Brief information about the project

Title	AP22684289 Hydrophobic-hydrophilic associates as a basis for the formation of programmable neural networks based on hydrophilic polymers
Relevance	The scientific needs that determine the relevance of the project are driven by the necessity for a deeper understanding of the processes occurring in systems based on hydrophilic polymers. The very existence of such entities as hydrophobic-hydrophilic associates (HHA) and their analogs indicates that polymer solutions are often far more complex systems than what is predicted by classical theory. The national significance of the project lies in its continuation of the nontrivial ideas developed by Kazakhstani physicochemical schools, which conduct interdisciplinary research at the intersection of polymer physical chemistry and information technology. The international significance of the project is defined by the fact that it also creates prerequisites for the implementation of new information systems based on quasi-biological principles. The project results are applicable for the further development of a new scientific direction emerging at the intersection of macromolecular chemistry and information technology.
Goal	Establishing the neural network properties of hydrophobic-hydrophilic associates, including those formed in solutions of polycarboxylic acids, and demonstrating their potential use for the creation of programmable structures based on hydrophilic polymers. The main problem addressed by the project is the systematic study of the neural network properties of a relatively new class of interpolymer reaction products—hydrophobic-hydrophilic associates, which form dynamic network structures—as well as the identification of the properties that enable the conversion of these entities into programmable neural networks. To achieve the project's objective, an accurate neural network model of the structure of hydrophobic-hydrophilic associates will be developed, applicable also to the formation of such associates in carboxylic acid solutions. This model will be validated through comparison with experimental data, and it will be demonstrated that these associates can be converted into neural networks that are programmable through macroscopic stimuli.
Tasks	Justification for studying the neural network properties of hydrophobic-hydrophilic associates and their analogs (task role – creating the methodological foundation for project implementation; measurable indicator – introductory article in a Kazakhstani journal). Development of a neural network model describing the formation of hydrophobic-hydrophilic associates and their analogs, including in carboxylic acid solutions (task role – establishing the theoretical foundation for the project; measurable indicator – verification of model functionality). Proof of the model's applicability for description in terms of finite algebraic structures, particularly Galois fields (task role – ensuring transition to description using logical variables; measurable indicator – verification of model functionality). Development of an experimental methodology for identifying properties of hydrophobic-hydrophilic associate analogs formed in carboxylic acid solutions (task role – supporting experimental activities; measurable indicator – compatibility

	with available measuring equipment). Conducting experiments aimed at verifying the adequacy of the constructed model (task role – validation of the proposed model; measurable indicator – consistency between experimental measurements and theoretical results). Comparison of experimental and theoretical results to prove the adequacy of the proposed neural network model for the formation of hydrophobic-hydrophilic associates and their analogs (task role – model verification; measurable indicator – agreement between measurement data and theoretical findings). Demonstration of the possibility to formulate the proposed model in terms of multi-valued logic (task role – enabling logical analysis of the neural networks under study; measurable indicator – publication in a high-ranking journal). Development of software algorithms for numerical analysis of neural networks modeling hydrophobic-hydrophilic associates and their analogs (task role – demonstrating feasibility of using such neural networks to build programmable structures; measurable indicator – patent or certificate of authorship for the algorithm). Development of software algorithms for logical analysis of neural networks modeling hydrophobic-hydrophilic associates and their analogs, including the use of Galois fields and multi-valued logic tools (task role – identifying programming algorithms for neural networks based on hydrophilic polymers; measurable indicator – patent or certificate of authorship for the algorithm). Implementation of software products enabling numerical and logical analysis of neural networks modeling hydrophobic-hydrophilic associates and their analogs (task role – measurable indicator – patent or certificate of authorship for the software). Performing numerical simulations demonstrating the possibility of converting the studied type of neural networks into programmable structures (task role – identifying specific programming approaches for the structures under consideration; measurable indicator – numerical data confirming programmability of such structures). Development of recommendations for creating programmable structures based on hydrophilic polymers, including for controlled drug delivery (task role – summarizing project outcomes; measurable indicator – article in a high-impact journal).
Expected and Achieved Results	The feasibility of studