3O_7$ ceramics, in particular, have shown the following:

1) one of the main mechanisms determining HTSC is closely related to the local structure of the environment of copper and oxygen ions [8];

2) HTSC in $YBa_2Cu_3O_7$ is explained by partial disproportionation of copper ions

$Cu^{3+} \rightarrow Cu^{2+}$ [9, 10].The chemical formulae of a number of experimentally obtained samples belonging to the system (yttrium - barium - copper - oxygen) are combined in [11, 12] by the formula $\mathbf{Y_2Ba_4Cu_{6+n}O_{14+n}}$, where according to the authors $n \geq 0$ and n – integers. Firstly, it should be noted that there cannot be a homologue with n = 0 in the ГС, i.e. there must be n > 0. Secondly, the formula of ХС must be electroneutral, which is not the case with the formula $\mathbf{Y_2Ba_4Cu_{6+n}O_{14+n}}$ when specifying the valence state of the copper ion as (2+) or (3+). In accordance with the fact that according to [9, 10] in the samples of the system ($Y^{3+} – Ba^{2+} – Cu^{2+} – Cu^{3+} – O^{2-}$) copper is contained in two different valence states, Cu^{2+} and Cu^{3+}, formula

$Y_2Ba_4Cu_{6+n}O_{14+n}$ according to [1-7] should be represented as:
$\mathbf{Y_2Ba_4Cu^{2+}_{4+n}Cu^{3+}_{2}O_{14+n}}$. For the same reasons, the formulae ($YBa_2Cu_3O_{7-\delta}$ [9, 10, 13] $\equiv Y_2Ba_4Cu^{2+}_4Cu^{3+}_2O_{14}$), ($Y_2Ba_4Cu_7O_{15-\delta}$ [9, 10, 13] $\equiv Y_2Ba_4Cu^{2+}_5Cu^{3+}_2O_{15}$) and ($Y_{1.2}Ba_{0.8}CuO_{4-\delta}$ [14] $\equiv Y_6Ba_4Cu^{2+}Cu^{3+}_4O_{20}$) should be considered as five components [1-7].

The existence of a homologous series of oxides $Y_nBa_mCu_{m+n}O_y$, where (m = 2, 3, 5; n = 1, 2) is reported in [15].

The paper [5] presents the results of calculating the formulas of the four ГС, which evolve towards the Y_2O_3, BaO, CuO and Cu_2O_3: $Y_{22n-16}Ba_{12}Cu^{2+}_{12}Cu^{3+}_6O_{33n+9}$, $Y_6Ba_{30n-18}Cu^{2+}_{12}Cu^{3+}_6O_{30n+12}$, $Y_6Ba_{12}Cu^{2+}_{30n-18}Cu^{3+}_6O_{30n+9}$ and $Y_6Ba_{12}Cu^{2+}_{12}Cu^{3+}_{22n-16}O_{33n+9}$.

Purpose of work: in this work the task is to develop a method of calculation of ГС of system ($A^{a+} – B^{u+} – D^{d+} – F^{f+} – C^{c-}$) in generalised form on the example of subsystem ($\mathbf{A^{a+} – F^{f+} – [B_{rd}D_{wb}]^{(r+w)bd+} – C^{c-}}$) and on the basis of the ГС formulae obtained by the calculation the calculation of the subsystem ($\mathbf{Li^{+} – Fe^{4+} – [Sr_3La_2]^{12+} – O^{2-}}$) n the basis of ПХС = $\mathbf{Li_6Sr_6La_4Fe^{4+}_6O_{27}}$ will be presented as an example of their use.

2. Subsystem ($\mathbf{A^{a+} – F^{f+} – [B_{rd}D_{wb}]^{(r+w)bd+} – C^{c-}}$).

$$\mathbf{ПХС_{n(bas)} = A_{tbdfc}B_{radfc}D_{wabfc}F_{vabdc}C_{(t+r+w+v)abdf}}$$

In order to calculate the ГС formula of a five-component system ($A^{a+} – B^{u+} – D^{d+} – F^{f+} – C^{c-}$) it is necessary to consider all possible chemical interactions of its simple and complex components and to choose from them those that are responsible for the formation of ГС. As it was found out from [1-7], this problem can be solved by geometrical features of a triangle and a triangular pyramid, if we represent the considered ХЭ system with their help. In the case of a five-component ХЭ system, the solution of this problem is possible only when it is represented by a triangular pyramid. In this case, the calculation of the ГС is performed using six subsystems ($A^{a+} – B^{b+} – [D_{wf}F_{vd}]^{(w+v)df+} – C^{c-}$), ($A^{a+} – D^{d+} – [B_{rf}F_{vb}]^{(r+v)bf+} – C^{c-}$), ($A^{a+} – F^{f+} – [B_{rd}D_{wb}]^{(r+w)bd+} – C^{c-}$), ($B^{b+} – D^{d+} –$

$-[A_{tf}F_{va}]^{(t\ +\ v)af+} - C^{c-})$, $(B^{b+} - F^{f+} - [A_{td}D_{wa}]^{(t\ +\ w)ad+} - C^{c-})$ and $(D^{d+} - F^{f+} - [A_{tb}B_{ra}]^{(t\ +\ r)ab+} - C^{c-})$ [6].

In each of these six subsystems, two subsystems are considered in the calculation, which are represented by the side faces of the pyramid:

$(A^{a+} - [D_{wf}F_{vd}]^{(w\ +\ v)df+} - C^{c-})$, $(B^{b+} - [D_{wf}F_{vd}]^{(w\ +\ v)df+} - C^{c-})$ and $(A^{a+} - B^{b+} - C^{c-})$ in the subsystem $(A^{a+} - B^{b+} - [D_{wf}F_{vd}]^{(w\ +\ v)df+} - C^{c-})$; or $(A^{a+} - [B_{rf}F_{vb}]^{(r\ +\ v)bf+} - C^{c-})$, $(D^{d+} - [B_{rf}F_{vb}]^{(r+v)bf+} - C^{c-})$ and $(A^{a+} - D^{d+} - C^{c-})$ in the subsystem $(A^{a+} - D^{d+} - [B_{rf}F_{vb}]^{(r+v)bf+} - C^{c-})$; or $(A^{a+} - [B_{rd}D_{wb}]^{(r\ +\ w)bd+} - C^{c-})$, $(F^{f+} - [B_{rd}D_{wb}]^{(r\ +\ w)bd+} - C^{c-})$ and $(A^{a+} - F^{f+} - C^{c-})$ in the subsystem $(A^{a+} - F^{f+} - [B_{rd}D_{wb}]^{(r\ +\ w)bd+} - C^{c-})$; or $(B^{b+} - [A_{tf}F_{va}]^{(t\ +\ v)af+} - C^{c-})$, $(D^{d+} - [A_{tf}F_{va}]^{(t+v)af+} - C^{c-})$ and $(B^{b+} - D^{d+} - C^{c-})$ in the subsystem $(B^{b+} - D^{d+} - [A_{tf}F_{va}]^{(t+v)af+} - C^{c-})$; or $(B^{b+} - [A_{td}D_{wa}]^{(t\ +\ w)ad+} - C^{c-})$, $(F^{f+} - [A_{td}D_{wa}]^{(t\ +\ w)ad+} - C^{c-})$ and $(B^{b+} - F^{f+} - C^{c-})$ in the subsystem $(B^{b+} - F^{f+} - [A_{td}D_{wa}]^{(t+w)ad+} - C^{c-})$; or $(D^{d+} - [A_{tb}B_{ra}]^{(t+r)ab+} - C^{c-})$, $(F^{f+} - [A_{tb}B_{ra}]^{(t+r)ab+} - C^{c-})$ and $(D^{d+} - F^{f+} - C^{c-})$ in the subsystem $(D^{d+} - F^{f+} - [A_{tb}B_{ra}]^{(t+r)ab+} - C^{c-})$.

For this purpose, in the triangular pyramid representing a five-component subsystem, two sub-subsystems should be distinguished, in each of which a ГС is formed, which develops towards a two-component chemical compound, either A_cC_a, or B_cC_b, or D_cC_d, or F_cC_f. In each of these sub-subsystems, there should be segments containing $ПХС_n$ and $ПЗК_n$ clusters that are linked to each other by reaction (8). These segments can be identified by considering the clusters that define the plane in which the ГС is formed. Such clusters are found in the subsystem represented by the corresponding side face of the pyramid and located opposite the ДХС towards which the ГС develops. One of these clusters is the one that interacts with the ДХС-directing to form the initial (baseline) $ПХС_{n(bas)}$. The second such cluster will be the ЗК, which according to (8) interacting with the anion forms the first one. This second ЗК is located at the base of the pyramid and consists only of cations. Thus, it can be concluded that the anion, ДХС-directing, and the aforementioned first cluster and the second «cationic» ЗК belong to the plane where the ГС is formed. On the segment that connects the «cationic» ЗК to the ДХС-directing, all the $ПЗК_n$ that belong to a given ГС and are linked to the $ПХС_n$ of the same ГС by the reaction (8) are located. All $ПХС_n$ of the same ГС are located on the segment containing $ПХС_{n(bas)}$ and ДХС-directing.

Consequently, the triangle-shaped plane thus constructed makes it possible to calculate the formula of the considered ГС on the basis of $ПХС_{n(bas)}$.

P.S. *In the text and in Fig. 1, the following designations are accepted: p. 1 ≡ ≡ point 1, p. 2 ≡ point 2, p. 3 ≡ point 3, etc.*

Calculation of five-component ГС-1, ГС-2, based on the base cluster ($\mathbf{A_{tbdfc}B_{radfc}D_{wabfc}F_{vabdc}C_{(t\ +\ r\ +\ w\ +\ v)abdf}}$ **= ПХС$_{n(bas)}$ = p. 1**), will be done with the participation in the formation of these ГС homologues of the three sub-subsystems

$(F^{f+} – [B_{rd}D_{wb}]^{(r+w)bd+} – C^{c-})$, $(A^{a+} – [B_{rd}D_{wb}]^{(r+w)bd+} – C^{c-})$ and $(A^{a+} – B^{b+} – C^{c-})$, which are the side faces of the triangular pyramid $(A^{a+} – F^{f+} – [B_{rd}D_{wb}]^{(r+w)bd+} – C^{c-})$. Such clusters turn out to be ($ЧХС_{n=1}$ = p. 2), ($ЧХС_{n=1}$ = p. 3) and ($ТХС_{n=1}$ = p. 4) – Fig. 1, where **ЧХС** and **ТХС** – three- and four-component XC, respectively.

The initial (base) cluster ($A_{tbdfc}B_{radfc}D_{wabfc}F_{vabdc}C_{(t+r+w+v)abdf}$ = $ПХС_{n(bas)}$ = p. 1) is located in the pyramid at the intersection of the segments (p. 2 – A_cC_a), (p. 3 – – F_cC_f) and (p. 4 – p. 5), which will define the cluster formulae as p. 2, p. 3, p. 4 and p. 5 - Fig. 1:

$\{vabdF_cC_f + af(\mathbf{B_{rdc}D_{wbc}C_{(r+w)bd}}$ **= p. 5**$) = a(\mathbf{B_{rdfc}D_{wbfc}F_{vbdc}C_{(r+w+v)bdf}}$ **= ЧХС$_{n=1}$ = p. 2**$)\}$ + $+ tbdfA_cC_a = \{tbdfA_cC_a + af(\mathbf{B_{rdc}D_{wbc}C_{(r+w)bd}}$ **= p. 5**$) =$ $f(\mathbf{A_{tbdc}B_{radc}D_{wabc}C_{(t+r+w)abd}}$ $= \mathbf{= ЧХС_{n=1} = p.\ 3)}\} + vabdF_cC_f =$ $bd\{tfA_cC_a + vaF_cC_f = \mathbf{A_{tfc}F_{vac}C_{(t+v)af}}$ **= ТХС$_{n=1}$** $= \mathbf{= p.\ 4)}\} + af(\mathbf{B_{rdc}D_{wbc}C_{(r+w)bd}}$ **= p. 5**$) =$ $A_{tbdfc}B_{radfc}D_{wabfc}F_{vabdc}C_{(t+r+w+v)abdf}$ = $ПХС_{n(bas)}$ = = p. 1)……..……(9)

In turn, the formula of the cluster (ДЗК = p. 6) located in the third corner of the pyramid base will be determined according to dependence (8) - Fig. 1:

$(B_{rdc}D_{wbc}C_{(r+w)bd}$ = p. 5$) = (c\mathbf{[B_{rd}D_{wb}]^{(r+w)bd+}}$ **= p. 6**$) + (r+w)bdC^{c-}$……..(10)

The cluster formulae ($B_{rdfc}D_{wbfc}F_{vbdc}C_{(r+w+v)bdf}$ = p. 2**),** ($A_{tbdc}B_{radc}D_{wabc}C_{(t+r+w)abd}$ = p.3) and ($A_{tfc}F_{vac}C_{(t+v)af}$ = p. 4) will define the cluster formulas as p. 7, p. 8 and p. 9, which consist only of cations, according to reaction (8) - Fig. 1:

$\{vbdcF^{f+} + (fc[B_{rd}D_{wb}]^{(r+w)bd+}$ = p. 6$) = (c\mathbf{[B_{rdf}D_{wbf}F_{vbd}]^{(r+w+v)bdf+}}$ **= p. 7**$)\} + (r+w+$ $+v)bdfC^{c-} = (B_{rdfc}D_{wbfc}F_{vbdc}C_{(r+w+v)bdf}$ = p. 2**)**……..(11)

$\{tbdcA^{a+} + (ac[B_{rd}D_{wb}]^{(r+w)bd+}$ = p. 6$) = c\mathbf{[A_{tbd}B_{rad}D_{wab}]^{(t+r+w)abd+}}$ **= p. 8**$)\} + (t+r+$ $+w)abdC^{c-} = (A_{tbdc}B_{radc}D_{wabc}C_{(t+r+w)abd}$ = p. 3)……..(12)

$c(tfA^{a+} + vaF^{f+} = \mathbf{[A_{tf}F_{va}]^{(t+v)af+}}$ **= p. 9**$) + (t+v)afC^{c-} = (A_{tfc}F_{vac}C_{(t+v)af}$ = p. 4)....(13)

The intersection of the segments (p. 7 – A^{a+}), (p. 8 – F^{f+}) and (p. 9 – $[B_{rd}D_{wb}]^{(r+w)bd+}$) at one point at the base of the pyramid will determine the formula of the four component charged cluster (**$ЧЗК_{n(bas)}$**) as p. 10, consisting only of cations and bound to the base cluster as p. 1 by reaction (8) - Fig. 1:

$(a[B_{rdf}D_{wbf}F_{vbd}]^{(r+w+v)bdf+}$ = p. 7$) + tbdfA^{a+} = (bd[A_{tf}F_{va}]^{(t+v)af+}$ = p. 9$) + (af[B_{rd}D_{wb}]^{(r+w)bd+} =$ $= p.\ 6) = (f[A_{tbd}B_{rad}D_{wab}]^{(t+r+w)abd+}$ = p. 8$) + vabdF^{f+} = (\mathbf{[A_{tbdf}B_{radf}D_{wabf}F_{vabd}]^{(t+r+w+v)abdf+} =}$ $\mathbf{= ЧЗК_{n(bas)} = p.\ 10}$)……...(14)

$(c[A_{tbdf}B_{radf}D_{wabf}F_{vabd}]^{(t+r+w+v)abdf+} = ЧЗК_{n(bas)}$ = p. 10$) + (t+r+w+v)abdfC^{c-} =$ $= (\mathbf{A_{tbdfc}B_{radfc}D_{wabfc}F_{vabdc}C_{(t+r+w+v)abdf} = ПХС_{n(bas)=1} = p.\ 1}$)……...(15)

As stated above, in the initial state, the location of the base cluster ($ПХС_{n(bas)}$ = p. 1) in the triangle $\{A_cC_a – F_cC_f – (B_{rdc}D_{wbc}C_{(r+w)bd}$ = p. 5$)\}$ is shown by the intersecting in p. 1 segments {(p. 2 – A_cC_a), (p. 3 – F_cC_f) and {p. 4 – ($B_{rdc}D_{wbc}C_{(r+w)bd}$ = p. 5)} - Fig. 1. Consequently, given that ГС develops towards ДХС, all ПСХ-homologues that belong to ГС-1 and ГС-2, including ($ПХС_{n(bas)}$ = p. 1), are located on the segment (p. 2 – – A_cC_a) in ГС-1 and on the segment (p. 3 – F_cC_f) in ГС-2 - Fig. 1.

In accordance with dependence (8), the segments containing all ПХС and ПЗК of the same ГС, and the anion **must be in the same plane of the pyramid** where this ГС is formed. Since $ПХС_n$ and $ПЗК_n$ are bound to the anion by reaction (8), then as a result of the continuation of the planes (p. 2 – A_cC_a – C^{c-}) and {p. 3 – F_cC_f – C^{c-}}up to the intersection with the base of the pyramid, the planes (p. 7 – A^{a+} – C^{c-}), (p. 8 – F^{f+} – C^{c-}) are obtained, which will contain all ПХС and ПЗК belonging to ГС-1 and ГС-2, respectively - Fig. 1. It can be seen from Fig. 1 that in each of the planes (p. 7 – A^{a+} – C^{c-}) and (p. 8 – F^{f+} – C^{c-})there are segments linking the ТЗК clusters as p. 7 and p. 8 with the ДХС, A_cC_a and F_cC_f clusters, towards which the ГС-1 and ГС-2 corresponding to them develop. This suggests that the ПЗК-homologues that belong to ГС-1 and ГС-2, including ($ПЗК_{n(bas)}$ = p. 11), are located on the segment (p. 7 – A_cC_a) in ГС-1, and also ($ПЗК_{n(bas)}$ = p. 12) (p. 8 – F_cC_f) в ГС-2 – Figs. 1-3.

Indeed, this is confirmed graphically (Fig. 1) and, as will be shown below, analytically.

2. 1. Subsystem (A^{a+} – F^{f+} – $[B_{rd}D_{wb}]^{(r+w)bd+}$ – C^{c-}). Calculation of the homologous series ГС-1 in the sub-subsystem {($[B_{rdf}D_{wbf}F_{vbd}]^{(r+w+v)bdf+}$ = p. 7) – A^{a+} – C^{c-}}. The direction of development ГС-1 – A_cC_a

The intersection of the segments (p. 7 – A_cC_a) and (p. 10 – C^{c-}) at the point (p. 11 = $ПЗК_{n(bas)}$) in the subsystem {($[B_{rdf}D_{wbf}F_{vbd}]^{(r+w+v)bdf+}$ = p. 7) – A^{a+} – C^{c-}} will determine the cluster formula ($ПЗК_{n(bas)}$ = p. 11), which belongs to ГС-1 - Figs. 1, 2:

$a[B_{rdf}D_{wbf}F_{vbd}]^{(r+w+v)bdf+}$ = p. 7) + $t$bdfA_cC_a = $c[A_{tbdf}B_{radf}D_{wabf}F_{vabd}]^{(t+r+w+v)abdf+}$ = = ЧЗК$_{n(bas)}$ = p. 10) + $t$abdfC^{c-} = $([\mathbf{A_{tbdfc}B_{radfc}D_{wabf}F_{vabdc}C_{tabdf}}]^{\mathbf{(r+w+v)abdfc+}} = \mathbf{ПЗК_{n(bas)}} = \mathbf{p.\ 11})$……...(16)

In the subsystem {($[B_{rdf}D_{wbf}F_{vbd}]^{(r+w+v)bdf+}$ = p. 7) – A^{a+} – C^{c-}} the base cluster ($ПХС_{n(bas)}$ = p. 1) interacting with A^{a+} begins to form ГС-1. The formula $ПЗК_{n(bas)+1}$ – the product of this interaction will be determined by the intersection of the segments (p. 1 – A^{a+}) and (p. 7 – A_cC_a) at the point (p. 13 = = $ПЗК_{n(bas)+1}$) - Fig. 1, 2:

($A_{tbdfc}B_{radfc}D_{wabfc}F_{vabdc}C_{(t+r+w+v)abdf}$ = $ПХС_{n(bas)}$ = p.1) + $(r+w+v)$bdfcA^{a+} = = (ac$[B_{rdf}D_{wbf}F_{vbd}]^{(r+w+v)bdf+}$ = p. 7) + $(t+r+w+v)$bdfA_cC_a = = $([\mathbf{A_{(t+r+w+v)bdfc}B_{radfc}D_{wabfc}F_{vabdc}C_{(t+r+w+v)abdf}}]^{\mathbf{(r+w+v)abdfc+}} = \mathbf{ПЗК_{n(bas)+1}} = \mathbf{p.\ 13})$……..(17)

The product of interaction of the cluster ($ПЗК_{n(bas)+1}$ = p. 13) with the anion is the cluster ($ПХС_{n(bas)+1}$ = p. 14), the formula of which will be determined by the intersection of the segments (p. 13 – C^{c-}) and (p. 2 – A_cC_a) in p. 14 - Figs. 1, 2:

($[A_{(t+r+w+v)bdfc}B_{radfc}D_{wabfc}F_{vabdc}C_{(t+r+w+v)abdf}]^{(r+w+v)abdfc+}$ = p. 13) + $(r+w+v)$abdfC^{c-} = = a($B_{rdfc}D_{wbfc}F_{vbdc}C_{(r+w+v)bdf}$ = p. 2) + $(t+r+w+v)A_cC_a$ = = $(\mathbf{A_{(t+r+w+v)bdfc}B_{radfc}D_{wabfc}F_{vabdc}C_{\{t+2(r+w+v)\}abdf}} = \mathbf{ПХС_{n(bas)+1}} = \mathbf{p.\ 14})$…...…..(18)

According to (3), the formula Δ will be determined for ГС-1:

$\Delta = (A_{(t+r+w+v)bdfc}B_{radfc}D_{wabfc}F_{vabdc}C_{\{t+2(r+w+v)\}abdf} = ПХС_{n(bas)+1} =$
$= p.\ 14) - (A_{tbdfc}B_{radfc}D_{wabfc}F_{vabdc}C_{(t+r+w+v)abdf} = ПХС_{n(bas)} = p.\ 1) =$
$= ([A_{(t+r+w+v)bdfc}B_{radfc}D_{wabfc}F_{vabdc}C_{(t+r+w+v)abdf}]^{(r+w+v)abdfc+} = ПЗК_{n(bas)+1} = p.\ 13) -$
$-([A_{tbdf}B_{radf}D_{wabf}F_{vabd}C_{tabdf}]^{(r+w+v)abdfc+} = ПЗК_{n(bas)} = p.\ 11) = \mathbf{A_{(r+w+v)bdfc}C_{(r+w+v)abdf}}$……(19)

In order to determine the formulas of XC and ЗК branches in ГС-1 according to (4) and (5), it is necessary to calculate the formula of the first homologue of this ГС-1 using expressions (6) and (7). At the same time, it is necessary to keep five components in the formula of the first homologue with the minimum content of the A^{a+} ion in it. In this case, two variants of the ratio of the parameter t and the product *k-(r +w + v)* are possible: $\mathbf{t \le k\text{-}(r + w + v)}$ **or** $\mathbf{k\text{-}(r + w + v) < t.}$

1) When $\boldsymbol{t \le k\cdot(r + w + v)}$, according to (6) and (7), given the above conditions, subtract the formula $(\Delta = A_{(r+w+v)bdfc}C_{(r+w+v)abdf})$ from the formulas $(A_{tbdfc}B_{radfc}D_{wabfc}F_{vabdc}C_{(t+r+w+v)abdf} = PCC_{n(bas)} = t.\ 1)$ and $(A_{tbdfc}B_{radfc}D_{wabfc}F_{vabdc}C_{(t+r+w+v)abdf} =$ $= ПХС_{n(bas)} = p.\ 1)$ and $([A_{tbdfc}B_{radfc}D_{wabfc}F_{vabdc}C_{tabdf}]^{(r+w+v)abdfc+} = ПЗК_{n(bas)} = p.\ 11)$ is not possible. Consequently, the clusters ($ПХС_{n(bas)} = p.\ 1$) and ($ПЗК_{n(bas)} = p.\ 11$) in ГС-1 will be the first homologues in this case, i.e., n(bas) = 1 and $k = 0$. Then, according to (4)-(7), the formulae of both branches of ГС-1 are defined as follows:

branch XC: $(A_{tbdfc}B_{radfc}D_{wabfc}F_{vabdc}C_{(t+r+w+v)abdf} = ПХС_{n(bas)=1} = p.\ 1) +$
$+ (n-1)\cdot A_{(r+w+v)bdfc}C_{(r+w+v)abdf} = \mathbf{A_{\{(n-1)(r+w+v)+t\}bdfc}B_{radfc}D_{wabfc}F_{vabdc}C_{\{n(r+w+v)+t\}abdf}}$…(20)

branch ЗК: $([A_{tbdf}B_{radf}D_{wabf}F_{vabd}C_{tabdf}]^{(r+w+v)abdfc+} = ПЗК_{n(bas)=1} = p.\ 11) + (n-1)\cdot$
$\cdot A_{(r+w+v)bdfc}C_{(r+w+v)abdf} = [\mathbf{A_{\{(n-1)(r+w+v)+t\}bdfc}B_{radfc}D_{wabfc}F_{vabdc}C_{\{(n-1)(r+w+v)+t\}abdf}}]^{(r+w+v)abdfc+}$..(21)

2) In the case where $\{\boldsymbol{k\cdot(r + w + v) < t}\}$, subtract the formula

$(\Delta = A_{(r+w+v)bdfc}C_{(r+w+v)abdf})$ from the formulas $(A_{tbdfc}B_{radfc}D_{wabfc}F_{vabdc}C_{(t+r+w+v)abdf} =$ $= ПХС_{n(bas)} = p.\ 1)$ and $([A_{tbdf}B_{radf}D_{wabf}F_{vabd}C_{tabdf}]^{(r+w+v)abdfc+} = ПЗК_{n(bas)} = p.\ 11)$ is possible. In this case, $\{1 < n(bas)\}$ and $(1 \le k)$.Then according to (6) and (7), after fitting the value of k, the formulae of the first homologues and the formulae of both branches of ГС-1 are determined:

$(A_{tbdfc}B_{radfc}D_{wabfc}F_{vabdc}C_{(t+r+w+v)abdf} = ПХС_{n(bas)} = p.\ 1) - k\cdot A_{(r+w+v)bdfc}C_{(r+w+v)abdf} =$
$= (\mathbf{A_{\{t-k(r+w+v)\}bdfc}B_{radfc}D_{wabfc}F_{vabdc}C_{\{t+(1-k)(r+w+v)\}abdf}} = ПХС_{n=1})$……..(22)
$([A_{tbdf}B_{radf}D_{wabf}F_{vabd}C_{tabdf}]^{(r+w+v)abdfc+} = ПЗК_{n(bas)} = p.\ 11) - k\cdot A_{(r+w+v)bdfc}C_{(r+w+v)abdf} =$
$= [(\mathbf{A_{\{t-k(r+w+v)\}bdfc}B_{radfc}D_{wabfc}F_{vabdc}C_{\{t-k(r+w+v)\}abdf}}]^{(r+w+v)abdfc+} = ПЗК_{n=1})$…….(23)

According to (4), (5), (22) and (23), the formulae of both branches of ГС-1 will be defined as follows:

branch XC: $A_{\{t-k(r+w+v)\}bdfc}B_{radfc}D_{wabfc}F_{vabdc}C_{\{t+(1-k)(r+w+v)\}abdf}]^{(r+w+v)abdfc+} = ПХС_{n=1}) +$
$+ (n-1)\cdot A_{(r+w+v)bdfc}C_{(r+w+v)abdf} = \mathbf{A_{\{(n-1-k)(r+w+v)+t\}bdfc}B_{radfc}D_{wabfc}F_{vabdc}C_{\{(n-k)(r+w+v)+t\}abdf}}$..(24)

branch ЗК: $[(A_{\{t-k(r+w+v)\}bdfc}B_{radfc}D_{wabfc}F_{vabdc}C_{\{t-k(r+w+v)\}abdf}]^{(r+w+v)abdfc+} =$
$= ПЗК_{n=1}) + + (n-1)\cdot A_{(r+w+v)bdfc}C_{(r+w+v)abdf} =$
$= \mathbf{[A_{\{(n-1-k)(r+w+v)+t\}bdfc}B_{radfc}D_{wabfc}F_{vabdc}C_{\{(n-1-k)(r+w+v)+t\}abdf}]}^{(r+w+v)abdfc+}$…….....(25)

2.2. Subsystem ($A^{a+} – F^{f+} – [B_{rd}D_{wb}]^{(r+w)bd+} – C^{c–}$) Calculation of the homological series ГС-2 of the sub-subsystem{($[A_{tbd}B_{rad}D_{wab}]^{(t+r+w)abd+}$ = p. 8) – $F^{f+} – C^{c–}$}. The direction of development ГС-2 – F_cC_f

The intersection of the segments (p. 8 – F_cC_f) and (p. 10 – $C^{c–}$) in (p. 12 = = ПЗК$_{n(bas)}$) will determine the cluster formula (ПЗК$_{n(bas)}$ = p. 12), which belongs to ГС-2 - Figs. 1, 3:

$f[A_{tbd}B_{rad}D_{wab}]^{(t+r+w)abd+}$ = p. 8) + $v$abd $F_cC_f = [A_{tbdf}B_{radf}D_{wabf}F_{vabd}]^{(t+r+w+v)abdf+}$ = = ЧЗК$_{n(bas)}$ = p. 10) + $v$abdf$C^{c–}$ = (**$[A_{tbdf}B_{radf}D_{wabf}F_{vabd}C_{vabdf}]^{(t+r+w)abdfc+}$ = =ПЗК$_{n(bas)}$ = p.12**)……..……(26)

Comparing the formulas of ПЗК$_{n(bas)}$, obtained by reaction (16) for ГС-1and by reaction (26) for ГС-2, it can be seen that ПЗК$_{n(bas)}$ = p. 11 = p. 12 at $t = v$.

In the sub-system {($[A_{tbd}B_{rad}D_{wab}]^{(t+r+w)abd+}$ = p. 8) – $F^{f+} – C^{c-}$} the base cluster (ПХС$_{n(bas)}$ = p. 1) interacting with F^{f+} begins to form ГС-2. The formula ПЗК$_{n(bas)+1}$, the product of this interaction, will be determined by the intersection of the segments (p. 1 – F^{f+}) and (p. 8 – F_cC_f) at the point (p. 16 = ПЗК$_{n(bas)+1}$) - Fig. 1, 3:

$(A_{tbdfc}B_{radfc}D_{wabfc}F_{vabdc}C_{(t+r+w+v)abdf}$ = ПХС$_{n(bas)=1}$ = p. 1) + $(t + r + w)$abdcF^{f+} = = (fc$[A_{tbd}B_{rad}D_{wab}]^{(t+r+w)abd+}$ = p. 8) + $(t + r + w + v)$abdF_cC_f = = (**$[A_{tbdfc}B_{radfc}D_{wabfc}F_{(t+r+w+v)abdc}C_{(t+r+w+v)abdf}]^{(t+r+w)abdfc+}$ = ПЗК$_{n(bas)+1}$ = p. 16)**.(27)

The product of interaction of cluster (ПЗК$_{n(bas)+1}$ = p. 16) with the anion is the cluster (ПХС$_{n(bas)+1}$ = p. 17), formula of which will be determined by the intersection of the segments (p. 16 – $C^{c–}$) and (p. 3 – F_cC_f) in p. 17 - Fig. 1, 3:

$([A_{tbdfc}B_{radfc}D_{wabfc}F_{(t+r+w+v)abdc}C_{(t+r+w+v)abdf}]^{(t+r+w)abdfc+}$ = ПЗК$_{n(bas)+1}$ = p. 16) + + $(t + r + w)$abdfC^{c-} = f($A_{tbdc}B_{radc}D_{wabc}C_{(t+r+w)abd}$ = p. 3**)** + $(t + r + w + v)F_cC_f$ = = (**$A_{tbdfc}B_{radfc}D_{wabfc}F_{(t+r+w+v)abdc}C_{\{v+2(t+r+w)\}abdf}$ = ПХС$_{n(bas)+1}$ = p. 17**)……..(28)

According to (3), the formula Δ will be defined for ГС-2:

$\Delta = (A_{tbdfc}B_{radfc}D_{wabfc}F_{(t+r+w+v)abdc}C_{\{v+2(t+r+w)\}abdf}$ = ПХС$_{n(bas)+1}$ = p. 17) – – ($A_{tbdfc}B_{radfc}D_{wabfc}F_{vabdc}C_{(t+r+w+v)abdf}$ = ПХС$_{n(bas)}$ = p. 1) = = ($[A_{tbdfc}B_{radfc}D_{wabfc}F_{(t+r+w+v)abdc}C_{(t+r+w+v)abdf}]^{(t+r+w)abdfc+}$ = ПЗК$_{n(bas)+1}$ = p. 16) – – ($[A_{tbdf}B_{radf}D_{wabf}F_{vabd}C_{vabdf}]^{(t+r+w)abdfc+}$ = ПЗК$_{n(bas)}$) = $\mathbf{F_{(t+r+w)abdc}C_{(t+r+w)abdf}}$ …...(29)

In order to determine the formulas of ХС and ЗК branches in ГС-2 in accordance with (4) and (5), it is necessary to calculate the formula of the first homologue of this ГС-2 using expressions (6) and (7). At the same time, it is necessary to keep five components in the formula of the first homologue with a minimum content of the F^{f+} ion in it. In this case, two variants of the ratio of the parameter v and the product k-$(t + r + w)$ are possible: $\boldsymbol{v \le k\cdot(t + r + w)}$ or $\boldsymbol{k\text{-}(t + r + w) < v}$.

When $\boldsymbol{v \le k\cdot(t + r + w)}$, according to (6) and (7) subtraction the formula ($\Delta = F_{(t+r+w)abdc}C_{(t+r+w)abdf}$) from the formulas ($A_{tbdfc}B_{radfc}D_{wabfc}F_{vabdc}C_{(t+r+w+v)abdf}$ = = ПХС$_{n(bas)}$ = p. 1) and ($[A_{tbdf}B_{radf}D_{wabf}F_{vabd}C_{vabdf}]^{(t+r+w)abdfc+}$ = ПЗК$_{n(bas)}$ = p. 12) is not possible.

Consequently, the clusters ($\Pi XC_{n(bas)}$ = p. 1) and ($\Pi ЗК_{n(bas)}$ = p. 12) in ГС-2 will be the first homologues, i.e., n(bas) = 1) and $k = 0$. Then, according to (4)-(7), the formulae of both branches of the ГС-2 are defined as follows:

branch XC: $(A_{tbdfc}B_{radfc}D_{wabfc}F_{vabdc}C_{(t+r+w+v)abdf} = \Pi XC_{n(bas)=1} = \text{p. 1}) +$
$+ (n-1)\cdot F_{(t+r+w)abdc}C_{(t+r+w)abdf} = \mathbf{A_{tbdfc}B_{radfc}D_{wabfc}F_{\{(n-1)(t+r+w)+v\}abdc}C_{\{n(t+r+w)+v\}abdf}}$.(30)

branch ЗК: $([A_{tbdfc}B_{radfc}D_{wabfc}F_{vabdc}C_{vabdf}]^{(t+r+w)abdfc+} = \Pi ЗК_{n(bas)=1} = \text{p. 12}) + (n-1)\cdot$
$\cdot F_{(t+r+w)abdc}C_{(t+r+w)abdf} = [\mathbf{A_{tbdfc}B_{radfc}D_{wabfc}F_{\{(n-1)(t+r+w)+v\}abdc}C_{\{(n-1)(t+r+w)+v\}abdf}}]^{(t+r+w)abdfc+}$.....(31)

If $\boldsymbol{k\cdot(t+r+w) < v}$, subtraction of the formula ($\Delta = F_{(t+r+w)abdc}C_{(t+r+w)abdf}$) from the formulas ($A_{tbdfc}B_{radfc}D_{wabfc}F_{vabdc}C_{(t+r+w+v)abdf} = \Pi XC_{n(bas)} = \text{p. 1}$) and ($[A_{tbdfc}B_{radfc}D_{wabfc}F_{vabdc}C_{vabdf}]^{(t+r+w)abdfc+} = = \Pi ЗК_{n(bas)} = \text{p. 12}$) is possible. Thus, $\{1 < n(bas)\}$ and $(1 \le k)$. Then after determining the value of k, the formulae of the first homologues of ГС-2 are defined according to (6) and (7) as follows:

$(A_{tbdfc}B_{radfc}D_{wabfc}F_{vabdc}C_{(t+r+w+v)abdf} = \Pi XC_{n(bas)} = \text{p. 1}) - k\cdot F_{(t+r+w)abdc}C_{(t+r+w)abdf} =$
$= (\mathbf{A_{tbdfc}B_{radfc}D_{wabfc}F_{\{v-k(t+r+w)\}abdc}C_{\{v+(1-k)(t+r+w)\}abdf}} = \Pi XC_{n=1})$……..(32)

$([A_{tbdfc}B_{radfc}D_{wabfc}F_{vabdc}C_{vabdf}]^{(t+r+w)abdfc+} = \Pi ЗК_{n(bas)} = \text{p. 12}) - k\cdot F_{(t+r+w)abdc}C_{(t+r+w)abdf} =$
$= [(\mathbf{A_{tbdfc}B_{radfc}D_{wabfc}F_{\{v-k(t+r+w)\}abdc}C_{\{v-k(t+r+w)\}abdf}}]^{(t+r+w)abdfc+} = \Pi ЗК_{n=1})$……...(33)

According to (4), (5), (32) and (33), the formulae of both branches of the ГС-1 are defined as follows:

branch XC: $A_{tbdfc}B_{radfc}D_{wabfc}F_{\{v-k(t+r+w)\}abdc}C_{\{v+(1-k)(t+r+w)\}abdf} = \Pi XC_{n=1}) + (n-1)\cdot$
$\cdot F_{(t+r+w)abdc}C_{(t+r+w)abdf} = \mathbf{A_{tbdfc}B_{radfc}D_{wabfc}F_{\{(n-1-k)(t+r+w)+v\}abdc}C_{\{(n-k)(t+r+w)+v\}abdf}}$…(34)

branch ЗК: $[(A_{tbdfc}B_{radfc}D_{wabfc}F_{\{v-k(t+r+w)\}abdc}C_{\{v-k(t+r+w)\}abdf}]^{(t+r+w)abdfc+} = \Pi ЗК_{n=1}) + (n-1)\cdot$
$\cdot F_{(t+r+w)abdc}C_{(t+r+w)abdf} = [\mathbf{A_{tbdfc}B_{radfc}D_{wabfc}F_{\{(n-1-k)(t+r+w)+v\}abdc}C_{\{(n-1-k)(t+r+w)+v\}abdf}}]^{(t+r+w)abdfc+}$……(35)

Table 1 summarises the results of the ГС formulae for the other subsystems of the system $(A^{a+} - B^{b+} - D^{d+} - F^{f+} - C^{c-})$.

3. **System $(Li^+ - Sr^{2+} - La^{3+} - Fe^{4+} - O^{2-})$. $\Pi XC_{n(bas)} \equiv Li_6Sr_6La_4Fe^{4+}{}_6O_{27}$**

For the system $(Li^+ - Sr^{2+} - La^{3+} - Fe^{4+} - O^{2-})$ we have: $A^{a+} \equiv Li^+$, $B^{b+} \equiv Sr^{2+}$, $D^{d+} \equiv La^{3+}$, $F^{f+} \equiv Fe^{4+}$, $C^{c-} \equiv O^{2-}$, a = 1, b = 2, d = 3, f = 4, c = 2, ab = 2, ad = 3, af = 4, ac = 2, bd = 6, bf = 8, bc = 4, dc = 6, df = 12, fc = 8, abd = 6, abf = 8, adf = 12, bdf = = 24, bdc = 12, bfc = 16, dfc = 24, abdf = 24, abfc = 16, abdc = 12, adfc = 24, bdfc = = 48, abdfc = 48.

For the sub-subsystem $(Li^+ - Fe^{4+} - [Sr_3La_2]^{12+} - O^{2-})$, when the base cluster is ($\Pi XC_{n(bas)} = A_{tbdfc}B_{radfc}D_{wabfc}F_{vabdc}C_{(t+r+w+v)abdf} \equiv Li_6Sr_6La_4Fe^{4+}{}_6O_{27} \equiv 3Li_2O + 6SrO + +2La_2O_3 + 6FeO_2$) can be written as follows: $t$bdfc = 6, t = 6/48, $r$adfc = 6, r = 6/24, $r$abdf = 6, $w$abfc = = 4, w = 4/16, $v$abdc = 6, v = 6/12, $v$abdf = 12, $v$abdc = 6, $(t + w)$ = = 18/48, $(t + r)$ = 18/48, $(t + v)$ = = 30/48, $(r + w)$ = 24/48, $(r + v)$ = 36/48, $(w + v)$ = = 36/48, $(t + r + w)$ = 30/48, $(t + w + v)$ = 42/48, $(r + w + v)$ = 48/48, $(t + r + v)$ = = 42/48, $(t + r + w + v)$ = 54/48.

Then the formulae of the clusters of the system $(Li^+ - Sr^{2+} - La^{3+} - Fe^{4+} - O^{2-})$, corresponding to the clusters as p. 5 and p. 6 of the system $(A^{a+} - B^{b+} - D^{d+} - F^{f+} - C^{c-})$, will be determined by equations (9) and (10):

$(B_{rdc}D_{wbc}C_{(r+w)bd} = \text{p. } 5) \equiv \mathbf{Sr_3La_2O_6}$ and $[B_{rd}D_{wb}]^{(r+w)bd+} = \text{p. } 6 \equiv \mathbf{[Sr_3La_2]^{12+}}$.....(36)

Consequently, the ГС calculation will be performed for the subsystem ($\mathbf{Li^+ – Fe^{4+} – [Sr_3La_2]^{12+} – O^{2–}}$).

3. 2, Subsystem ($\mathbf{Li^+ – Fe^{4+} – [Sr_3La_2]^{12+} – O^{2–}}$). The direction of development ГС-3 – ($\mathbf{A_cC_a \equiv Li_2O}$)

According to (19), when $(r + w + v)$abdc = 576/48 and $(r + w + v)$abdf = =1152/48, the value of $(\Delta = A_{(r+w+v)bdfc}C_{(r+w+v)abdf}) \equiv Li_{2304/48}O_{1152/48}$ will be determined.

Since $\{(t = 6/48) < (r + w + v = 48/48)\}$, n(bas) = 1 and $k = 0$. Consequently, the ГС-3 formula will be determined according to (20):

branch XC - $A_{\{(n-1)(r+w+v)+t\}bdfc}B_{radfc}D_{wabfc}F_{vabdc}C_{\{n(r+w+v)+t\}abdf} \equiv$

$\equiv Li_{\{(n-1)(r+w+v)+t\}bdfc}Sr_{radfc}La_{wabfc}Fe^{4+}{}_{vabdc}O_{\{n(r+w+v)+t\}abdf} \equiv \mathbf{Li_{48n-42}Sr_6La_4Fe^{4+}{}_6O_{24n+3}}$…(37)

3. 3. The direction of development ГС-4 – ($\mathbf{F_cC_f \equiv FeO_2}$)

According to (29), when $(t + r + w)$abdc = 360/48 and $(t + r + w)$abdf = = 720/48, the value of $(\Delta = F_{(t+r+w)abdc}C_{(t+r+w)abdf}) \equiv Fe^{4+}{}_{360/48}O_{720/48} = FeO_2$ will be determined.

Since $\{(v = 24/48) < (t + r + w = 30/48)\}$, n(bas) = 1 and $k = 0$. Consequently, the ГС-3 formula will be determined according to (30):

branch XC - $A_{tbdfc}B_{radfc}D_{wabfc}F_{\{(n-1)(t+r+w)+v\}abdc}C_{\{n(t+r+w)+v\}abdf} \equiv$

$\equiv Li_{tbdfc}Sr_{radfc}La_{wabfc}Fe^{4+}{}_{\{(n-1)(t+r+w)+v\}abdc}O_{\{n(t+r+w)+v\}abdf} \equiv \mathbf{Li_{12}Sr_{12}La_8Fe^{4+}{}_{15n-3}O_{30n+24}}$…(38)

Table 2 presents the results of the ГС formulae calculation in generalised form for other subsystems of the system ($Li^+ – Sr^{2+} – La^{3+} – Fe^{4+} – O^{2–}$).. In particular, in the sub-subsystem ($[Sr_3Fe^{4+}{}_3]^{18+} – La^{3+} – O^{2–}$), which belongs to the subsystem ($Li^+ – La^{3+} – – [Sr_3Fe^{4+}{}_3]^{18+} – O^{2–}$), and in the sub-subsystem ($[Li_3Fe^{4+}{}_3]^{15+} – La^{3+} – O^{2–}$), which belongs to the subsystem ($Sr^{2+} – La^{3+} – [Li_3Fe^{4+}{}_3]^{15+} – O^{2–}$), and in the sub-subsystem ($[Li_3Sr_3]^{9+} – La^{3+} – O^{2–}$), which belongs to the subsystem ($La^{3+} – Fe^{4+} – – [Li_3Sr_3]^{9+} – O^{2–}$), experimentally obtained in the work[16] cluster $ПХС_n \equiv \equiv Li_{0.5}Sr_{0.5}La_{1.5}Fe^{4+}{}_{0.5}O_4$ in ГС with the formula $Li_6Sr_6La_{14n-10}Fe^{4+}{}_6O_{21n+6}$ turned out to be the second homologue: ($ПХС_{n=2} \equiv Li_6Sr_6La_{18}Fe^{4+}{}_6O_{48} \equiv Li_{0.5}Sr_{0.5}La_{1.5}Fe^{4+}{}_{0.5}O_4$) [16]. Considering the continuity of ГС, we should expect that the cluster ($ПХС_{n=1} \equiv Li_6Sr_6La_4Fe^{4+}{}_6O_{27}$)exists.

4. Conclusion

The present work presents a method for calculating the ГС formulas of a five-component system ($A^{a+} – B^{b+} – D^{d+} – F^{f+} – C^{c–}$) in a generalised form. The five-component system of ХЭ ions for calculation of ГС formulae required to be represented by a triangular pyramid. This, in turn, forced the pyramids to be used in the form of six subsystems, which are represented by the side faces of the pyramid. In each of these subsystems of the ХЭ, two sub-subsystems containing ГС that evolve towards the ДХС were considered in the calculation.

The sub-subsystem constructed in this way has geometrical features of a triangle, which make it possible to calculate the ГС formula in a generalised form on the basis of the known $ПХС_{n(bas)}$.

The system $(Li^{+} – Sr^{2+} – La^{3+} – Fe^{4+} – O^{2–})$ or, more precisely, the subsystem $(Li^{+} – Fe^{4+} – [Sr_3La_2]^{12+} – O^{2–})$.is used as an example of application of the obtained calculation results.

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Table 1

ГС formulas of the subsystems of the system (A^{a+}-B^{b+}-D^{d+}-F^{f+}-C^{c-})

Subsystem	XC branch formula in ГС
$\Pi XC_{n(bas)} \equiv A_{tbdac}B_{radac}D_{wabfc}F_{vabdc}C_{(t+r+w+v)abdf}$	
$A^{a+} - B^{b+} - [D_{wabfc}F_{vabdc}]^{(w+v)abdfc+} - C^{c-}$	$A_{\{(n-1-k)(r+w+v)+t\}bdfc}B_{radfc}D_{wabfc}F_{vabdc}$ $C_{\{(n-k)(r+w+v)+t\}abdf}$
	$A_{tbdfc}B_{\{(n-1-k)(t+w+v)+r\}adfc}D_{wabfc}F_{vabdc}$ $C_{\{(n-k)(t+w+v)+r\}abdf}$
$A^{a+} - D^{d+} - [B_{radfc}F_{vabdc}]^{(r+v)abdfc+} - C^{c-}$	$A_{\{n-1-k)(r+w+v)+t\}bdfc}B_{radfc}D_{wabfc}F_{vabdc}$ $C_{\{(n-k)(r+w+v)+t\}abdf}$
	$A_{tbdfc}B_{radfc}D_{\{(n-1-k)(t+r+v)+w\}abfc}F_{vabdc}$ $C_{\{(n-k)(t+r+v)+w\}abdf}$
$A^{a+} - F^{f+} - [B_{rd}D_{wb}]^{(r+w)bd+} - C^{c-}$	$A_{\{(n-1-k)(r+w+v)+t\}bdfc}B_{radfc}D_{wabfc}F_{vabdc}$ $C_{\{(n-k)(r+w+v)+t\}abdf}$
	$A_{tbdfc}B_{radfc}D_{wabfc}F_{\{(n-1-k)(t+r+w)+v\}abdc}$ $C_{\{(n-k)(t+r+w)+v\}abdf}$
$B^{b+} - D^{d+} - [A_{tbdfc}F_{vabdc}]^{(t+v)abdfc+} - C^{c-}$	$A_{tbdfc}B_{\{(n-1-k)(t+w+v)+r\}adfc}D_{wabfc}F_{vabdc}$ $C_{\{(n-k)(t+w+v)+r\}abdf}$
	$A_{tbdfc}B_{radfc}D_{\{(n-1-k)(t+r+v)+w\}abfc}F_{vabdc}$ $C_{\{(n-k)(t+r+v)+w\}abdf}$

$B^{b+} - F^{f+} - [A_{tbdfc}D_{wabfc}]^{(t+w)abdfc+} - C^{c-}$	$A_{tbdfc}B_{\{(n-1-k)(t+w+v)+r\}adfc}D_{wabfc}F_{vabdc}C_{\{(n-k)(t+w+v)+r\}abdf}$
	$A_{tbdfc}B_{radfc}D_{wabfc}F_{\{(n-1-k)(t+r+w)+v\}abdc}C_{\{(n-k)(t+r+w)+v\}abdf}$
$D^{d+} - F^{f+} - [A_{tbdfc}B_{radfc}]^{(t+r)abdfc+} - C^{c-}$	$A_{tbdfc}B_{radfc}D_{\{(n-1-k)(t+r+v)+w\}abfc}F_{vabdc}C_{\{(n-k)(t+r+v)+w\}abdf}$
	$A_{tbdfc}B_{radfc}D_{wabfc}F_{\{(n-1-k)(t+r+w)+v\}abdc}C_{\{(n-k)(t+r+w)+v\}abdf}$

Table 2

ГС formulas of the subsystems of the system(Li^{+}-Sr^{2+}- La^{3+} - Fe^{4+} -O^{2-})

Subsystem	XC branch formula in ГС
$ПХС_{n(bas)=1} \equiv Li_6Sr_6La_4Fe^{4+}{}_6O_{27}$	
Li^{+} - Sr^{2+} - $[La_2Fe^{4+}{}_3]^{18+}$ - O^{2-}	$Li_{48n-42}Sr_6La_4Fe^{4+}{}_6O_{24n+3}$
	$Li_6Sr_{21n-15}La_4Fe^{4+}{}_6O_{21n+6}$
Li^{+} - La^{3+} - $[Sr_3Fe^{4+}{}_3]^{18+}$ - O^{2-}	$Li_{48n-42}Sr_6La_4Fe^{4+}{}_6O_{24n+3}$
	$Li_6Sr_6La_{14n-10}Fe^{4+}{}_6O_{21n+6}$
Li^{+} - Fe^{4+} - $[Sr_3La_2]^{12+}$ - O^{2-}	$Li_{48n-42}Sr_6La_4Fe^{4+}{}_6O_{24n+3}$
	$Li_{12}Sr_{12}La_8Fe^{4+}{}_{15n-3}O_{30n+24}$
Sr^{2+} - La^{3+} - $[Li_3Fe^{4+}{}_3]^{15+}$ - O^{2-}	$Li_6Sr_{21n-15}La_4Fe^{4+}{}_6O_{21n+6}$
	$Li_6Sr_6La_{14n-10}Fe^{4+}{}_6O_{21n+6}$
Sr^{2+} - Fe^{4+} - $[Li_3La_2]^{9+}$ - O^{2-}	$Li_6Sr_{21n-15}La_4Fe^{4+}{}_6O_{21n+6}$
	$Li_{12}Sr_{12}La_8Fe^{4+}{}_{15n-3}O_{30n+24}$
La^{3+} - Fe^{4+} - $[Li_3Sr_3]^{9+}$ - O^{2-}	$Li_6Sr_6La_{14n-10}Fe^{4+}{}_6O_{21n+6}$
	$Li_{12}Sr_{12}La_8Fe^{4+}{}_{15n-3}O_{30n+24}$

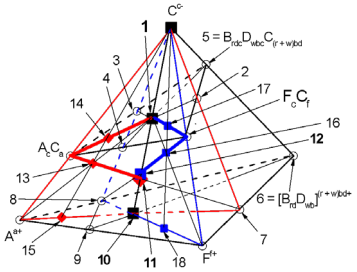

Figure 1. *Subsystem (A^{a+}-F^{f}-$[B_{rd}D_{wb}]^{(r+w)bd+}$-$C^{c-}$) in the system ($A^{a+}$-$B^{b+}$-$D^{d+}$-$F^{f+}$-$C^{c-}$)*

$1 - ПХС_{n(bas)} = A_{tbdfc}B_{radfc}D_{wabfc}F_{vabdc}C_{(t+r+w+v)abdf}$, $2 - B_{rdfc}D_{wbfc}F_{vbdc}C_{(r+w+v)bdf}$,
$3 - A_{tbdc}B_{radc}D_{wabc}C_{(t+r+w)abd}$, $4 - A_{tfc}F_{vac}C_{(t+v)af}$, $5 - B_{rdc}D_{wbc}C_{(r+w)b}$,
$6 - [B_{rd}D_{wb}]^{(r+w)bd+}$, $7 - ([B_{rdf}D_{wbf}F_{vbd}]^{(r+w+v)bdf+}$, $8 - [A_{tbd}B_{rad}D_{wab}]^{(t+r+w)abd+}$,
$9 - [A_{tf}F_{va}]^{(t+v)af+}$, $10 - (ЧЗК_{n(bas)} = [A_{tbdf}B_{radf}D_{wabf}F_{vabd}]^{(t+r+w+v)abdf+})$,
$11 - (ПЗК_{n(bas)} = [A_{tbdfc}B_{radfc}D_{wabf}F_{vabdc}C_{tabdf}]^{(r+w+v)abdfc+})$ – ГС-1,
$12 - (ПЗК_{n(bas)} = [A_{tbdfc}B_{radfc}D_{wabf}F_{vabdc}C_{rabdf}]^{(t+w+v)abdfc+})$ – ГС-2,
$13 - ([A_{(t+r+w+v)bdfc}B_{radfc}D_{wabfc}F_{vabdc}C_{(t+r+w+v)abdf}]^{(r+w+v)abdfc+} = ПЗК_{n(bas)+1})$ – ГС-1,
$14 - (A_{(t+r+w+v)bdfc}B_{radfc}D_{wabfc}F_{vabdc}C_{\{t+2(r+w+v)\}abdf} = ПХС_{n(bas)+1})$ – ГС-1,
$15 - ([A_{(t+r+w+v)bdfc}B_{radfc}D_{wabfc}F_{vabdc}]^{(r+w+v)abdfc+} = ЧЗК_{n(bas)+1})$ – ГС-1,
$16 - ([A_{tbdfc}B_{radfc}D_{wabfc}F_{(t+r+w+v)abdc}C_{(t+r+w+v)abdf}]^{(t+r+w)abdfc+} = ПЗК_{n(bas)+1})$ – ГС-2,
$17 - (A_{tbdfc}B_{radfc}D_{wabfc}F_{(t+r+w+v)abdc}C_{\{v+2(t+r+w)\}abdf} = ПХС_{n(bas)+1})$ – ГС-2,
$18 - ([A_{tbdfc}B_{radfc}D_{wabfc}F_{(t+r+w+v)abdc}]^{(t+r+w)abdfc+} = ЧЗК_{n(bas)+1})$ – ГС-2.

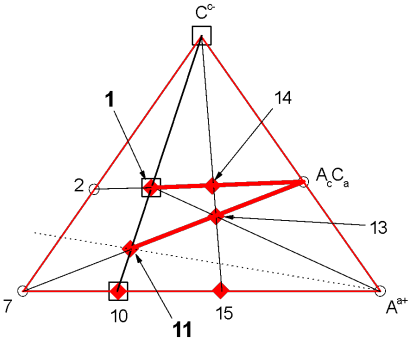

Figure 2. *ГС-1 in sub-subsystem (p. 7 – A^{a+} – C^{c-}).*

$1 - ПХС_{n(bas)} = A_{tbdfc}B_{radfc}D_{wabfc}F_{vabdc}C_{(t+r+w+v)abdf}$, $2 - B_{rdfc}D_{wbfc}F_{vbdc}C_{(r+w+v)bdf}$,
$7 - ([B_{rdf}D_{wbf}F_{vbd}]^{(r+w+v)bdf+}$, $10 - (ЧЗК_{n(bas)} = [A_{tbdf}B_{radf}D_{wabf}F_{vabd}]^{(t+r+w+v)abdf+})$,
$11 - (ПЗК_{n(bas)} = [A_{tbdfc}B_{radfc}D_{wabf}F_{vabdc}C_{tabdf}]^{(r+w+v)abdfc+})$,
$13 - ([A_{(t+r+w+v)bdfc}B_{radfc}D_{wabfc}F_{vabdc}C_{(t+r+w+v)abdf}]^{(r+w+v)abdfc+} = ПЗК_{n(bas)+1})$,
$14 - (A_{(t+r+w+v)bdfc}B_{radfc}D_{wabfc}F_{vabdc}C_{\{t+2(r+w+v)\}abdf} = ПХС_{n(bas)+1})$,
$15 - ([A_{(t+r+w+v)bdfc}B_{radfc}D_{wabfc}F_{vabdc}]^{(r+w+v)abdfc+} = ЧЗК_{n(bas)+1})$.

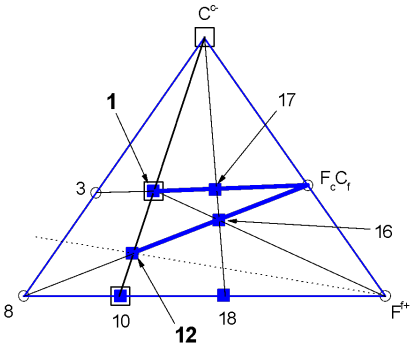

Figure 3. *ГС-2 in sub-subsystem (p. 8 – A^{a+} – C^{c-}).*

1 – $ПХС_{n(bas)} = A_{tbdfc}B_{radfc}D_{wabfc}F_{vabdc}C_{(t+r+w+v)abdf}$, 2 – $B_{rdfc}D_{wbfc}F_{vbdc}C_{(r+w+v)bdf}$,
3 – $A_{tbdc}B_{radc}D_{wabc}C_{(t+r+w)abd}$, 8 - $[A_{tbd}B_{rad}D_{wab}]^{(t+r+w)abd+}$,
10 – $(ЧЗК_{n(bas)} = [A_{tbdf}B_{radf}D_{wabf}F_{vabd}]^{(t+r+w+v)abdf+})$,
12 – $(ПЗК_{n(bas)} = [A_{tbdfc}B_{radfc}D_{wabf}F_{vabdc}C_{rabdf}]^{(t+w+v)abdfc+})$,
16 – $([A_{tbdfc}B_{radfc}D_{wabfc}F_{(t+r+w+v)abdc}C_{(t+r+w+v)abdf}]^{(t+r+w)abdfc+} = ПЗК_{n(bas)+1})$,
17 – $(A_{tbdfc}B_{radfc}D_{wabfc}F_{(t+r+w+v)abdc}C_{\{v+2(t+r+w)\}abdf} = ПХС_{n(bas)+1})$,
18 – $([A_{tbdfc}B_{radfc}D_{wabfc}F_{(t+r+w+v)abdc}]^{(t+r+w)abdfc+} = ЧЗК_{n(bas)+1})$.

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PLACEBO EFFECTS BASED ON THE STUDY ABOUT THE DOMINANT BY ACADEMICIAN A.A. UKHTOMSKY

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Annotation. *From the physiological point of view, the placebo effect poses a certain problem for modern medicine, since often even competently developed treatments due to placebo cannot be explained. The present study is the first to analyse the placebo effect from the point of view of the physiological teachings about the dominant academic A.A. Ukhtomsky. The authors have shown that placebo often represents the dominant with all its properties, therefore, using the doctrine of academician A.A. Ukhtomsky about the dominant, from the point of view of physiology it is much more effective to predict and explain various placebo effects. We have proved for the first time that the physiological mechanism of placebo effect is carried out through the formation of treatment dominance. Besides, it is shown for the first time that the physiological mechanism of placebo effect has the property of conditional reflex of the first order and corresponds to all parameters of the doctrine of academician I.P. Pavlov about conditional reflexes and organically structurally fits into the treatment dominant. The results of the conducted research allowed us, firstly, to show for the first time that placebo drugs act through the functional system of anticipatory reflection of reality of academician P.K. Anokhin. Secondly, it allows the treatment dominant to act in advance, improving the efficiency of the treatment dominant. Besides, the performed research allowed to generalise various manifestations of placebo action in human diseases and to show that the formation of the dominant at placebo is quite within the classical mechanisms of normal and pathological physiology at various pathologies.*

Keywords: *placebo, the effect of drugs, A.A. Ukhtomsky's dominant, physiological mechanisms of placebo application.*

Relevance. Communication between a patient and a doctor should be structured in such a way as to necessarily take into account the patient's opinion and wishes, which allows building a harmonious relationship between them [8, 13, 15, 31]. Focusing on empathic care to enhance physician empathy will make communication more effective and efficient [12, 18, 28, 33, 56, 68]. We note today with warmth and gratitude that throughout the history of the development of civilisation, the great Greek, Byzantine and Arab physicians of the past - Hippocrates, Erasistratus, Herophilus, Praxagoras of Cos, Oribasius of Pergamum, Euriphon of Cnidus, Aecius of Amida, Alexander of Trallus, Paul of Aegina; Abu Bakr Muhammad ibn Zakariyya al-Razi, Ibn al-Haysam, Ammar ibn Ali al-Mausili, Abu-l-Qasim Khalaf ibn Abbas al-Zahrawi, Ibn Sina (Avicenna) and others made a great contribution to the development of various sections of medical science [32]. Judging by today's standards of their achievements, it is obvious that they used very strange and bizarre methods of treating the sick and injured, because they had very little knowledge of human anatomy and physiology [25, 50].

Over time, anatomical and physiological descriptions of the human body began to appear, and the need for scientific explanation of many treatment methods became an urgent task not only for physicians, but also for the entire scientific medical community. An important historical period during which scientific scepticism about the efficacy of certain medical remedies emerged is in the second half of the 18th century and includes such specific treatments as mesmerism, Perkinism and homoeopathy.

For example, Franz Anton Mesmer (1734-1815), a German Enlightenment physician and astrologer, hypothesised that some people possessed "magical magnetism" and were capable of emitting telepathic energy.

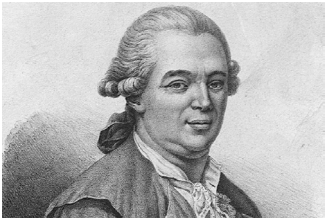

Figure 1. *Franz Anton Mesmer.*

F.A. Mesmer believed that there are gravitational waves that emanate from the planets in the form of invisible and elusive gas and fill the Universe. These waves permeate the atmosphere and affect everything on earth. According to his theory,

the power of magnetism is peculiar to some people, who can transmit it not only over distances, but also revive and even kill living beings.

As for homoeopathy, the issue of its use in clinical practice, including from the legal point of view, for a long time causes various disputes and doubts [10, 11, 34, 44]. It should be noted that homoeopathy has become quite widespread in Russia, as evidenced by the opening by the highest permission of Emperor Nicholas I by pharmacist Fyodor Yakovlevich Bachman (Bachmann Theodor Friedrich Ernst) of the first homoeopathic pharmacy on August 23, 1834 in St. Petersburg.The new pharmacy was consecrated by Father John of Kronstadt, who during the opening said: "Your method is the most reasonable and correct. Divine wisdom itself has not found a more correct means to cure mankind, which is angry with sin and countless diseases, than the cure of like with like".

In 1866, the Dr Willmar Schwabe Company for the production of phytopharmaceuticals was founded in Leipzig, and in 1867 his monograph "Manual for the Manufacture of Homoeopathic Medicines" was published.

Figure 2. *Willmar Schwabe***.**

Homoeopathy as a medical system of treatment was created by Christian Friedrich Samuel Hahnemann (1755 – 1843), a German professor at the University of Leipzig, in 1796.

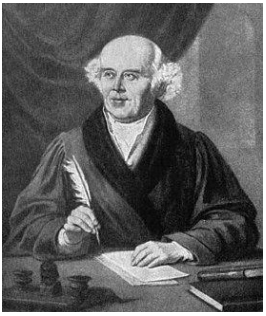

Figure 3. *Christian Friedrich Samuel Hahnemann.*

It should be noted that during the development of homoeopathy up to the present day, the heated debates of supporters and opponents of this method of treatment are not silent.

Thus, in our country in 1995 was issued an order of the Ministry of Health of the Russian Federation № 335 of 29.11.95 "On the use of homoeopathy in practical health care", allowing the use of homoeopathic methods of treatment in practical health care. Thus, we can conclude that federal legislative acts do not hinder the activity of a doctor using the homoeopathic method of treatment.

Concerning placebo, it should be noted that for the first time in 1955 the placebo effect was described in the article "Powerful Placebo" by an American professor at Harvard Medical School, physician Henry Knowles Beecher (1904 - 1976).

Figure 4. *Henry Beecher.*

As an anaesthetist during World War II, Henry Beecher treated American infantrymen suffering from German bombing raids.

When the morphine supply ran out, the patient was given an injection of saline, which relieved the pain. He also found that about one-third of patients recovered with the use of dummy pills that did not contain any active drugs. Note that this article was not the first to introduce the idea of the "placebo effect".

The term placebo was first used by T.C. Graves in 1920 on the pages of The Lancet. On 16 June 1966, in the New England Journal of Medicine, he published an article entitled "Ethics and Clinical Research" in which he drew attention to 22 examples of unethical clinical trials that endangered the lives of patients, thus laying the foundation for human research. Beecher's 1955 article "*The Powerful Placebo*" was not the first to introduce the idea of the placebo effect. In his 1955 article, Beecher speaks of placebo effects only in special cases, when he contrasts them with the effects of drugs.

Touching briefly on history, we note that since 1940, the medical literature indicates that mention of placebos has been noted in more than 100,000 articles. Ignorance of the placebo effect is now no longer acceptable and that research into

the use of placebos in clinical practice should not only be continued but improved [1, 9, 27, 35, 42, 43, 46, 47, 53, 72].

A number of authors believe that the placebo effect goes far beyond the therapeutic context traditionally prescribed to it, and that its study contributes to the understanding of the nature of mental functions and is useful for specialists from different fields, including psychologists and educators [16].

The use of the word "placebo", which means "I will be glad" in Latin in clinical research appeared gradually over time to refer to a control group that receives a sham treatment, as was done with sham mesmerism, sham wands in Perkinism and sham homoeopathy. Therefore, the word *"pretense"* was gradually replaced by the word *"placebo"*. Another important point that was crucial to the modern use of placebos in clinical trials was the growing realisation that even doctors and clinical researchers are subject to imagination and bias. This led to the use of the double-blind method in which neither the researcher nor the patient knew the nature of the therapy being tested [50].

Today, the placebo effect, or response, is an excellent model for understanding how the brain works. Placebos have been used not only to confirm the effectiveness of therapies, but also traditionally as an example of a powerful mind-body interaction. For example, in Mesmerism and Perkinism, the main finding was that imagination played an important role in the therapeutic outcome, thus emphasising the important role of the mind in modulating a range of physiological functions. Following this psychological perspective of the placebo phenomenon, the placebo concept has permeated the psychological literature over the years [16, 50].

To date, evidence of placebo effects and response to placebo has been obtained, which can be viewed from several internal and external perspectives. Internal factors can influence the patient and the research physician. Patient expectations and previous experience are considered the two main internal determinants of placebo response. Other patient determinants include neural systems under treatment, situational factors and reactions to the environment, and personality traits.

Placebo responses include personality factors such as empathy, perceived experience, clinical relationship with the patient and the physician's belief in the efficacy of the treatment, as well as the patient's belief in the treating physician. The French philosopher and writer Michel de Montaigne (1533 - 1592) observed in 1572, "There are some people who are affected by the mere sight of a physician."

Figure 5. *Michel de Montaigne.*

External determinants include the type of study design, the influence of advertising or the cultural environment. These determinants do not act in isolation, but rather form a complex interaction that ultimately influences the promotion or containment of placebo effects in clinical and research settings [49].

Current learning theories suggest that conditioning depends heavily on the processing of prediction errors signalling a discrepancy between expected and observed outcomes. This line of research provides a framework through which classical theories of placebo effects, expectancies and conditioning can be reconciled. Brain regions associated with the processing of prediction errors (anterior cingulate cortex, orbitofrontal cortex, or contiguous nucleus) overlap with those involved in placebo effects. Consideration is given to the possibility that the magnitude of objective neurochemical responses to placebo administration will depend on individual comparisons of expected efficacy. Expectancy-performance comparisons emerge as a cognitive mechanism that, in addition to associations with reward, appears to contribute to the robustness of the organism's responses to placebo [63]. In particular, patients with rheumatoid osteoarthritis have been found to respond better to treatments that target both peripheral and central pain disorders [17, 24, 54, 65, 66, 70, 73].

When choosing treatment, it should not be forgotten that many medications are expensive [58, 62, 67].

Clinical trials in cardiology have provided clinicians with evidence that the placebo effect is a clinical benefit induced by interaction with the caregiver and the health care system in the absence of a biologically active intervention, and it has been used successfully for millennia. The placebo response is the result of the interaction of psychosocial mechanisms, human attitudes and biases functioning at specific neuroanatomical locations with known genes and neurotransmitters. This occurs with or without the administration of an inactive substance. The placebo

effect results from activation of opioid, cannabinoid and dopaminergic pathways involved in reward, anticipation, conditioning and pain modulation. Eleven specific brain anatomical features identified by positron emission tomography and magnetic resonance imaging were implicated. Polymorphisms in the structural genes for catecholamine-O-methyltransferase and fatty acid amide oxidase significantly affect the response to placebo. The placebo effect may be important for symptom suppression in angina pectoris, paroxysmal atrial fibrillation, and congestive heart failure. In the absence of deliberate deception, there are no ethical concerns and, given its efficacy, it is time to consider how best to use placebos in clinical practice [64].

Physician analyses of the mechanisms of placebo use have shown that patients have expectations as a result of treatment and this has a significant impact on what we actually experience. Expectation has been established as a key process underlying the placebo effect. Studies in both laboratory and clinical settings consistently show that when people take a pharmacologically inert substance (placebo) but believe it to be the active substance, they experience both the subjective sensations and physiological effects expected from that active substance. Expectation also occupies an important place in the response to the "real" treatment. These findings suggest that clinicians can not only improve the effectiveness of treatments by promoting positive expectations in patients [52], but also their body's resistance to the effects of medication [48, 59, 60, 66, 69, 71].

In placebo research in psychiatry, a small effect has been obtained in studies of psychiatric disorders, both overall and for those who received sham psychotherapy. This effect was observed in patients with anxiety or depression, but not in the treatment of schizophrenia [14, 22, 45, 61].

The analysis of literature sources has shown that at present the mechanisms of placebo action have not yet been sufficiently investigated, although a large practical clinical material has been accumulated, proving that the placebo effect really exists [19, 21, 51, 55, 57].

Since the placebo mechanisms from the point of view of modern science are multifaceted and have not yet been studied sufficiently, we decided [2, 3, 4, 5, 6, 38, 39, 40, 41] to study the placebo effect from the point of view of the doctrine of dominance of academician A.A. Ukhtomsky [36, 37], which can generalise all the effects of placebo on the human organism into one concept.

The great Russian physiologist Alexei A. Ukhtomsky (1875-1942) entered the history of physiology and psychology as the author of the doctrine of dominance, a fundamental aspect of human behaviour.

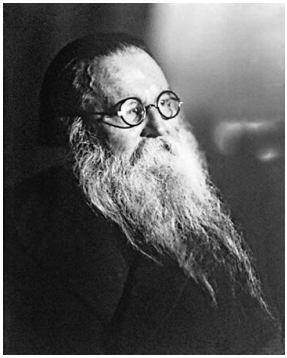

Figure 6. *Aleksey Alekseevich Ukhtomsky.*

Let us list the main properties of the dominant centre established by A.A. Ukhtomsky: increased excitability, inertia in time, ability to summarise external stimuli, the external expression of dominance is a stationary supported work or working posture of the organism.

This article was written on the basis of generalisation of the literature on placebo effects and the works of physiologist academician A.A. Ukhtomsky on dominance, as well as the study of the so-called "food" dominance in male students. dominant is a huge mobile association of nerve cells, the final activity of which is aimed at achieving some physiological modality (some goal, for example, an unconditional food reflex) [5, 6]. When the goal is achieved, the dominant disappears and makes room for a new dominant, as a result of which the organism releases a narrowly focused concentrated nervous energy to achieve various other goals. The main property of the dominant is to take over the motor pathways to the muscles, which can be easily explained by the need to move in order to realise the dominant. In many cases it is by motor activity that we can determine whether there is a dominant and what kind of dominant or not.

In 12 students of youthful age we have performed a food dominant, which consists in the study of Ph of saliva before and after eating a slice of lemon. It is well known that the reaction of saliva is slightly alkaline, and its Ph is the most important indicator of oral homeostasis. Due to the fact that the Ph of saliva varies from 6.2 to 7.5 during the day, we conducted a study of food dominance in the morning hours between 9 and 11 hours two hours after a meal. We took into account that the Ph of saliva is lower in the morning hours than the evening hours.

The study complied with the principles of voluntariness, individual rights and freedoms guaranteed by Articles 21 and 22 of the Constitution of the Russian Federation, as well as the Order of the Ministry of Health and Social Development of Russia №774n of 31 August 2010. "On the Ethics Council". The study

was conducted in compliance with the ethical standards set out in the Declaration of Helsinki and European Community Directives (8/609EC) and informed verbal consent of the students.

It was found that the Ph of saliva in the 19.4±0.7 years old young men we studied ranged from 6.4 to 7.7 during the period from 9 to 11 hours before the consumption of a slice of lemon. The Ph values of saliva in 2 students were 6.5; in 3 - 6.7; in 3 - 6.8; in 1 - 7.0; in 2 - 7.3; in 1 - 7.4 (Fig. 7).

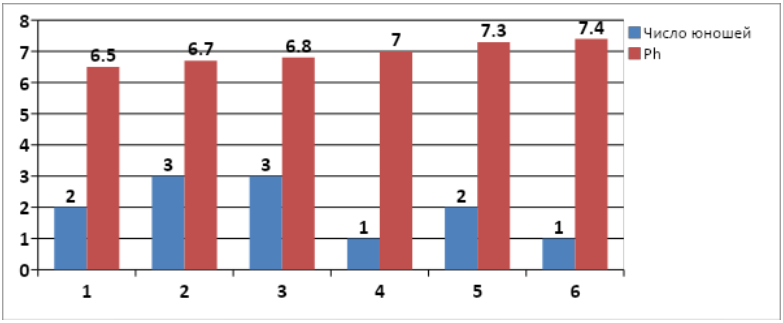

Figure 7. *Salivary Ph value in adolescent students before lemon consumption.*

In 5 minutes after the consumption of a lemon slice, the Ph of saliva in all young men changed towards a decrease. Thus, in 4 young men Ph of saliva decreased to 5.8; in 3 - to 5.6; 3 - to 5.5; in 1 - to 5.4 and in 1 - to 5.3 (Fig. 8).

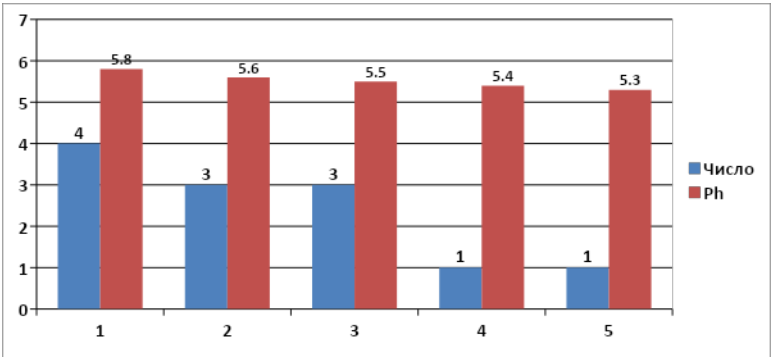

Figure 8. *Saliva Ph value in adolescent students after lemon consumption.*

It can be stated that even short-term consumption of lemon containing acid causes a sharp decrease in the Ph of saliva. We noticed that in 20 minutes from the moment of lemon consumption Ph of saliva returned to the initial values.

Thus, the "food" dominant, caused by the consumption of a small portion of lemon, contributed to the activation of the autonomic nervous system in the form of increased production of saliva and a decrease in its Ph, which is important in terms of, for example, the occurrence of dental caries. It is an active state of excitation of a newly formed large group of neurons, which is aimed at achieving a certain goal of the organism. The main property of dominant is priority control and possession of efferent pathways of the nervous system, especially the muscular system, due to the possession of muscles dominant can achieve the goal and be satisfied. Once the goal is achieved, the dominant disappears and gives control of efferent pathways (including muscles) to another dominant, so that the latter can be satisfied. If it is a food dominant, then after receiving food it fades away, but after some time hunger excites the receptors, the food dominant intensifies and selects its efferent pathways for satisfaction (especially important are the nerve pathways controlling muscles).

We believe that the placebo effect occurs in those people in whom, when the placebo is applied, there arises in the brain an action goal (I will get better, the placebo will make me feel better). These thoughts must be stable, a person must truly believe in it, these thoughts must last for a certain period of time. Then the treatment dominant will be formed, which will be strengthened daily by taking the placebo medicine. The formation of the placebo treatment dominant will have the same properties as other dominants in the body. In case of correct prescription of medicines, the patient in any case will form a cure dominant, i.e. the organism will be ordered by the cure dominant to switch on adaptive physiological mechanisms of repair of the organism cells (especially during sleep), to synchronise the rhythms of work of all organs and systems of the organism, as it was in a healthy organism before. Here we should pay attention to the fact that the human organism "repairs" its cells every day, and information about how a healthy cell should work is taken from DNA. This is no surprise to us. So why is it that when the body from an external stimulus, like a placebo, begins to carry out its well-known programme of repairing its body, the placebo is strongly criticised by a number of doctors. We believe that not only placebo drugs can trigger the body's healing response, but also other therapies such as acupuncture. Many of the methods of shaping the dominant response to recovery can switch on or reinforce the body's natural repair dominant response. This can be some kind of stress or intense experience such as travelling, hunting, fishing, being frightened, great joy, intense sport, etc. The mechanism of this healing is the same, the external influence must be much greater in strength of excitation of receptors (back afferentation) than the disease dominant in the patient.

Academician I.P. Pavlov wrote about it, pointing out that there is a struggle of dominants for efferent pathways in the organism, and that the struggle of dominants is the most difficult process in the organism and the most energy-consuming [26].

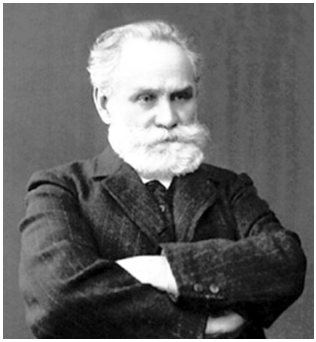

Figure 9. *Ivan Petrovich Pavlov.*

The method of psycho-concentration, which has been well developed over millennia by the Indian yogis, can also be used to destroy the dominance of illness and activate the dominance of recovery. Note that the yogic method requires long training and considerable concentration of the human will.

We believe that the placebo effect in the human body arises and is formed to a greater extent on the basis of the fundamental laws of the nervous system. Academician I.P. Pavlov in experiments on animals proved that the basic principle of the nervous system is a conditioned reflex [26]. When a light bulb is switched on (a conditional signal, an informational substitute for food) and five minutes later food is given (unconditional reinforcement, irritating receptors in the mouth and stomach), it is repeated dozens of times, and only the lighting of the light bulb leads to the production of saliva and gastric secretion, resulting in a conditioned reflex of the first order. It is clear that it is not the light bulb that the dog's saliva is produced for, but a virtual image of food is formed in the dog's brain, which switches on the light bulb.

Let us give a brief historical background. Working in the laboratory of Pavlov I.P., Anokhin P.K. believed that the conditioned reflex has the property of anticipatory reflection of reality [7]. However, Pavlov I.P. [26] stood firmly on the concept that the conditioned reflex is only a simple response of the nervous system (even the reflexive simple theory of the brain's work was revolutionary at that time).

Figure 10. *Pyotr Kuzmich Anokhin.*

For example, for example, an engineer plans to build a bridge, he has the bridge plan and all parameters in his head, the bridge is not there yet, but the virtual model (mental model) is already there, the bridge is being built, and all parameters of the bridge correspond to the mental model of anticipatory reflection. Academician Anokhin P.K. was awarded the Lenin Prize for his works on the theory of functional system.

In connection with the above, the mechanism of placebo action can be presented as the development of a conditioned reflex (more complicated as in Pavlov's dog, as the human brain is a more perfect mechanism of nature). When a placebo drug is given (it is like Pavlov's conditioned signal when a light bulb was lit) and after that, according to the reflex theory, unconditional reinforcement should follow, it is replaced by psychoconcentration of thoughts and belief in recovery. Such repetition of events can lead to the development of a conditioned reflex according to Pavlov, the conditioned stimulus placebo, unconditional reinforcement is a thought and belief in recovery. If the thoughts of recovery after placebo are expressed and have the power of reverse afferentation to suppress other dominants, then the thought of recovery becomes the strongest in the brain, it begins to own all the resources of the organism. Then the placebo cure really leads to recovery or significant relief of the disease.

The study of the placebo effect required the application of a blind method, when the patient does not know whether he is receiving a real drug or a placebo. However, this was not enough, because the doctor, knowing what the patient receives in some unconscious way (look, movements, timbre of speech, behaviour, etc.) showed that the patient receives a placebo or a drug. Therefore, the double-blind method was used to analyse the placebo effect, when neither the patient nor the doctor knows whether the patient is receiving a placebo or a drug. This double-blind method is used to study new drugs, because in some cases the placebo effect exceeds the effect of the tested drug [20, 23, 29, 30].

The proven therapeutic effect of placebo drug administration raises the assumption that to the real mechanism of action of the drug may be added (or subtracted) and psychological effect in the form of placebo stimulation of the therapeutic result. We believe that the use of drugs for treatment causes the formation of therapeutic dominance (as in placebo therapy), based on the physiological mechanisms of development of conditioned reflex according to the teachings of Academician I.P. Pavlov.

Let's consider this process of formation of a conditioned reflex in drug therapy and formation of treatment dominance. The use of a drug models the process of giving a conditioned signal (according to Pavlov it is the switching on of a light bulb). Then the drug enters the body through the mouth or through injection (and other methods) and causes the body to change the activity of a number of functional systems. Receptors of the body register these changes and due to afferent impulsation through nerves transmit information to the brain (both in the subcortical centres of subconsciousness and in the neurons of the cortex). A permanent focus of excitation of a large group of neurons in the cerebral cortex is formed, which is informationally connected with the drug delivery. This effect plays the role of unconditional reinforcement (Pavlov's analogue would be the reinforcement of a conditioned reflex in a dog with food). The focus of excitation in the brain during drug intake is constantly intensified as a result of impulses from internal receptors. The mentally ill person (unconsciously or with the help of logic) indoctrinates himself and begins to believe in his recovery, which leads to the formation of the recovery dominant. As a result, the dominant gains strength, takes more and more executive mechanisms into its subordination, activates in DNA the reading of reserve regulatory genes and the synthesis of regulatory proteins, which was proved in the study of stress, including cold adaptation. Drug-induced recovery begins to have the same properties as normal recovery.

It should be noted that the doctor can also form a will to treat a given patient. Then the patient at the level of subconsciousness reads information from the doctor (tone of voice, look, etc.) and as if fulfils and realises the subconscious will of the doctor to improve his condition by strengthening the dominant of recovery. This mechanism is confirmed by the fact that they began to use double-blind method of efficacy analysis for evaluation of medicines, because it was noticed that if the doctor knows where the medicine is used and where the placebo is used, the results of placebo use are significantly improved.

We believe that the patient's recovery (if formed) and the doctor's treatment of the patient (if formed) begin to interact, reinforcing each other. Hence we can conclude that the doctor's psyche plays a significant role in the patient's recovery due to the subconscious interaction of the dominant of the patient's recovery and the dominant of the doctor's treatment. It should be remembered that such interac-

tion of dominants at a heavy load in the doctor's work often leads to the effect of "burnout" of the doctor. It is connected with the fact that academician I.P. Pavlov proved in his experiments that formation of dominants and their change is the most energy-consuming process in the central nervous system. Proceeding from this it turns out that a doctor forms a dominant treatment for each patient, which should be of such power to strengthen the dominant of recovery in the patient. For example, during a year of work a doctor will have a large number of changes of dominants (different patients), which considerably exhausts the tone of his central nervous system. The doctor's desire to treat and desire to cure increase when he uses new medicines, new methods of treatment, undergoes advanced training, i.e. any reason for stimulation of mental processes in the brain, when he wants to prove to everyone that he can solve the most complicated problems. The greater is the doctor's desire to cure the patient, the greater can be the placebo effect due to the interaction of treatment dominants in the doctor and the patient.

Conclusion. Academician A.A. Ukhtomsky created the doctrine of dominant as a newly formed in the brain centre of association of neurons, the work of which is aimed at achieving any goal needed by the organism. Once the goal is achieved, the dominant is satisfied and gradually fades away. The analysis of placebo effect of a drug from the point of view of the dominant allows to order this knowledge, creates a model of prediction of placebo effects, to bring a scientific fundamental base to the theory of placebo application.

The works of academician I.P. Pavlov on conditioned reflexes fit well into the doctrine of dominance. By analysing the sources of special medical and pedagogical literature available to us, we have shown that the placebo effect has the property of a conditioned reflex of the first order.

Further development of the reflex theory of brain work in the works of academician P.K. Anokhin highlighted the anticipatory action (virtual reality) of the work of the functional system of the organism. P.K. Anokhin proved that the conditioned reflex has the property of anticipatory reflection of reality (at the conditioned reflex at switching on a light bulb gastric juice is secreted in 5 minutes, but not on the light bulb, but on the food that was given 5 minutes after switching on the light bulb). Analysis of placebo effect from the point of view of P.K. Anokhin's works has shown that the use of placebo drugs, in a number of cases, forms a functional system of placebo action, which fits into a more extensive dominant treatment of the patient, preserving all the properties of the functional system of academician P.K. Anokhin.

Conclusions.

1. The physiological mechanism of placebo effect is carried out through the formation of treatment dominance, which was first presented by academician A.A. Ukhtomsky. We have shown for the first time that the mechanism of the placebo

effect has the property of a conditioned reflex of the first order and corresponds to all parameters of the doctrine of academician I.P. Pavlov about conditioned reflexes and organically structurally fits into the treatment dominance.

2. The results of our work have shown that the use of placebo drugs acts through the functional system of anticipatory reflection of reality of academician P.K. Anokhin and allow the treatment dominant to act in advance, improving the efficiency of the treatment dominant.

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PREDICTOR OF SEASONAL EXACERBATION OF ULCER DISEASE

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Summary. *The widespread prevalence of peptic ulcer disease (PU) explains the incessant interest of the medical community in the issues of its etiology and pathogenesis. As clinical practice shows, numerous concepts and long-term adherence to the Maastricht criteria have not led to the expected results of relapse-free cure of the disease. Unfortunately, it has not yet been possible to significantly reduce their frequency; Moreover, the widespread prescription of antibacterial therapy has exacerbated the problem of antibiotic resistance. Scientists around the world are trying to find possible options that can prevent the formation of resistance of microorganisms in the gastroduodenal zone to antimicrobial agents. However, to achieve a successful result, the medical community needs to "move away" from the Helicobacter pylori thinking strategy and begin to look for new mechanisms for the occurrence of acid-related diseases [1, 2].*

In addition, the annually increasing number of complications in patients with gastrointestinal tract (GIT) pathology and the development of antibiotic resistance associated with anti-Helicobacter therapy pose new challenges to improve approaches to eliminating symptoms and preventing relapses of peptic ulcers and chronic gastritis. These approaches, including, among other things, the use of melatonin in complex therapy, require further targeted study.

Keywords: *peptic ulcer of the stomach and duodenum (DPC), melatonin.*

Peptic ulcer is a multifactorial disease that develops when an imbalance occurs between the cytoprotective factors of the mucous membrane of the stomach and

duodenum and agents of aggression towards the latter. This leads to the development of inflammatory-destructive changes and damage to the mucous membrane of the organ [3].

The main factors of protection of the mucous membranes of the gastrointestinal tract include saliva, mucus mucin, bicarbonates, prostaglandins, proper blood flow, epithelial regeneration, immune defense, and aggression factors include Helicobacter pylori (HP) and other gastric bacteria, hyperproduction of hydrochloric acid and pepsin, bile acids, histamine, impaired gastric evacuation function, duodenogastric reflux [4].

It must be emphasized that about 90% of the gastrointestinal tract microbiota is represented by obligate physiological microflora, and only 10% is opportunistic microorganisms, including HP [5]. This raises an interesting question: how does the composition of microbes change during ulcerative disease?

It can be assumed that with the recurrence of ulcerative disease, a microbial imbalance occurs at the locus of the inflammatory-erosive-ulcerative defect, however, the leading position of HP in these nosologies is difficult to prove [6]. In this regard, gastroenterological researchers will probably have to look for new mechanisms for the development of gastrointestinal pathology, patterns and, possibly, new methods of therapeutic intervention.

An artificially extended photoperiod from day to day contributes to desynchronosis of the biological rhythms of our body. A disrupted circadian system of MT production leads to inhibition of its universal effects, in particular antioxidant, anti-stress, anti-inflammatory, which ultimately can lead to organic pathology [7]. In modern conditions, a long absence of adequate sleep in the dark leads to chronodestruction and changes in the biological rhythm of hormone secretion.

Our aim was to optimize the early diagnosis of duodenal ulcer (DU) with the determination of melatonin in the blood, depending on seasonal exacerbation during the year. To study the prospects of using the hormone melatonin as an early diagnostic and prognostic marker of PUD.

Material and methods. The main group consisted of 60 patients upon receipt of informed consent with DU. All underwent a comprehensive examination, the diagnosis was made on the basis of anamnestic, clinical data, the results of esophagogastroduodenoscopy (EGD) and histological examination of duodenal mucosal biopsy specimens. The groups of examined persons did not differ significantly by sex and age. The study of melatonin in the blood was carried out using the method of high performance liquid chromatography with tandem mass spectrometry (HPLC-MS). The control group consisted of 40 healthy people.

EGD was performed on the basis of the generally accepted technique with Olimpus, Exera (cIF160) endoscopes no later than 8.00, on an empty stomach, with targeted biopsy taking from the affected area of the mucous membrane. The

material was delivered to the histopathological laboratory for further study within 1–1.5 hours after sampling.

Blood for the study was taken at the initial contact before the start of treatment, upon receipt of the informed consent of the examined persons. As a comparison, melatonin indices obtained in a group of healthy volunteers were used.

To do this, the patient on an empty stomach, before breakfast no later than 8.00 am, took venous blood (with EDTA) with the implementation of certain recommendations: 1) before donating blood, patients refrained from eating for at least 8 hours; 2) 48 hours before the test, the intake of estrogens and androgens, alcohol was excluded, the day before the analysis - physical and emotional overstrain, at least 10-12 hours before the test, they stopped taking drugs, strong tea and coffee, and smoking 3 hours before. Before the morning blood sampling, you should have a good night's sleep.

After taking the blood, the tube was cooled in a vertical position for about 30 minutes. at room temperature. Before being sent to the laboratory, the blood was stored in a refrigerator at a temperature of +2 +8°C; transportation was carried out in a thermal container at an identical temperature.

The determination of venous concentrations of melatonin, a biomarker of enteral immunity and the circadian link, was carried out by high-performance liquid chromatography with tandem mass spectrometry (HPLC-MS) on an Agilent 1200 chromatograph (Agilent, USA) with a Sciex 6500+ Triple Quad mass detector (Sciex, USA). Substance used for calibration and controls manufactured by Sigma Ald.

The reference values of these manufacturers are recommended to consider the concentration of melatonin in the blood in the range of 0.00-200 pg / ml without distinction by sex, age and seasonal periods.

The reliability of the analysis results was assessed by the concentration of the indicator in the control sample.

The obtained data were statistically processed on a computer using the Microsoft Excel 2007 package of special application programs with the calculation of the arithmetic mean (X) and the mean error of the arithmetic mean (m). The significance of differences in the groups was judged by calculating the Student's t-test - t and the degree of probability -p. Differences were considered significant at $p < 0.05$.

Results and discussion. Among 60 patients with PUD, there were 36 (60%) women and 24 (40%) men. The average age of the patients was 35 ± 10 years, the largest number was at the age of 20-35 years.

Determination of venous concentrations of the hormone melatonin in healthy individuals in different seasons of the year made it possible to establish the interval of the norm.

In 30 (50%) of the examined patients with DU, the level of melatonin was determined in autumn and winter, the values of the control group were significantly reduced, amounting to lower (1 ± 0.57 pg / ml in 99% ($p < 0.001$), which indicated circadian desynchronosis and associated with this development of ulcerative defects in the duodenum. In all the remaining 30 (50%) patients, the hormone concentration was determined in spring and summer and was also significantly reduced relative to the control group, amounting to lower values (10 ± 0.58 mg/l) ($p < 0.001$).

The data obtained showed a decrease in melatonin secretion during exacerbation of DU in the autumn-winter period, 1 pg/ml or less, and in the spring-summer season, 10 pg/ml or less.

1. Patient M., 22 years old, went to the clinic on July 30, 2021. with complaints of pain in the epigastric region that occurs on an empty stomach, 1 hour after eating, hungry and night pains, vomiting at the height of pain, which brings relief. Objectively: the condition is satisfactory. Height 165 cm, body weight 62 kg. The tongue is slightly coated with white. Heart sounds are rhythmic, clear. Pulse 79 in 1 minute. AD 120/80 mm. rt. Art. Vesicular breathing in the lungs. The abdomen is of the correct form, soft, slightly painful in the epigastric region. General blood and urine tests, biochemical blood tests were within normal limits.

An endoscopic examination in the lower wall of the duodenal bulb revealed an ulcerative defect D-0.6x0.5x0.5 cm, deep, with an inflammatory shaft.

The patient's melatonin concentration in the blood was 6.00 pg/ml. Based on the fact that the value of melatonin in the blood was below 10 pg/ml (spring-summer season), the patient was predicted exacerbation of peptic ulcer.

The patient was prescribed appropriate treatment.

2. Patient P., 22 years old, went to the clinic on 2.10.2021. with complaints of aching pain in the epigastric region that occurs 1.5-2 hours after eating, hungry pains, and night pains.

Objectively: the condition is satisfactory. Height 167 cm, body weight 65 kg. The tongue is slightly coated with white. Heart sounds are rhythmic, clear. Pulse 72 in 1 minute. AD 120/80 mm. rt. Art. Vesicular breathing in the lungs. The abdomen is of the correct form, soft, slightly painful in the epigastric region. General blood and urine tests, biochemical blood tests were within normal limits.

An endoscopic examination revealed an ulcer D-0.5x0.4x0.4 cm in the duodenal bulb.

The patient's melatonin concentration in the blood was 0.849 pg/ml. Based on the fact that the value of melatonin in the blood was below 1 pg/ml (autumn-winter season), the patient was predicted exacerbation of peptic ulcer.

The patient was prescribed appropriate treatment.

The revealed changes indicate duodenal mucosal dysplasia, which was confirmed by histological examination of biopsy specimens, and allow these patients to be included in the group of increased risk of ulcer exacerbation.

Summing up, we came to the following conclusion that an exacerbation of peptic ulcer is predicted when the melatonin content in the blood of patients is 10 pg/ml and below. However, the concentration of the hormone in different seasons is different: in the spring-summer period, the concentration of the hormone is 10 pg / ml or less, while in the autumn-winter season it is 1 pg / ml or less. Respectively, with a peptide content of more than 10 pg/ml in spring and summer, and more than 1 pg/ml in autumn and winter, it is judged that the patient does not suffer from peptic ulcer.

Thus, amplitude changes in melatonin in the blood can be used as a laboratory marker of desynchronosis associated with the risk of developing acid-dependent diseases, in particular DU.

Conclusion. Based on the results of the study, it was revealed that the melatonin curve changes depending on the season of the year. With its value of 10 pg/ml or less in the spring-summer period and 1 pg/ml or less in the autumn-winter season, a recurrence of duodenal ulcer is predicted.

Thus, melatonin as a marker of seasonal exacerbation of DU can be proposed for use in clinical diagnostic laboratories.

No conflict of interest.

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EVALUATION OF THE EFFECTIVENESS OF A METHOD FOR MODIFYING ANTIBACTERIAL THERAPY FOR INFECTIONS CAUSED BY CARBAPENEMASE-PRODUCING STRAINS OF *KLEBSIELLA PNEUMONIAE*

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Abstract. *The widespread distribution of multi-resistant strains of K. pneumoniae in the structure of severe infections of various localizations has been shown. Carbapenemase genes were detected for carbapenemase-producing strains of K. pneumoniae (serine - KPC, OXA-48 and metallo-β-lactamases - NDM, VIM, IMP). Options for empirical and etiotropic antibacterial therapy, including combination, for patients with infections caused by carbapenemase-producing strains of K. pneumoniae were analyzed, its effect on the duration of hospitalization of patients and mortality was assessed, and ways to optimize etiotropic therapy depending on the type of carbapenemases produced by the pathogen were reflected.*

Keywords: *K. pneumoniae, antibiotic resistance, carbapenemases, antibacterial therapy.*

Relevance. Antibiotic resistance is of enormous socio-economic importance and for most developed countries of the world in the last decade it has been presented as a threat to national security. According to the results of a large-scale systematic review covering data from all continents, in 2019, mortality due to antibiotic resistance of microorganisms was 64 cases per 100,000 population. Up to 600,000 deaths per year are attributed to infections caused by antibiotic-resistant strains of *K. pneumoniae* [1]. This problem is most pressing for intensive care units, surgical and oncology departments, where mortality among patients with infections caused by multidrug-resistant strains of *K. pneumoniae* is 40-50%, and untimely administration of effective antibacterial therapy remains a recognized risk factor for its increase [2].

Over the past 10-12 years, both throughout the world and in the Republic of Belarus, there has been a negative trend towards the emergence and rapid spread of carbapenem-resistant K. pneumoniae strains in hospital healthcare institutions. According to the European Society for Surveillance of Antimicrobial Resistance (EARS-Net), in 2019, the prevalence of carbapenem-resistant *K. pneumoniae* isolates in our country was 75% and is the highest among all countries in the European Region. This resistance is primarily due to the production of carbapenemases: serine - *KPC-type, OXA-48-type and metallo-β-lactamases - NDM-type, VIM-type, IMP-type*. The prevalence of certain molecular types of carbapenemases varies significantly in different regions and changes dynamically over time. Thus, in general, in the territories of the Republic of Belarus and the Russian Federation, as well as in Kazakhstan, the presence of *blaOXA-48* is more typical for carbapenem-resistant strains of K. pneumoniae - 67.4%, while at the same time *NDM-type, KRS-type* and coproduction of two serines or serine and metallo-β-lactamases [3]. Among K. pneumoniae isolates isolated in 2021 from patients with sepsis in 9 hospitals in Minsk, resistance to carbapenems in 32.7% of cases was due to the presence of b*laOXA-48* + *blaNDM* simultaneously, in 38.1% - *blaOXA-48* + *blaNDM* + *blaKRS*, and only in 12.2% - the presence of only serine carbapenemases *blaOXA-48* [4]. Carbapenem-resistant strains of K. pneumoniae almost always have multidrug resistance phenotypes, which is reflected in the clinical ineffectiveness of the use of "reserve" antibiotics (tigecycline, colistin, amikacin, fosfomycin), and in addition, such pathogens have a pronounced ability to clonally spread in hospitals [5,6].

The results of numerous studies in the field of treatment of infections caused by multidrug-resistant strains of *K. pneumoniae* have noted the superiority of combination antibacterial therapy compared to monotherapy. However, to resolve the issue of choosing an effective treatment regimen, the strategy of rational use of "old" antibiotics and conservation of "new" antibiotics, based on knowledge of the mechanisms of resistance formation, is of great importance [2]. Thus, the use of the "new" drug ceftazidime/avibactam for the treatment of infections caused by *K. pneumoniae* with resistance to carbapenems, without detection of carbapenemases, will lead to its clinical ineffectiveness in cases where the pathogen produces metallo-β-lactamases and, as a consequence, the emergence of resistance to this antibiotic in future. Thus, the determination of various molecular types of carbapenemases for "problem" pathogens in modern conditions is of extremely important practical importance. The gold standard for rapid detection of carbapenemase genes is the molecular genetic method, in particular, PCR research, which is characterized by almost 100% sensitivity and specificity. In emergency situations, PCR can be carried out on native material, and not just on a pure culture

of the pathogen, which can significantly reduce the time for choosing effective etiotropic therapy [7].

Purpose of the study. Evaluation of the effectiveness of etiotropic antibacterial therapy (ABT) for infections caused by *K. pneumoniae* strains, depending on the type of carbapenemases they produce.

Materials and methods. The study included 51 patients with severe forms of infections of various localizations caused by multi-resistant strains of K. pneumoniae, who were treated at the Vitebsk Regional Clinical Hospital from September 2020 to November 2021. Identification of the pathogen was carried out using a test ID 32E ATB Expression systems (BioMerieux, France) on the basis of the Republican Scientific and Practical Center "Infection in Surgery". The sensitivity of K. pneumoniae to antibacterial drugs (ABD) was studied by serial microdilution in Mueller-Hinton broth with MIC determination in accordance with ISO 207761:2006. When interpreting the results, we were guided by the EUCAST assessment criteria, version 10.0 [8]. For all K. pneumoniae isolates, carbapenemase genes (*blaKPC, blaOXA-48, blaNDM, blaVIM, blaIMP*) were detected by real-time PCR. The diagnostic kits "AmpliSens MDR KPC/OXA-48-FL" and "AmpliSens MDR MBL-FL" produced by the Central Research Institute of Epidemiology of Rospotrebnadzor, Russian Federation, and the iCycler iQ 5 thermal cycler (BioRad) were used in the work. The interpretation of the results was carried out in accordance with the instructions of the manufacturer of the diagnostic kits.

Statistical processing of the results was carried out using the StatSoft STATISTICA 10 program. When describing the central tendency and degree of dispersion of these quantitative characteristics, arithmetic means and 95% confidence intervals for them, medians, 1st and 3rd quartiles were calculated (representation form - median (1st quartile; 3rd quartile) , as well as the minimum and maximum values of the data in the series. To assess the statistical significance of differences in quantitative characteristics, the Mann-Whitney U test was used; to assess the statistical significance of differences in frequencies and proportions, the Chi-square test was used, if necessary, with Yates' correction for continuity Kaplan-Meier survival analysis was used to assess the effect of mortality on the length of hospitalization, and the statistical significance of differences in survival curves in the study and control groups was determined using the log-rank test.

Results and discussion. Of the 51 patients studied, 20 (39.2%) were diagnosed with the underlying disease "sepsis", 15 (29.4%) - "pneumonia", 9 (17.6%) - "infections of the skin and soft tissues" (including infected burns), in 2 cases (3.9%) - "peritonitis", in 5 patients (2.0%) other purulent-inflammatory diseases were diagnosed. The mean age of patients was 53.4 years (95% CI: 50.4-56.6). Patients were randomly divided into two groups: study (n=22; mean age 53.5 years, 95% CI: 49.5-57.4) and control (n=29; mean age 53.1 years, 95% CI: 50.1-56.2).

All clinical isolates of *K. pneumoniae* were isolated in diagnostically significant quantities from sputum, blood, wound or drainage fluid of patients and were resistant to cefotaxime, cefepime, ciprofloxacin, levofloxacin and to all carbapenems tested (meropenem, doripenem, ertapenem). The level of colistin resistance among *K. pneumoniae* isolates obtained from material from patients in the main group was 50%, and in the control group – 41.4%.

All studied carbapenem-resistant *K. pneumoniae* strains had different carbapenemases genes, both serine and metallo-β-lactamases. In patients from the main group, the infectious agents were co-producers of bovine and *OXA-48* carbapenemases (6 isolates), co-producers of bovine, *OXA-48* and *NDM* carbapenemases (6 isolates), co-producers of bovine, OXA-48 and VIM -carbapenemases (8 isolates), co-producers of *KPC, OXA-48 and IMP-carbapenemases* (2 isolates). In the control group of patients, the isolated K. pneumoniae isolates were also co-producers of KPC and OXA-48 carbapenemases (6 isolates), co-producers of KPC, OXA-48 and NDM carbapenemases (14 isolates), co-producers of *KPC, OXA-48* carbapenemases 48 and VIM carbapenemases (9 isolates).

For empirical ABT, patients from the main and control groups were prescribed ABDs or their combinations depending on the nosological form of the infection and in accordance with regulatory documents approved in the Republic of Belarus (the combinations of ABPs used are listed in the table). However, 3 patients of the main group were prescribed a regimen of two carbapenems and colistin due to the fact that at the previous stage of treatment (these patients were transferred from other hospitals) they had already been prescribed 3rd or 4th generation cephalosporins, carbapenems and fluoroquinolones for a long time.

Table

Schemes of combined empirical and etiotropic therapy prescribed to patients of the main and control groups with severe infections caused by multi-resistant strains of K. pneumoniae

Main group (n=22)			**Control group (n=29)**	
Empirical ABT	**Etiotropic ABT**		**Empirical ABT**	**Etiotropic ABT**
	KPC+OXA-48	**KPC+OXA-48 +MBL**		
CP+FQ (n=7)	CP+CP (n=1)	CP+TGC (n=2)	CS-4+FQ (n=8)	CP+FQ (n=7)
CP (n=4)	CP+CP+COL (n=5)	CP+TGC+COL (n=11)	CS-4 (n=8)	CS-4+FQ (n=2)
FQ (n=3)		TGC+COL (n=3)	CP (n=5)	FQ (n=4)
CS-1 (n=2)			CP+FQ (n=4)	CP (n=3)
CS-4 (n=1)			CS-3 (n=1)	COL (n=2)
CS-4+FQ (n=1)			FQ (n=1)	CP+COL (n=1)
CP+COL (n=1)			CP+AG (n=1)	CP+AG (n=1)
CP+CP+COL (n=3)			CS-4+AG (n=1)	COL+AG (n=1)

			TGC (n=1)
			AG (n=2)

Note: CP – carbapenem, FQ– fluoroquinolone, CS-1 – 1st generation cephalosporin, CS-3 – 3rd generation cephalosporin, CS-4 – 4th generation cephalosporin, COL – colistin, AG – aminoglycoside, TGC – tigecycline.

Etiotropic ABT was prescribed after receiving the results of a bacteriological examination and the sensitivity profile of K. pneumoniae to AMPs. In the main group, when adjusting treatment, the type of carbapenemases isolated was additionally taken into account. In the control group, ABT was changed after it was determined to be ineffective in 24 patients (82.7%) only taking into account the antibiogram data.

The study outcomes taken into account were patient recovery or death. In the main group, 5 deaths (22.7%) were recorded, 17 patients were discharged with recovery. In the control group, 23 deaths (79.3%) were registered, 6 patients were discharged with recovery. These differences were statistically significant (Chi-square test with Yates correction): $p = 0.0002$. As can be seen from the results obtained, mortality in the control group significantly (≈3.5 times) exceeded that in the main group, and this difference is statistically highly significant, despite the small size of the studied sample.

The average duration of hospitalization of patients in the main group was 52.6±27.8 bed days (95% CI: 40.2-64.9), the median was 45 bed days (38; 59), the minimum duration of hospitalization was 20 beds -days, maximum – 132 bed days. The average duration of hospitalization of patients in the control group was 25.2±17.8 bed days (95% CI: 18.4-32.0), the median was 20 bed days (12; 34), the minimum duration of hospitalization was 5 beds -days, maximum – 69 bed days. The duration of hospitalization in the main and control groups was statistically significantly different (Mann-Whitney U test): $p = 0.000036$. As can be seen, the duration of hospitalization of patients in the main group is significantly (≈2 times) and statistically significantly longer than that in the control group, which is explained by the high and, in most cases, early mortality of patients in the control group due to the lower effectiveness of their antibacterial therapy. This conclusion is confirmed by the results of our Kaplan-Meier survival analysis (see figure).

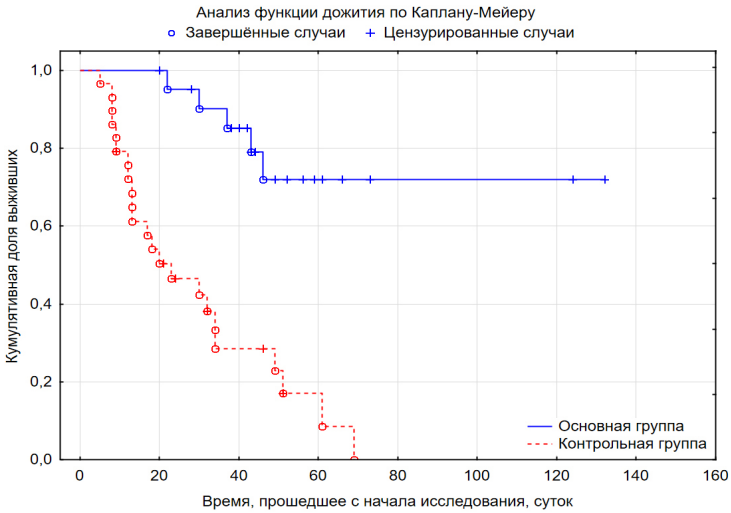

Figure. *Comparative analysis of Kaplan-Meier survival functions of the main and control groups of patients with severe infections caused by multi-resistant strains of K. pneumoniae*

The figure shows that by 70 days from the start of the study, all patients in the control group either died or were discharged from the hospital; The median survival function was 20.4 days (12.0, 43.4). At the same time, there were no deaths among patients in the main group after 50 days of observation; Most of the patients from this group were safely discharged from the hospital with recovery. Due to the relatively low mortality rate, it was not possible to estimate the median survival function of the main group; 25‰ of the survival function was 44.7 days. The difference between the survival curves of the study and control groups was statistically highly significant (log-rank test, $p = 0.00001$).

Conclusions. Replacing ABT regimens in patients with severe infections caused by multidrug-resistant strains of *K. pneumoniae*, based on determining the level of their resistance to ABP, as well as identifying and analyzing genes responsible for the production of various types of carbapenemases, is an effective method for correcting etiotropic therapy and leads to a significant reduction in mortality in this group of patients.

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DESTRUCTION OF THE MATRIX OF BIOFILMS OF *STAPHYLOCOCCUS AUREUS* BY NEUTROPHILS OF THE BLOOD OF PATIENTS WITH INFECTIOUS INFLAMMATORY DISEASES OF THE MAXILLOFACIAL REGION

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Summary. *To date, the problem of prevention and treatment of infectious inflammatory diseases of the maxillofacial region is one of the leading unresolved issues among dental diseases. This pathology has a significant spread in the Republic of Belarus and in the world as a whole. Increasingly, there is an atypical clinical course of these diseases. There is a need for further study of the etiology and pathogenesis of inflammatory diseases of the maxillofacial region.*

The purpose of this study was to study the degree of destruction of the matrix of biofilms produced by S. aureus by neutrophils of blood in patients with infectious inflammatory diseases of the maxillofacial region. 104 patients (50 (48,1%) women and 54 (51,9%) men) with infectious inflammatory diseases of the maxillofacial region were examined, who underwent inpatient treatment in the Dental Purulent Department of the Vitebsk Regional Clinical Hospital from 2018 to 2022. To assess the effect of neutrophils on biofilms of microorganisms - agents of infectious inflammatory diseases of the maxillofacial region, a method was developed to determine the degree of destruction of the matrix of S. aureus produced biofilms.

Keywords: *maxillofacial region, neutrophils, biofilm, dentistry.*

Introduction. Treatment of patients with infectious inflammatory diseases of the maxillofacial region at the present is a complex and unresolved problem for practical healthcare both in the Republic of Belarus and around the world. This

is due to the fact that the prevalence of infectious inflammatory diseases of the maxillofacial region of odontogenic origin is constantly increasing. Patients with inflammatory processes of the maxillofacial region account for up to 90% of the total number of outpatient dental cases and up to 60% of the total number of patients in dental departments of hospitals [1-3].

The problem of prevention and treatment of infectious diseases is one of the priorities in practical healthcare. In the general structure of surgical morbidity, purulent inflammatory processes have one of the leading places, they are observed in 40-60% of all surgical patients [4-6].

An important reason for the complicated course of biofilm infections is the increased resistance of biofilm producing bacteria to immune effectors. Violation of the regulation of the inflammation process inevitably leads to a significant change in its course and reduces the protective potential of the macroorganism. At the same time, the inflammatory response and the immune system are increasingly considered as a single phenomenon [3, 4].

Today there is no doubt that it is necessary to revise the concept of pathogenesis of various chronic infections by introducing into it existing data on biofilms that require the use of new methods of diagnosis and treatment.

It has been found that bacteria capable of forming microbial biofilms are etiological factors in many acute and chronic bacterial infections of humans.

The problem of the interaction of microbial biofilms and the immune system has not been sufficiently studied, there is an idea of some reactions of immune effectors with components of biofilms *in vivo*. Studies have proven that neutrophils attack and penetrate biofilms formed by *Staphylococcus aureus*. Later, the ability of neutrophils to deeply destroy biofilms was proved, and the mechanisms of neutrophil activation in this process were studied. It has been shown that neutrophils can destroy biofilms by phagocytosis, but the degree of destruction of biofilms depended on the degree of their maturity. Mature biofilms were characterized by higher resistance to neutrophils attacks. It has been experimentally proven that biofilm making microorganisms use special mechanisms to redirect neutrophil attacks against themselves. However, to date, the details of the interaction of neutrophils and biofilms produced by agents of inflammatory diseases of the maxillofacial region remain insufficiently studied, which emphasizes the relevance of the present study [4-8].

The purpose of the research – to study the degree of destruction of the matrix of biofilms produced by *S. aureus* by neutrophils of blood of patients with infectious inflammatory diseases of the maxillofacial region.

Objects and methods of research. 104 patients (50 (48.1%) women and 54 (51.9%) men) with infectious inflammatory diseases of the maxillofacial region who were hospitalized to the dental purulent department of the Vitebsk Regional Clinical Hospital from 2018 to 2022, and 40 practically healthy individuals

(20 women (50%), 20 men (50%)) were included into the studied sample. The sample was divided into 4 subgroups: 1st subgroup (26 people) were the patients with acute purulent odontogenic periostitis of the jaw, 2nd subgroup (26 people) – patients with acute purulent odontogenic osteomyelitis of the jaw, 3rd subgroup (26 people) – patients with odontogenic abscess of the maxillofacial region, 4th subgroup (26 people) – patients with maxillofacial phlegmon. The criteria for inclusion of patients in the study were: diagnosis – acute odontogenic infectious inflammatory process of the maxillofacial region and neck; age – over 18 years; availability of voluntary informed consent to participate in the study. The exclusion criteria were: age under 18; pregnancy; concomitant diseases in the acute phase; presence of alcohol and drug abuse in the anamnesis; absence of voluntary informed consent.

Before carrying out therapeutic interventions, venous blood was taken on an empty stomach with a puncture from the ulnar vein three times: at the initial admission of the patient to the hospital (sample 1), on the 3rd day of treatment (sample 2) and at the end of treatment (sample 3). The blood samples were centrifuged for 10 minutes at 3000 rpm, divided into supernatant and sedimentary fractions. The blood serum was taken with a biochemical pipette into plastic sterile test tubes.

To assess the effect of neutrophils on biofilms produced by agents of infectious inflammatory diseases of the maxillofacial region, a method was developed to determine the degree of destruction of the matrix of *S. aureus* biofilms. A sterile inert polymer membrane is placed in a sterile Petri dish with Muller-Hinton agar, 0.5 ml of the suspension of the microorganism is added at a concentration of 1.5×10^8 colony-forming units (CFU)/ml and 5 ml of 0.9% NaCl is also added. The Petri dish is incubated for 3 days at a temperature of 37°C. Next, the membrane is removed from the Petri dish, the biofilm is washed off the membrane with a sterile saline solution. A 0.5% solution of Congo Red is added to the resulting suspension in excess. The suspension is washed twice with 0.9% NaCl, followed by matrix concentration by centrifugation at 200 g for 75 minutes after each washing.

Just before the experiment, a working suspension of the matrix is prepared. To do this, a 0.9% NaCl solution is diluted with a matrix suspension to an optical density of 2.5 units of optical density (UOD) on a multichannel spectrophotometer at a wavelength of 492 nm for 150 µl of matrix suspension in the well of a 96-well plate for ELISA. Next, 0.1 M phosphate buffer solution with a pH of 7.4 is used to bring the optical density of the suspension to 2 units of optical density.

To isolate neutrophils, 5-6 ml of venous blood is taken on an empty stomach into plastic tubes with heparin taken in an amount of 10-15 units per 1 ml of blood. Next, incubate the blood at 37°C in the thermostat for 30 minutes at an angle of 45°. Plasma with cellular elements is layered on a double density gradient of 1 ml sterile ficoll-verografin solution with a density of the upper layer of 1.075-1.077 g/cm^3, the lower one – 1.119-1.120 g/cm^3. The gradient solution is centrifuged with

plasma at 600 g for 20 minutes. The neutrophil ring is collected and transferred to sterile centrifuge tubes. The cells are washed twice from the gradient with a Hanks solution and once with a sterile saline solution of sodium chloride in a volume of 2 ml for 7 minutes at 200 g.

Neutrophils are dissolved to a concentration of 5×10^6 cells per 1 ml using a sterile saline solution of sodium chloride with a Goryaev chamber. Then the ability of isolated neutrophils to destroy the biofilm matrix is determined. 300 µl of biofilm suspension and 100 µl of neutrophil suspension are introduced into the Eppendorf tube and incubated for the day at 37°C. The reaction mixture is centrifuged for 10 minutes at 8000 g to precipitate undisturbed biofilm elements and neutrophils, after which 150 µl of the additive is transferred to the wells of a 96-well polystyrene plate for enzyme immunoassay.

The reaction is accounted for by increasing the optical density of the mixture determined with the F300 TP spectrophotometer at a wavelength of 492 nm due to the release of Congo red during the destruction of the exopolymer matrix. As a negative control, a sterile saline solution was used instead of a neutrophil suspension. The values were presented as the concentration of Congo red (µg/ml). To convert the UOD into µg/ml of Congo red, the formula was used:

$$X = (0.101 + 11.04 \times [\text{UOD of the sample} - \text{UOD of control}])^2$$

where X is the concentration of the Congo red,
UOD of the sample – optical density of the sample,
UOD of control – optical density of control.

The data obtained during the research were processed with Statistica 10.0 software package (StatSoft Inc., USA). The statistical significance of the difference between the comparison groups was determined using the nonparametric Kruskal-Wallis test. The difference was considered significant at $p\leq0,05$.

Results and discussion.

Statistical analysis of data from various samples in the comparison groups showed the following results (see Table 1):

Table 1.

Statistical characteristics of Congo red concentrations in samples from patients with infectious inflammatory diseases of the maxillofacial region

Time of collecting the sample	N	Mean	95% confidence interval (CI)	Min/max	Standard deviation (SD)
Day of admission	80	0,304	0,276…0,332	0,153/0,697	0,126
3rd day of treatment	80	0,428	0,392…0,464	0,201/0,909	0,162
Day of discharge	80	0,702	0,662…0,724	0,468/1,319	0,181

On the day of admission before the start of antibacterial therapy, the amount of Congo red released after the interaction of the stained matrix and blood neutrophils was 0.304±0.126 µg/ml (95% CI: 0.276...0.332; min 0.153 max 0.697), on the third day – 0.428±0.162 µg/ml (95% CI: 0.392...0.464; min 0.201 max 0.909), on the day of discharge – 0.702±0.181 µg/ml (95% CI: 0.662...0.742; min 0.468 max 1.319), which indicated an increase in the amount of Congo red released from the stained matrix of *S. aureus* biofilms, destroyed by the neutrophils of the blood. In the control group, the amount of Congo red released from the matrix of *S. aureus* biofilm was 0.267±0.076 micrograms/ml (95% CI: 0.662...0.742; min 0.181 max 0.483). At the same time, when analyzing the statistical significance of the differences in these characteristics using the Kruskal-Wallis criterion, it was found that there are statistically significant differences between the three samples: the amount of Congo red extracted from the matrix on the day of admission is significantly lower than on the 3rd day of treatment ($p=0.00004$) and on the day of the patient's discharge from the hospital ($p<0.00001$). It was also found that this characteristic was significantly different for samples taken on the 3rd day of treatment and on the day of discharge ($p<0.00001$), which indicates an increase in the activity of blood neutrophils in relation to *S. aureus* biofilm by the 3rd day of treatment, as well as a steady increase in this activity by the time of completion of treatment (Figure 1).

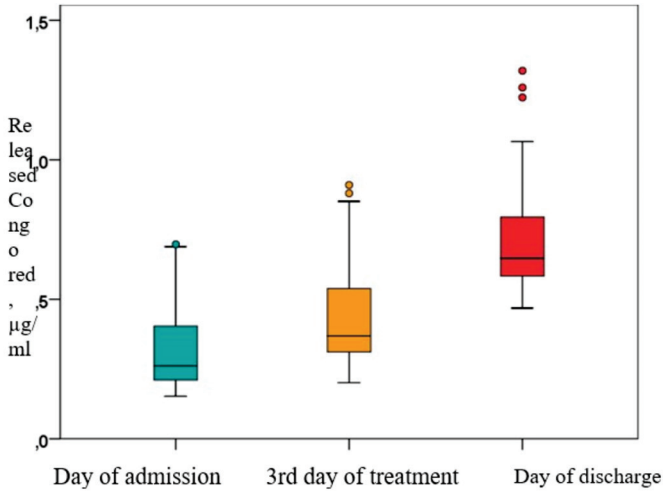

Figure 1. *The amount of Congo red released from S. aureus biofilms isolated from the matrix of the comparison groups*

When studying four subgroups of the sample, it was found that in subgroup 1 (patients with acute purulent odontogenic periostitis of the jaw) on the day of admission, the amount of Congo red after the interaction of the stained matrix and blood neutrophils was 0.461±0.11 micrograms/ml (95% CI: 0.411...0.511), on the 3rd day - 0.603±0.17 μg/ml (95% CI: 0.523...0.68), on the day of discharge – 0.899±0.245 μg/ml (95% CI: 0.807...0.99). In subgroup 2, the following results were obtained: on the day of admission – 0.267±0.083 μg/ml (95% CI: 0.227...0.307), on the 3rd day of hospital stay - 0.366±0.099 μg/ml (95% CI: 0.318...0.413), on the day of discharge the amount of released Congo red was 0.606±0.082 μg/ml (95% CI: 0.567...0.645). In a subgroup 3 (patients with odontogenic abscess of the maxillofacial region) on the day of admission, the amount of released Congo red was 0.242±0.043 μg/ml (95% CI: 0.222...0.262), on the 3rd day - 0.345±0.063 μg/ml (95% CI: 0.316...0.374), on the day of discharge – 0.623±0.069 μg/ml (95% CI: 0.591...0.656). In subgroup 4, the studied criterion on the day of admission was 0.235±0.086 μg/ml (95% CI: 0.195...0.275), on the 3rd day - 0.385±0.134 μg/ml (95% CI: 0.321...0.449), on the day of discharge – 0.665±0.151 μg/ml (95% CI: 0.595...0.736).

When analyzing the results obtained in each subgroup using the Kruskal-Wallis test, it was found that there are statistically significant differences between 4 subgroups of the sample by the studied criterion: in subgroup 1, the amount of Congo red released on the day of admission is significantly lower than on the day of discharge ($p<0.00001$), and the result obtained by the 3rd day of treatment is also significantly lower than on the day of discharge ($p=0001$). In subgroup 2, on the day of discharge, the calculated amount of Congo red released from the S. aureus biofilm matrix is significantly higher than on the day of admission ($p<0.00001$), and higher than on the 3rd day of treatment ($p=0.0002$). Comparison of the free Congo red concentrations on the day of admission and on the 3rd day of treatment in subgroups 1 and 2 revealed no significant differences ($p>0.05$). In subgroup 3 of the studied sample, the calculated amount of Congo red released from the biofilm matrix on the day of discharge was significantly higher than on the day of admission ($p<0.00001$) and higher than on the 3rd day of treatment ($p=0.0003$); in addition, the studied criterion on the 3rd day of treatment was significantly higher than on the day of admission ($p=0.007$). Analysis of the data from subgroup 4 showed that on the day of discharge, the studied characteristic was significantly higher than on the day of admission ($p<0.00001$), and higher than on the 3rd day of treatment ($p=0.002$), and also significantly higher on the 3rd day of treatment than on the day of admission ($p=0.005$), which is shown in Figure 2.

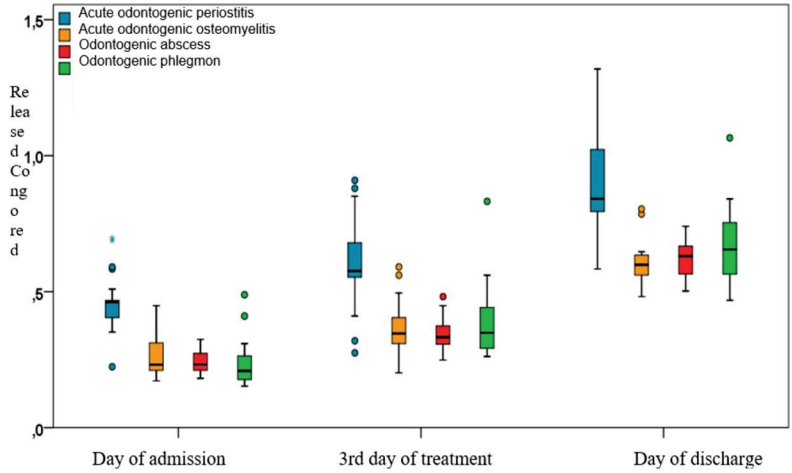

Figure 2. *The amount of Congo red released from matrix of S. aureus biofilms in patients with infectious inflammatory diseases of the maxillofacial region of various propagation*

Statistical analysis demonstrates an increase in the amount of Congo red released from the biofilm matrix of *S. aureus*, which indicates an increase in neutrophil activity in the presence of a biofilm produced by bacterial agent of infectious inflammatory diseases of the maxillofacial region, while it was found that for patients with diagnosis "acute purulent odontogenic periostitis of the jaw" and "acute odontogenic osteomyelitis of the jaw" there were no significant differences in this characteristic on the day of admission and on the 3rd day of treatment, while in groups with diagnosis "odontogenic abscess of the jaw" and "odontogenic phlegmon of the jaw" significant difference was found for the studied parameter on the day of admission and on the 3rd day of treatment, which indicates a decrease in neutrophil activity in subgroups 3 and 4 and a more pronounced systemic immune response in patients with these nosologies.

Conclusion. The present study demonstrated that neutrophils from blood of patients are able to effectively destroy the matrix of biofilms produced by *S. aureus.* Such activity of neutrophils was found to be highest in patients with acute purulent odontogenic periostitis of the jaw. At the same time, the activity of neutrophils in relation to the biofilm matrix tends to increase during the course of the disease, steadily increasing from the moment of hospitalization to the time of discharge, which probably reflects an increase in the effectiveness of local and systemic protective reactions of the body in relation to agents of purulent inflammatory diseases of the maxillofacial region over time.

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THE PROBABILITY OF REPEATED CARDIOVASCULAR EVENTS IN PATIENTS WITH UNSTABLE CORONARY ARTERY ATHEROSCLEROSIS WITHIN A YEAR AFTER THEIR STENTING

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Resume. *The aim of the study was to create a logistic regression model that will allow us to assess the likelihood of recurrent cardiovascular events in patients with unstable coronary artery atherosclerosis within 12 months after PCI and coronary artery stenting using various parameters of the immune system and other indicators of routine research methods. 83 patients (58 men and 25 women) aged 43 to 60 years (mean age 53.1±5.6 years) with a diagnosis of myocardial infarction were examined, who underwent coronary artery stenting. The levels of interleukins 4, 6, 8, 10 and 18, tumor necrosis factor alpha (TNF-α), the number of vascular adhesion molecules sVCAM-1, immune system parameters (T- and B-cell immunity, IdA, IgG, IgM, phagocytic number, phagocytic index, circulating immune complexes), neutrophil elastase and BAPNA-amidase activity in blood serum were evaluated. Using discriminant analysis, "classification trees" and logistic regression with subsequent ROC-analysis of the factors studied, a prediction model was developed that includes the age of patients, the level of IL-6, IgG, circulating immune complexes, the number of active T-lymphocytes, and the phagocytic index of lymphocytes. AUC of the model (area under the curve) = 0.845 (95%CI 0.645-1.0), sensitivity – 80%, specificity – 90.9%. The developed model makes it possible to predict the occurrence of repeated cardiovascular events within 12 months after coronary artery stenting in patients with myocardial infarction.*

Keywords: *prognosis, cardiovascular events, stenting, immune system.*

Relevance. At this moment, active surgical tactics, namely thromboextraction and angioplasty with stenting of a symptom-related artery, are recognized as one of the effective methods of treating acute cardiovascular events [1]. At the same time, 1.7-5% patients develop postoperative complications in the early postoperative period develop, and the appeareance of drug-coated stent restenosis may

occur in 5-10% of patients during the first 6 months after percutaneous coronary intervention (PCI), which adversely affects the quality of life of these patients. Inflammation that occurs in response to damage to the vascular wall during stent implantation into the coronary artery should be considered as one of the independent risk factors for PCI complications [1].

Scientific publications of domestic and foreign scientists (E. I. Chazov, 2008, V. V. Kukharchuk, 2011, M. I. Lutai, 2004, M. A. Danilova, 2011, O. L. Barabash, 2011, V. V. Kashtalap, 2014, P. M. Ridker 2009, P. Libby, 2015), were shown the significant role of cytokines as biomarkers of subclinical inflammation in the progression of atherosclerosis in chronic coronary heart disease (CHD), acute coronary syndrome (ACS), and in the development of recurrent cardiovascular events.

According to a number of studies, there are other potential markers of atherosclerosis progression: cellular elements of immunity (various immunoglobulins), adhesion molecules (for example, VCAM-1), proteolytic enzymes (for example, neutrophil elastase) [2-6].On the other hand, the level of circulating cytokines does not necessarily reflect their actual activity, therefore, the determination of multidirectional markers of atherosclerosis progression in combination with routine clinical, laboratory and instrumental indicators can become the basis for the creation of new prognostic models for the development of adverse cardiovascular events.

Aim. To create a logistic regression model that will allow us to assess the likelihood of recurrent cardiovascular events in patients with unstable coronary artery atherosclerosis within 12 months after PCI and coronary artery stenting using various parameters of the immune system and other indicators of routine research methods.

Materials and methods. 83 patients (58 men and 25 women) aged 43 to 60 years (mean age 53.1±5.6 years) with a diagnosis of myocardial infarction were examined, who underwent coronary artery stenting. The patients underwent clinical examination and treatment on the basis of the cardiology department of the Vitebsk Regional Clinical Hospital and the examination of persons from the control group was conducted on the basis of the Vitebsk State Medical University clinic.

Diagnosis of myocardial infarction (MI, ACS with ST elevation) was carried out in accordance with the criteria of the European Society of Cardiology (2017) [7]. The diagnosis was verified according to coronary angiography, ECG results and biochemical blood analysis. 29 patients (34.9%) were diagnosed with small-focal left ventricular MI of the anterior septum region, 54 patients (65.2%) with large–focal left ventricular MI (36 patients with lower wall MI, 14 patients

with anterior septum MI, 4 patients with posterobasal MI). All of them belonged to type 1 – spontaneous MI.

The average period of hospitalization in the hospital was 14 ± 3 days, which falls on the acute and acute period of MI development, then patients were rehabilitated in the health care institution "Vitebsk Regional Clinical Cardiology Center" for at least 14 days.

Blood sampling was performed after a twelve-hour starving in the morning from v. ulnaris on the first day of hospitalization and on the 14th day. The blood was centrifuged at 10000 rpm for 10-15 minutes. The resulting serum was stored in a freezer at -20 ° C for no more than 12 months before the study. The level of interleukins 4, 6, 8, 10 and 18, tumor necrosis factor alpha (TNF-α), vascular adhesion molecule sVCAM-1 was determined on the basis of the VSMU research laboratory, according to the instructions for the use of cytokine manufacturers (Vector-Best company (RUS) and Cloud-CloneCorp (USA) for sVCAM-1), the activity of neutrophil elastase and BAPNA amidase in blood serum was determined by appropriate methods [8]. The assessment of the immune system indicators (T- and B-cell immunity, IdA, IgG, IgM, phagocytic number, phagocytic index, circulating immune complexes (CEC)) was carried out according to the generally accepted methodology (D. K. Novikov, 2000, V. V. Yanchenko, 2003).

Statistical processing of the obtained results was carried out using STATISTICA v.10.0 software packages (license No. STA999K347156W belongs to VSMU) and MedCalc 15.8. For all types of analysis, the results were considered statistically significant at $p<0.05$.

Results. The cytokine profile and the level of proteolytic enzymes in the examined patients are presented in Table 1.

Table 1.

Indicators of the immune system and the activity of proteolytic enzymes in the blood serum of the examined persons

Parameter/Pick-up time	1st day Me;LQ-UQ	14th day Me;LQ-UQ
IL-4, pg/ml	0,63; 0,43-1,16	0,43; 0,29-0,87
IL-6, pg/ml	8,54; 4,78-18,924	4,78;* 1,08-12,08
IL-8, pg/ml	18,824; 8,95-66,05	11,3; 6,78-24,65
IL-10, pg/ml	2,74; 2,19-5,39	1,44;* 1,3-3,63
IL-18, pg/ml	194,81; 129,56-320	227,1; 145,67-245,54

TNF-α, pg/ml	13,423; 7,01-38,955	9,91; 6,75-12,43
sVCAM-1, pg/ml	44,919; 29,86-68,29	39,86; 25,98-57,87
Elastase activity, picocatals	0,527; 0,303-0,914	0,503; 0,256-0,875
BAPNA-amylase activity, picocatals	1,82; 1,259-3,063	1,147; 1,07-2,87
T-lymphocytes ($CD3^+$), %	48; 43-49	50; 44-54
Activated T-lymphocytes ($CD3^+CD4^+HLA\text{-}DR^+$), %	28; 24,33-31,5	29; 26-34
T-helpers ($CD3^+CD4^+$), %	27; 23,4-26,45	29; 24,5-30
T-killers ($CD3^+CD8^+$), %	19; 15,4-23,4	20; 16-24,5
IRI (immunoregulatory index)	1,63; 1,12-1,93	1,65; 1,23-2,07
B-lymphocytes ($CD19^+$), %	16; 14-20	18;* 16-21
IgA, g/l	1,99; 1,6-2,7	2,3; 1,72-2,91
IgM, g/l	0,73; 0,51-1	0,85; 0,58-1,18
IgG, g/l	9,53; 8,25-11,09	10,7;* 9,07-12,08
Circulating immune complexes, units.	71; 60-97	84;* 65-112
Phagocytic index, %	73; 65-84	78,5; 67,1-88
Phagocytic number, units.	8,2; 7,4-10	8,8; 7,7-10,5

According to Table 1, it was revealed that after 14 days of hospitalization in patients with MI (before discharge from the hospital), statistically significant differences according to the Mann-Whitney criterion were obtained for IL-6 ($p=0.017$), IL-10 ($p<0.001$), as well as for all studied immunoglobulins (IgA, $p=0.014$; IgM, $p=0.012$; IgG, $p=0.03$), B-lymphocytes ($p=0.04$).

After the end of their hospitalization, patients were dynamically monitored at intervals of 3 months for 1 year. At the end of this period, a telephone survey of patients was conducted using the Rose questionnaire for exacerbation of the course of coronary artery atherosclerosis, manifested by the progression of coronary artery disease (the appearance of pain behind the sternum, heart failure,

shortness of breath, high blood pressure (BP) with the development of progressive angina or repeated myocardial infarction), with repeated hospitalization due to main desease. The patients answered all the suggested questions (Table 2).

Table 2.

Results of a survey of patients with MI 12 months after hospitalization

Parameter	Repeated hospitalization	Pain behind the sternum (angina pectoris)	Heart rhythm interruptions (arrhythmia)	Shortness of breath	Increased blood pressure
Number of patients, n(%)	21 (25,3%)	43 (51,8%)	21 (25,3%)	15 (18,1%)	29 (34,9%)
Hospitalized patients, n (% of patients with complaints)		18 (34,8%)	14 (66,7%)	15 (100%)	15 (51,7%)

According to the data presented in Table 2, 43 (51.8%) patients had complaints of pain behind the sternum during the year, 18 of which (41.8%) were hospitalized for the resumption of symptoms; 21 (25.3%) patients had complaints of heart failure, 66.7% of which were hospitalized; in 15 patients – shortness of breath, of which all were hospitalized, in 29 patients – not achieving the BP targets, of which 51.7% were hospitalized. Thus, the main reason for repeated hospitalization was the presence of pain behind the sternum during physical exertion, which was accompanied in patients by the appearance of heart failure, shortness of breath and increased blood pressure, or the listed complaints themselves provoked the presence of pain behind the sternum. The data obtained on the number of repeated hospitalizations (25.3%) in patients 1 year after a coronary event and stenting are consistent with the data of M. N. Mammadov et al. (2022), where 23% of patients without diabetes mellitus and with acute forms of coronary artery disease were re-admitted to the hospital 1 year after the coronary event [9].

Based on the data obtained, as well as after conducting a discriminate analysis and constructing "classification trees" to make a decision on the selection of patients who need observation after PCI and stenting, a logistic regression model was developed with a special formula for calculating the final results and subsequent ROC analysis.

$$Y = \frac{EXP(-14{,}26 + 0{,}239 \times C - 0{,}11 \times D - 0{,}006 \times E + 0{,}0067 \times F - 0{,}13 \times G + 0{,}22 \times H)}{1 + EXP(-14{,}26 + 0{,}239 \times C - 0{,}11 \times D - 0{,}006 \times E + 0{,}0067 \times F - 0{,}13 \times G + 0{,}22 \times H)}$$

where Y is the desired value of the cut–off point;

C – age of patients, years;

D – the number of activated T-lymphocytes (CD3+CD4+HLA-DR+), 10^9/l (blood sampling for all immunological parameters was carried out at the end of the acute period of myocardial infarction on the 14th day of hospitalization);

E – phagocytic index of leukocytes, %;

F – the number of circulating immune complexes (CIC), units;

G – level of IL-6 in pg/ml;

H – the IgG level in g/L.

Finallly, all the values obtained, which were less than the cut-off point value (0.463), were attributed to the group of patients with no exacerbation of coronary atherosclerosis. Values equal to or greater than the cut-off point were assessed as belonging to patients with a high probability of developing repeated cardiovascular events within 12 months.

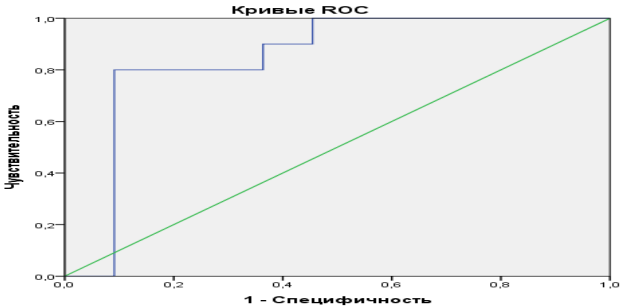

Figure 1. *ROC-curve of the final probability determination model*

The sensitivity of the model is 80%, the specificity is 90.9%, (p=0.038, Figure 1). The power of the model covers 84.5% of observations – the AUC of the model (area under the curve) = 0.845 (95%CI 0.645-1.0).

Example 1.

Patient C. Age – 51 years, activated T-lymphocytes (CD3+CD4+HLA-DR+) – 31.0%, PHI – 69.0%, CIC – 65 units, IL-6 – 3.1 pg/ml, IgG – 9.05 g/l.

The calculated value of the logistic regression (Y) is 0.020149.

Conclusion: the probability of developing a recurrent cardiovascular event is low, a favorable course is possible.

Example 2.

Patient N. Age – 60 years, activated T-lymphocytes (CD3+CD4+HLA-DR+) – 22.0%, PHI – 77.0%, CIC – 83 units, IL-6 – 2.2 pg/ml, IgG – 9.4 g/l.

The calculated value of the logistic regression (Y) is 0.496972.

Conclusion: the probability of developing a recurrent cardiovascular event is high, the risk of repeated hospitalization is high.

Discussion.

The PCI procedure with stenting has been an effective method of myocardial revascularization in recent years in case of sudden thrombosis in a particular coronary artery. This manipulation not only restores blood flow in the ischemic myocardium, but also significantly reduces the concentration of proinflammatory cytokines, which contribute to excessive damage to cardiomyocytes [1].

Thus, according to the results of studies by L. N. Slatova, a significant decrease, almost to reference values, in the level of proinflammatory cytokines (except TNF-α) 10 days after PCI was revealed [10].On the other hand, according to D. E. Monopoly et al. [10], signs of subclinical inflammation persist after PCI, and initially high levels of pro-inflammatory cytokines CRP and IL-6 contribute to an increased risk of restenosis and/or stent thrombosis [10]. According to our data, the level of all proinflammatory cytokines (with the exception of IL-18) decreased after 14 days, however, statistically reliable results were obtained only for IL-6, therefore subclinical inflammation in varying degrees of activity probably persists, which is consistent with the above researcher's data.

One of the most effective "methods" of treating certain forms of coronary heart disease is primary and, most often, secondary prevention of these pathologies, which allows timely provision of the necessary specialized care to patients, depending on the situation [11]. Existing scales (TIMI-score-STEMI; PURSUIT; TIMI-score-non STEMI; CADILLAC; GRACE; PAMI risk score; RECORD 1-2-3; CRUSADE; SYNTAX score; BCIS-1 Myocardial Jeopardy score, etc.) demonstrate different prognostic power in assessing the risk of fatal events and the development of recurrent MI at different times from the moment of hospitalization of patients [10]. At the same time, we found only 6 prognostic scales (FRISC 2011, KEMScore 2011, the model of M. V. Zykov 2012, the model of A.V. Panina 2013, the model of A.V. Schmidt et al. 2014, the model of L. N. Slatova 2016) [11, 12], taking into account the presence of certain cytokines, although the results of numerous studies revealed a positive weak correlation between the scores on the scales CADILLAC and CRP, IL-8; GRACE and IL-12; RAMI and IL-12, CRP, which indicates the applicability of these cytokines in prognostic scales [11, 12]. It should be noted that the diagnostic significance of models including cytokines is the highest among all other scales, since the special criterion of ROC analysis (mathematical modeling programs) AUC in these models was more than 0.85 - which is considered the best result for statistical modeling.

According to our data, the proposed model, including age, cytokine IL-6, as well as other immunological parameters (CIC, active T-lymphocytes, phagocytic index, IgG) has AUC = 0.845, which is defined as a "good" model for forecasting, while not requiring significant financial costs, because the indicators of the system the immunity presented in the model is included in routine practice, and the

definition of IL-6 does not significantly increase the cost of the study per patient (about 5 BYN).

Thus, the obtained model can be used in a complex of medical services aimed at the secondary prevention of myocardial infarction, for example, in the timely prevention of the severe recurrent cardiovascular events and, accordingly, in reducing the cost of treatment with the necessary hospitalization of the patient, in particular, the cost savings are from 2.13 BYN for small-focal MI or progressive angina pectoris up to 5,28 BYN with large-focal MI for every 1 BYN spent on prevention of cardiovascular events.

Conclusion. The developed model of logistic regression using the level of IL-6, IgG, CIC, the number of active T-lymphocytes, the phagocytic index of lymphocytes and the age of patients allows predicting the occurrence of repeated cardiovascular events within 12 months in patients after PCI and coronary artery stenting. The sensitivity of the model is 80%, the specificity is 90.9%, (p=0.038). The power of the model covers 84.5% of observations – the AUC of the model (area under the curve) = 0.845 (95%CI 0.645-1.0).

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ARTIFICIAL EMOTIONAL INTELLIGENCE MANAGEMENT SYSTEM: DIAGNOSTICS AND REHABILITATION

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Abstract. *The work is devoted to the creation of an artificial emotional intelligence management system that allows for diagnosis and rehabilitation. The structural scheme of the system, the scheme of interrelations of software modules in the system is presented.*

Keywords: *artificial emotional intelligence, cognitive dysfunctions, the scheme of interrelations of software modules.*

The digital transformation of society is an integral factor of progress. The intensification of all spheres of human activity is associated with an increase in the risks of psycho-emotional dysfunctions against the background of stress and decompensation. The human factor has been and remains at the forefront of digital transformation. Of particular relevance are studies of unsolved problems of cognitive dysfunctions and brain patterns, such as affects, qualia, the possibility of emotional diagnosis and rehabilitation. The lack of research of these problems has prompted scientific research to solve them [1, p. 59; 2, p. 84].

The object of the study is the processes of interaction of cognitive dysfunctions with the hardware and software complex, tools, adaptation methods and specialized processing coming from the means of collecting information about the state of the object during psycho-emotional diagnostics. The purpose of the research is to develop the scientific foundations of means and methods for determining the functional indicators of an object in the process of psycho-emotional diagnostics based on instrumental tools, the practical use of the decision-making system of artificial emotional intelligence as an effective means for assessing the positive intellectual functional impact on the object, determining the choice of optimal solutions for self-regulation of psycho-emotional states of the individual .

The research work solves the important fundamental scientific problem of integrating the interaction of digital resources based on AEI through the creation of appropriate models, methods and IT. Research methods: system analysis, defi-

nition and decomposition of the general goal, main function, separation of the system from the environment; functional, component and structural decomposition; determination of informative parameters, justification and minimization of independent controlled variables were carried out using methods of formalized representation of systems. Fundamental and applied scientific research focuses on the development and operation of tools for identifying artificial emotional intelligence, processing cognitive information, modern brain research technologies based on the mechanism of processing cognitive information of the human brain. Emotion recognition is an important research area in various fields. Human emotions have many manifestations. Therefore, emotion recognition can be realized by analyzing facial expressions, speech, behavior or physiological signals. These signals are collected by different sensors.

An analysis of the current state of research into tools for recognition and modeling of artificial emotional intelligence made it possible to identify current tasks on this problem, compare the advantages and disadvantages of various tools for recognizing emotions, which will facilitate the algorithmization of existing problems. Emotion is a biochemical impulse of exogenous and endogenous factors of the life process, a complex manifestation of a person's physiological and psychological states, a mental process of medium duration, reflecting a subjective evaluative attitude towards existing or possible situations and the objective world. Emotions are automatic and primary patterns of goal-directed cognitive-behavioral organizations. They perform three main functions: coordination, signaling and information. First, emotions coordinate organs and tissues, thereby predisposing the body to peculiar reactions. Second, emotional episodes signal a person's current state. Third, emotions inform the brain for purposes of interpretation and evaluation. Emotional experiences include mental representations of arousal, relationships, and situations.

The research and development of the scientific foundations of means and methods for determining the psycho-emotional indicators of an object in the process of drug-free therapy was carried out on the basis of instrumental tools, the practical use of the decision-making system of artificial emotional intelligence as an effective means for assessing the positive intellectual functional impact on the object, determining the choice of optimal solutions for self-regulation of psycho-emotional states of the individual . The block diagram of the artificial emotional intelligence system is shown in Fig. 1. The system is represented by a variety of computer devices of external users; intelligent interface with external users; automated workstation (AWS) - visualization module; AWS of a special interactive service - a personal account; knowledge base; diagnostic module; router; module of specialized knowledge; electronic library; cognitive dysfunction simulator module; biofeedback simulator module; a testing module and a computer device for a database operator, a module for generating reporting forms.

A formal attempt at computer design of emerging psycho-emotional processes using modern sophisticated tools, modeling the dynamic flow of recursive effects, is of great importance for the further development of the theorizing and research of emotions, contributes to the modeling of neural networks in the field of nonlinear dynamic modeling and the construction of a computational model of emerging emotional processes.

The practical result of the development is to increase the accuracy of differential diagnosis of the level of development of cognitive abilities and the possibility of rehabilitation based on cognitive training.

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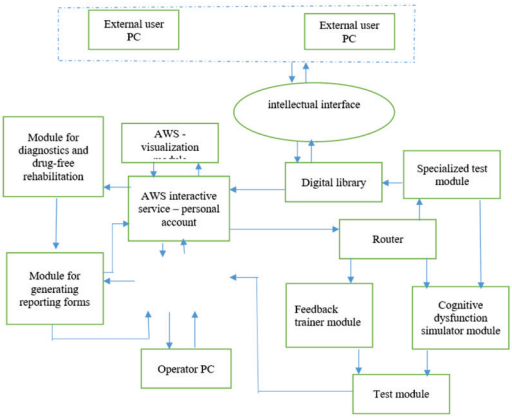

***Figure 1**. Block diagram of the artificial emotional intelligence system*

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SYNTHESIS OF THE FLUX LINKAGE REGULATOR FOR THE AUTOMATIC CONTROL SYSTEM OF THE TRACTION ELECTRIC DRIVE OF A ROBOTIC CITY ELECTRIC BUS

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Abstract *The article discusses the issue of synthesizing a flux linkage control system for vector frequency control of an asynchronous electric drive by tuning the flux linkage control loop and the flux linkage setting unit to a modular optimum. This allows the flux regulator to be used in traction electric drive systems of vehicles, including electric buses, which operate in two zones of electric drive speed control.*

Keywords: *regulator, flux linkage, automatic control system, electric bus, traction electric drive, asynchronous electric motor, modular optimum.*

Since the controlled coordinates of the electric bus electric drive are engine torque, stator current and rotor flux linkage, it seems appropriate to use a direct vector control system to meet the specified technological requirements. The synthesis of the system begins with the synthesis of the rotor flux linkage control channel. This channel contains two circuits: a current control circuit and a flux linkage control circuit. The transfer functions of all these controllers are determined by the method of sequential optimization of circuits (subordinate control) based on the modular optimum condition [1, c. 54].

The problem with synthesizing a flux linkage control loop is the fact that the asynchronous electric drive of an electric bus works in two speed control zones, and as a result, the magnetic field is weakened in the second control zone. Based on this, it is necessary to design a special unit for setting the flux linkage and determine the parameters for setting the flux linkage voltage for two zones of electric drive speed control. It is the synthesis of such a system that is the goal of this research.

To simplify the synthesis of controllers, we neglect the internal feedback of the control object in terms of flux linkage and current, and take all small time constants of the sensors and converter equal to the small uncompensated time constant.

As noted above, the block diagram of the control object contains two channels along the axes *x–y*, which is explained by the fact that the controlled quantities of the control object are control voltages u_{1X} and u_{1Y}. Because the direct vector control system of the asynchronous machine involves calculating the rotor flux linkage vector $\overline{\Psi}_2$ and its position using a speed sensor, to implement the system it is necessary to synthesize two automatic control system channels: the rotor flux linkage control channel, which is a separate independent circuit, and the stator current control channel [2], [3].

The flux linkage control channel contains a current regulator $Reg.cur._X$ and flux regulator Reg_{FL}. The stator current control channel contains a current regulator $K_{REG.CUR.Y}$. As current and flux linkage regulators we use PI regulators with modular optimum settings. The transfer functions of the controllers can be determined by the method of sequential optimization of circuits based on the modular optimum condition, assuming that the influence of cross-couplings is either not significant or is compensated.

The frequency, amplitude and phase of the voltage on the motor are controlled by pulse-width modulation of sinusoidal phase voltages. In the structure of a control system, a power converter can be approximately represented by a 1st order inertial link with amplification and a transfer function [4].

$$W(p) = \frac{\beta}{T_\mu p + 1}.$$

Since currently the most applicable are autonomous inverters based on transistor power switches with high performance, the time constant of the converter can be taken equal to a small uncompensated time constant τ.

A small uncompensated time constant for an electric drive with a pulse modulator is usually selected in the range from 0,0005 to 0,005 c. We will accept τ = 0,001 c.

The converter gain β is determined as the ratio of the largest values of the inverter voltage amplitude and the amplitude of the control signal according to the formula

$$\beta = \frac{|U_{1MAX}|}{U_{CONT.MAX}},$$

where U_{1MAX} are maximum values of stator voltage vectors in axes *x–y*, V;
$U_{CONT.MAX}$ is maximum control voltage value (10 V).

The flux linkage control loop includes an axis current control loop *x* and can also be adjusted to a modular optimum. The block diagram of this circuit is shown in fig. 1.

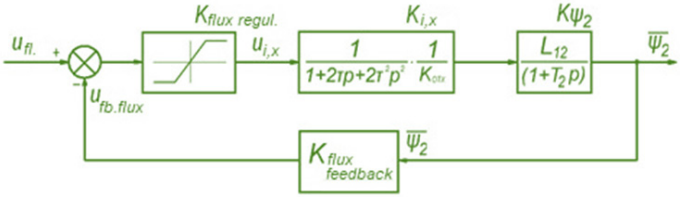

Figure 1. *Block diagram of the flux linkage circuit*

The transfer function of the flux linkage PI controller:

$$K_{FL.REG.} = \frac{1+T_2 p}{T_{INT.FL.}}.$$

The open-loop flux linkage equation:

$$K_{FL.REG} \cdot W_{CL.CUR.X} \cdot W_{\Psi 2} \cdot K_{FB.FL} = W_{FL.REG.}$$

According to the condition of tuning to the modular optimum, the expression for the required transfer function of the open flux linkage loop has the form

$$W_{FL.REG} = \frac{1}{4 \cdot \tau p \cdot \left(1+2 \cdot \tau p+2 \cdot \tau^2 p^2\right)}.$$

Express the transfer function of the flux linkage controller $W_{FL.REG}$:

$$W_{FL.REG} = \frac{K_{FB.CUR} \cdot \left(1+2 \cdot \tau p+2 \cdot \tau^2 p^2\right) \cdot \left(T_2 p+1\right)}{4 \cdot \tau p \cdot \left(1+2 \cdot \tau p+2 \cdot \tau^2 p^2\right) \cdot L_{12} \cdot K_{FL.REG}} = \frac{K_{FB.CUR} \cdot \left(T_2 p+1\right)}{4 \cdot \tau p \cdot L_{12} \cdot K_{FL.REG}},$$

where $K_{FB.CUR}$ is a flux linkage feedback coefficient is defined as

$$K_{FL.FB} = \frac{U_{FL.CL.MAX}}{\Psi_2}. \qquad (1)$$

Substitute the values into the formula (1):

$$K_{FL.FB} = \frac{10}{0,953} = 10,493 \text{ V} / Wb.$$

The transfer function for a closed flux linkage loop is given by

$$W_{CL.L.FL.} = \frac{L_{12} \cdot K_{FB.FL}}{\grave{O}_{INT.FL.} p \cdot \left(1+2\tau^2 p^2+2\tau p\right) \cdot K_{FB.CUR.X} + L_{12} \cdot K_{FB.FL.}} \cdot \frac{1}{K_{FB.FL}}.$$

By optimizing the circuit according to the modular optimum, we calculate the integration time constant of the current regulator $T_{INT.REG.CUR.}$, s according to the formula [4]

$$T_{INT.REG.CUR} = \frac{4 \cdot L_{12} \cdot K_{FL.FB} \cdot \tau}{K_{FB.CUR,X}}. \quad (2)$$

Substitute the numerical values into the formula (2):

$$T_{INT.REG.CUR} = \frac{4 \cdot 0,0049 \cdot 10,493 \cdot 0,001}{0,034} = 0,006\ c.$$

The final expression for the closed flux linkage loop taking into account expression (2) has the form

$$W_{FL.CL.CIR} = \frac{1}{1+4\tau p+8\tau^2 p^2+8\tau^3 p^3} \cdot \frac{1}{K_{FL.FB}}.$$

Thus, the transfer function of the open-loop flux linkage takes the form

$$W_{FL.REG} = \frac{0,034 \cdot (0,46p+1)}{4 \cdot 0,001p \cdot 0,0049 \cdot 10,493} = 76,07 + \frac{165,369}{p} = \frac{1+0,46p}{0,006p}.$$

The transfer function of the closed loop flux linkage takes the form

$$W_{CL.L.FL} = \frac{1}{1+4 \cdot 0,001p+8 \cdot 0,001^2 p^2+8 \cdot 0,001^3 p^3} \cdot \frac{1}{10,493} = \frac{1}{8,394 \cdot 10^{-8} p^3+8,394 \cdot 10^{-5} p^2+0,042+10,493}.$$

Taking into account the found transfer functions, the block diagram of flux linkage control shown in Fig. 1 will take the following form

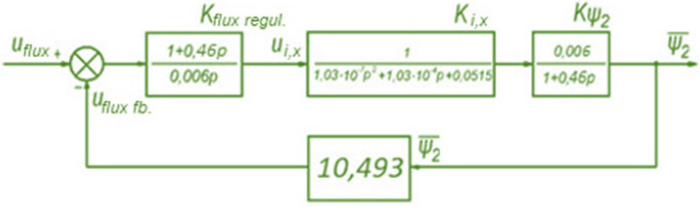

Figure 2. *Block diagram of a certain flux linkage circuit*

The parameters of the rotor flux linkage setting block are determined based on the equation

$$\Psi_2 = \sqrt{\frac{2 \cdot R_2^{'} \cdot M_{\dot{u}}}{3 \cdot \omega_0 \cdot s \cdot p_N^2}}.$$

Express the value of rotor flux linkage from formula (1):

$$\frac{U_{CL.FL.}}{K_{FL.FB}} = \sqrt{\frac{2 \cdot R_2^{'} \cdot M_{NOM} \cdot (1-s_N)}{3 \cdot \omega_0 \cdot s \cdot p_N^2}}. \quad (3)$$

Express the voltage setting of the flux linkage from equation (3)

$$U_{CL.FL} = K_{FL.FB} \cdot \sqrt{\frac{2 \cdot R_2^{'} \cdot M_{NOM} \cdot (1 - s_N)}{3 \cdot \omega_0 \cdot s \cdot p_N^2}}. \quad (4)$$

Substitute the values into the form (4)

$$U_{CL.FL.} = 10,493 \cdot \sqrt{\frac{2 \cdot 0,011 \cdot 1000 \cdot (1 - 0,013)}{3 \cdot \omega \cdot 0,013 \cdot 2^2}} = 10,493 \cdot \sqrt{\frac{21,714}{\omega}}.$$

Thus, the flux linkage setting voltage takes the following values at different speed ranges

$$\begin{cases} U_{CL.FL.} = 10, \ \omega \leq \omega \ ; \\ U_{CL.FL.} = 10,493 \cdot \sqrt{\dfrac{21,714}{\omega}}, \ \omega > \omega_{NOM}. \end{cases}$$

Based on the calculations carried out, a flux linkage control system was synthesized for vector frequency control of an asynchronous electric drive by adjusting the flux linkage control loop and the flux linkage setting unit to a modular optimum, which is an important aspect in the design of traction electric drives with dual-zone speed control, which include the electric drive of a robotic electric bus.

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APPLICATION OF ALLOWANCE CLASSIFICATION FOR ROTATIONAL BODY TYPE PARTS REMOVED BY MACHINING TO AUTOMATE THE TECHNOLOGICAL PREPARATION OF PRODUCTION

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Abstract. *The research relates to the field of automation of technological preparation of production in the development of a technological process for manufacturing parts of the "body of rotation" type. The problem of excessive diversity of technological equipment and methods of technological unification are considered. As a basis for classifying products and grouping parts during the process of technological unification, an element such as technological allowance is proposed. An approach to creating a classification of technological allowances removed during machining is proposed and a set of parameters is defined that allow the allowance to be unambiguously specified. The developed classification will make it possible to create an algorithm for grouping parts automatically for the purpose of further application of unified processing methods, determining the need for cutting tools, predicting the labor intensity of machining and centralized implementation of advanced methods of processing parts.*

Keywords: *technological preparation of production, technological unification, automation of the development of technological processes.*

Introduction. In the conditions of modern production, there is an increase in the range of machines and devices with a simultaneous decrease in the volume of their production, which affects the increase in quality requirements and a reduction in the time for manufacturing products (by 3-4 times) and requires a clear organization of the entire production process. An integral stage of the production

process is technological preparation of production (TPP), which is a complex of interconnected processes that ensure the technological readiness of the enterprise to produce products in a given volume with established technical and economic indicators [1].

TPP is characterized by high labor intensity, which is largely felt in the conditions of single and small-scale production types. One of the main directions of the Chamber of Commerce and Industry is the development of high-quality technological processes (TP) [2].

Relevance. One of the disadvantages of modern engineering production is the excessive variety of technological support means. It lies in the fact that at enterprises when processing similar or identical parts, various technological support is developed. This is explained by the difference in the composition of the technological equipment in the workshops, different specialists with different skill levels are involved in the developments, and there is a lack of information about these developments. As a result, to manufacture structurally and technologically similar parts, various technological processes can be developed, different tools and cutting modes can be used under identical conditions, and often different technological equipment [3].

In order to reduce the means of technological support, methods of technological unification were developed. Technological unification is the minimization of varieties of technological processes that are similar in content. There are 3 types of technological unification:

- typical;
- group;
- modular.

A standard technological process is developed for the manufacture, under specific production conditions, of a typical representative of a group of products that have common design and technological features [4]. A typical representative of a product group includes a product, the processing of which requires the largest number of main and auxiliary operations characteristic of products included in this group. Work on typing TP usually begins with the classification of surfaces and their combinations. The classification features are:

- shape of surfaces;
- required accuracy;
- part material.

The group method is a method of technological process unification in which for groups of products that are homogeneous in certain design and technological characteristics, the same type of high-performance processing methods are established using homogeneous and quickly adjustable production tools [1]. The creation of group processes for manufacturing parts can be based on various methods of grouping them [5]:

• by structural and technological similarity of parts;

• by elementary surfaces of parts, which makes it possible to establish processing options for these surfaces, and from a combination of elementary processes to obtain a technological process for processing any part;

• according to the prevailing types of parts processing (types of equipment), the unity of technological equipment and the commonality of machine setup.

Modular technology is based on the representation of parts as a set of design and technological modules (DTM), which are understood as a combination of surfaces designed to jointly perform a service function. The modular principle of technological design ensures the development of technological processes from ready-made blocks for each part or assembly unit. An assembly unit, a part of an assembly unit, a part or its component element can serve as a DTM [3].

Formulation of the problem. When developing technical solutions, it is necessary to achieve continuity of technical solutions, which should reduce the variety of processes and means, eliminate duplication of work in technological preparation of production, reduce its labor intensity and duration, expand the scale of distribution of progressive means and processes and ensure production flexibility. The first stage in the framework of technological unification work is the analysis of the range of manufactured products and the classification of processed parts. This task is very labor-intensive. Existing methods and software do not allow automation of the process, as a result of which the quality of this stage depends entirely on the qualifications of specialists.

Due to the fact that the choice of processing method, cutting tool and type of equipment is primarily influenced by the allowance removed during machining and the quality of the finishing surface, an approach is proposed in which, to classify parts of the "body of rotation" type, the initial feature will be a parameterized allowance, divided into elementary forms.

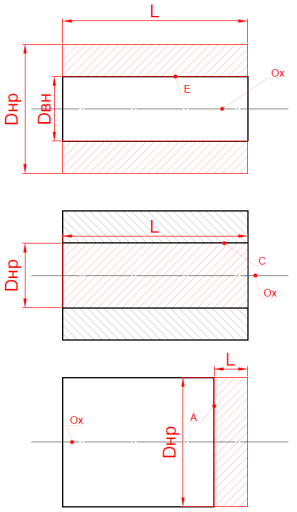
Theoretical part.

The initial data for classification are the design documentation (CD) for the part and its workpiece. The report describes an approach to classifying technological allowances according to their geometric shape:

1. Cylindrical shape
2. Prismatic shape

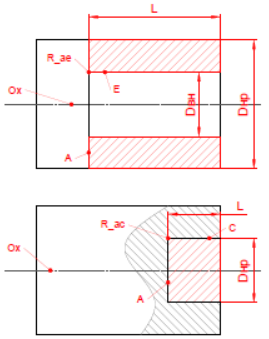
When developing the classification, special cases for cylindrical and prismatic allowances were analyzed (Table 1).

Table 1

<table>
<tr><th>№</th><th>Stock configuration options</th></tr>
<tr><td>1</td><td>Special cases for cylindrical allowance
 

Options:
L – length (mm)
Dнр – outer diameter of allowance (mm)
Din – internal diameter of the allowance (mm)

A, E, C – allowance surfaces adjacent to the surface of the part. Take the value of a set of type {x, Ra, HB, IT}. where x – takes values 1 or 0. Value 1 – if this surface is mated to the surface of the part, 0 – if there is no mating with the surface of the part. Ra, HB, IT – characteristics of the mating surface of the part (roughness according to Ra, hardness according to the Brinell scale, tolerance of the mating surface in microns) with the specified allowance surface. In cases where there is no pairing, the parameters Ra, HB, IT take the value 0

Additional parameter:
Ra_vn – radius or chamfer of mating surfaces
 
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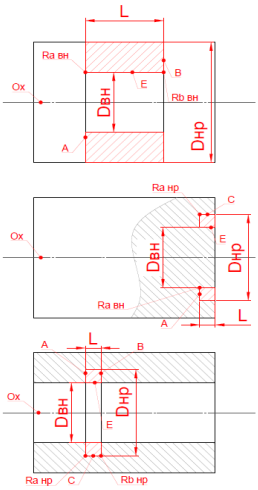
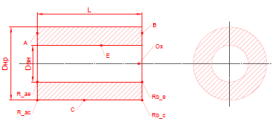
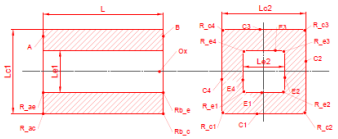
		Extra options Ra_nr, vn, nr– radius or chamfer of mating surfaces
	The following types of cylindrical allowances were also analyzed:	
1.1	One of the allowance surfaces has a bend radius	
1.2	One of the allowance surfaces is not parallel to the axis of rotation of the part	
1.3	The axis of symmetry of the allowance does not coincide with the axis of rotation of the part.	
2	Prismatic shaped allowances were similarly classified and special cases were considered	
2.1	One of the allowance surfaces has a bend radius.	
2.2	One of the allowance surfaces is located at an angle to the axis of rotation of the part.	

Based on special cases, a summary table of parameters has been developed for each type of allowance (Table 2)

Table 2

Parameter	**Value**	
Form	Cylindrical F = 0	Prismatic F = 1
Geometric dimensions	G = {L, Dнр, Dвн, R_AE, R_AC, R_BE, R_BC}	G = {L, Lnr1, Lnr2, Lvn1, Lvn2, R_AE, R_AC, R_BE, R_BC, R_C_{12}, R_C_{23}, R_C_{34}, R_C_{41}, R_E_{12}, R_E_{23}, R_E_{34}, R_E_{41}}
Characteristics of adjacent surfaces	S = {A, B, C, E}	S = {A, B, C_1, C_2, C_3, C_4, E_1, E_2, E_3, E_4}

The presence of bending of the allowance surfaces	m, R	
Not parallel to the axis of rotation of the part and the allowance surfaces	α	
Displacement of the axis of rotation of the allowance relative to the axis of rotation of the part	β, ex	not applicable
General view of allowances		
Many allowance options	{F, G, S, m, R, α, β, ex}	{F, G, S, m, R, α}

An example of grouping allowances for a part of the "rotation body" type.
Initial data:
1. Design documentation for the workpiece (Fig. 1)

Figure 1.

2. Design documentation for the part (Fig. 2)

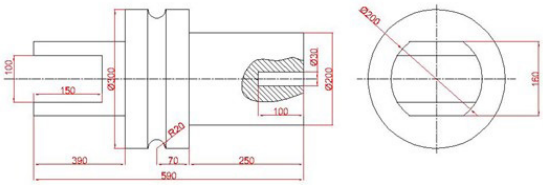


Figure 2.

In accordance with the developed classification, the entire allowance was divided into 9 parts (Fig. 3)

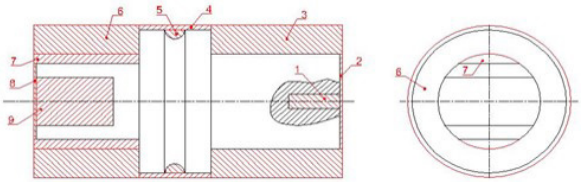


Figure 3.

Each part of the allowance is specified by the set:

1 - {F = 0, G = { L = 105, Dnr = 30, Dvn = 0; R_AE = 0, R_AC = 0, R_BE = 0, R_BC = 0}, S = {A = {1, Ra, HB, IT}, B = {0, 0, 0, 0}, C = {1, Ra, HB, IT}, E = {0, 0, 0, 0}}, m = 0, R = 0, α = 0, β = 0, ex = 0};

2 - {F = 0, L = 5, Dnr = 200, Dvn = 0, A = {1, Ra, HB, IT}, B = {0, 0, 0, 0}, C = {0, 0, 0, 0}, E = {0, 0, 0, 0}, Ra1 = 0, Ra2 = 0, Rb1 = 0, Rb2 = 0, m = 0, ά = 0, β = 0, ex = 0, Rs= 0};

3 - {F = 0, G = { L = 255, Dnr = 310, Dvn = 200; R_AE = 0, R_AC = 0, R_BE = 0, R_spheresBC = 0}, S = {A = {1, Ra, HB, IT}, B = {0, 0, 0, 0}, C = {0, 0, 0, 0}, E = {1, Ra, HB, IT}}, m = 0, R = 0, α = 0, β = 0, ex = 0};

4 - {F = 0, G = { L = 140, Dnr = 310, Dvn = 300; R_AE = 0, R_AC = 0, R_BE = 0, R_BC = 0}, S = {A = {0, 0, 0, 0}, B = {0, 0, 0, 0}, C = {0, 0, 0, 0}, E = {1, Ra, HB, IT }}, m = 0, R = 0, α = 0, β = 0, ex = 0};

5 - {F = 0, G = { L = 40, Dnr = 300, Dvn = 300; R_AE = 0, R_AC = 0, R_BE = 0, R_BC = 0}, S = {A = {0, 0, 0, 0}, B = {0, 0, 0, 0}, C = {0, 0, 0, 0}, E = {1, Ra, HB, IT }}, m = 20, R = 20, α = 0, β = 0, ex = 0};

6 - {F = 0, G = { L = 205, Dnr = 310, Dvn = 200; R_AE = 0, R_AC = 0, R_BE = 0, R_BC = 0}, S = {A = {0, 0, 0, 0}, B = {1, Ra, HB, IT}, C = {0, 0, 0, 0}, E = {1, Ra, HB, IT}}, m = 0, R = 0, α = 0, β = 0, ex = 0};

7 – {F = 1, G = { L = 205, Lnr_1 = 20, Lnr_2 = 0, Lvn_1 = 0, Lvn_2, R_AE = 0, R_AC = 0, R_BE = 0, R_BC = 0, R_C_{12} = 0, R_C_{23} = 0, R_C_{34} = 0, R_C_{41} = 0, R_E_{12} = 0, R_E_{23} = 0, R_E_{34} = 0, R_E_{41} = 0}}, S = { A = {0, 0, 0, 0}, B = {1, Ra, HB, IT }, C_1 = {0, 0, 0, 0}, C_2 = {0, 0, 0, 0}, C_3 = {1, Ra, HB, IT }, C_4 = {0, 0, 0, 0}, E_1 = {0, 0, 0, 0}, E_2 = {0, 0, 0, 0}, E_3 = {0, 0, 0, 0}, E_4 = {0, 0, 0, 0}}, m = 0, R = 0, α = 0};

8 – {F = 0, G = { L = 5, Dnr = 200, Dvn = 0; R_AE = 0, R_AC = 0, R_BE = 0, R_BC = 0}, S = {A = {0, 0, 0, 0}, B = {1, Ra, HB, IT }, C = {0, 0, 0, 0}, E = {0, 0, 0, 0}}, m = 0, R = 0, α = 0, β = 0, ex = 0};

9 - {F = 1, G = { L = 150, Lnr_1 = 100, Lnr_2 = 0, Lvn_1 = 0, Lvn_2 = 0, R_AE = 0, R_AC = 0, R_BE = 0, R_BC = 0, R_C_{12} = 0, R_C_{23} = 0, R_C_{34} = 0, R_C_{41} = 0,

$R\_E_{12} = 0$, $R\_E_{23} = 0$, $R\_E_{34} = 0$, $R\_E_{41} = 0$}}, S = { A = {0, 0, 0, 0}, B = {1, Ra, HB, IT }, C_1 = {0, 0, 0, 0}, C_2 = {0, 0, 0, 0}, C_3 = {1, Ra, HB, IT }, C_4 = {0, 0, 0, 0}, E_1 = {0, 0, 0, 0}, E_2 = {0, 0, 0, 0}, E_3 = {1, Ra, HB, IT }, E_4 = {0, 0, 0, 0}}, m = 0, R = 0, α = 0}.

The significance of the work. Using a set of data sets compiled for each part from the nomenclature manufactured in production, it is possible to group to create unified technological processes. Based on the accumulated information and using machine learning methods, it is possible to:

- unify methods for processing parts;
- predict labor intensity for new parts;
- determine the need for equipment and tools;
- centrally introduce new and more advanced processing methods.

Conclusion. The developed classification of technological allowances is the basis for the selection of technically and economically sound types of processing, unification of technological equipment and will allow the creation of an algorithm for the automated development of technological processes. It will also allow solving the problems of centralized implementation of promising products and technological processing methods.

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DIGITAL ARCHITECTURE AS PART OF THE INNOVATION PROCESS IN THE CONSTRUCTION INDUSTRY

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Abstract. *Digital architecture in construction is an important innovation that is transforming the way buildings and infrastructure are designed, managed and constructed. In this article, the authors discuss the key aspects of digital architecture in the construction industry and its impact on the efficiency, safety and sustainability of construction projects.*

Keywords: *BIM, digital architecture, process, construction, design.*

Architectural design and its development have undergone a significant evolution from manual drafting and physical experimentation with materials to computer-aided design and extensive analysis. Tracking this transformation requires an understanding of the ever-changing requirements for structural innovation and the large-scale aspects of designing a facility with functional features.

BIM *(Building Information Modeling)* is an acronym for building information modeling. It is a full life cycle management method based on architectural design, construction management, collaborative design, operation and maintenance, which enables buildings to save energy consumption, reduce pollution and other means to achieve green and energy saving [1]. Building Information Modeling Technology uses the latest technologies to assist in project management, construction procedure control, cross-sector collaboration, external communication, decision support and risk management, etc.

In this way, BIM architecture becomes more efficient, sustainable and profitable in terms of time and money.

The planning phase of the design process is extremely important. Information flow is analyzed during the preparation of contracts and BIM documents. The architectural office can agree on the scope of work that should not be changed after a certain date or after the completion of specific tasks. On the other hand, the very division of the design process into phases allows for the analysis of individual parts of the work and their purpose. Through the detailed procedures contained in the EIR (Employer's Information Requirements) and BEP (Execution Plan) and the planning of the design phase, architects avoid many misunderstandings and underestimated works [2].

When developing a concept, architects are challenged to design a facility that is not only functional and responsive to the client's conditions, but also adequately responds to its surroundings. Analysis of utilities, neighboring buildings, applicable local land use plans or historical and social aspects are some of the components of a conceptual design. Another example of the use of BIM in conceptual design is the preparation of insolation and shading schemes (Fig. 1). By introducing information like location, surroundings and position of the object with respect to the sides of light, we can properly and efficiently perform this type of analysis using BIM model [2].

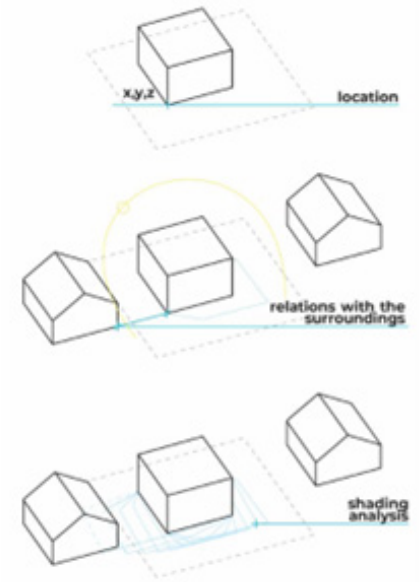

Figure 1. *Shading analysis using a 3D model after providing location and position information in relation to the sides of the world [2]*

In the world of architecture, technology has become an indispensable tool to drive innovation and improve efficiency. When utilizing digital architecture with BIM technologies, architects can improve metrics such as:

1. Cost savings and improved project performance

By applying BIM technology, architects can improve every stage of the design process, from conceptualization through the construction and operational phases. By creating a digital representation of the building, designers are able to model a variety of design options, evaluate their performance, and make informed decisions. With BIM's ability to identify conflicts, perform energy analysis, and perform cost estimating, architects are able to detect and resolve potential problems early, reducing the need for late adjustments, changes, and overall project costs. In addition, BIM's parametric modeling capabilities allow architects to quickly improve designs, saving time and increasing overall efficiency [2].

2. Communication between all project participants

Traditional architectural design processes are often complicated by the separation of interests of different participants working independently of each other. This can lead to misunderstandings, delays and significant financial losses. BIM enables close communication and collaboration between all participants in a construction and design project. This is accomplished by creating a common digital model that serves as a central repository for project data and information. Here is how the interconnection between the participants in BIM takes place:

Architects - create an architectural model of the project, including the building's exterior, room layout, and other architectural details. This model serves as a starting point for the rest of the project participants.

Consulting engineers for HVAC, electrical and technical utilities add their own models and data to BIM. This allows them to integrate systems and ensure optimal building performance.

Contractors - can use BIM to develop construction schedules, resource management and budgeting. They can also verify that their plans match real site conditions.

Customers - can actively engage with BIM by monitoring project progress, making decisions and providing feedback based on the visualizations and data provided by BIM. When working in this way, the customer contributes to a deeper understanding of the project and informed decision making.

One of the core elements of BIM is effective information management, which includes controlling model versions, ensuring data validity and integrity, and managing access to information. This aspect is critical to ensure the reliability and availability of data during the design and construction processes.

Another not insignificant element of BIM is to provide interdisciplinary model coordination that avoids collisions, conflicts and errors in real time in design and in construction.

The interaction of all BIM participants results in a more uniform approach to design and construction, leading to increased efficiency, reduced risk and improved project outcomes.

3. Pushing the boundaries of design

The use of information technology opens up a wide range of possibilities for architects in the design of buildings and structures. An information model integrates and stores building data into one consolidated digital model. In the digital model, architects can integrate design components and combine architectural elements with engineering and structural solutions. This allows for more efficient work and more effective designs [3].

Digital technologies offer architects the opportunity to create real-time visualizations of objects that promote a better understanding of design and improve communication between client.

BIM technology allows you to manage changes in architecture. Architects have the ability to react quickly to changes and solve problems. This leads to avoiding costly fixes and also improves overall project control.

As a result, the use of BIM opens up a wide range of possibilities for architects, which contributes to more efficient work and, as a result, leads to the formation of better and more modern architectural solutions.

Thus, digital architecture, or digital design and modeling in construction, presents a number of significant advantages in the construction industry:

- improved design: digital architecture enables architects, engineers and designers to create detailed and accurate digital models of buildings, which contributes to better and more efficient design;
- reducing errors and conflicts: with digital architecture, conflicts and errors in a project can be detected and resolved early in the project, reducing the likelihood of costly corrections late in the construction process.;
- better resource management: BIM allows you to accurately estimate the materials and resources required for construction, helping to optimize costs and reduce waste;
- improved building maintenance and management: once construction is complete, digital models can be used to effectively manage and maintain the building throughout its lifecycle;
- simulation and analysis: using numerical models, various analyses such as energy consumption analysis, thermal calculations and indoor climate simulations can be carried out to optimize the project in terms of efficiency and sustainability.

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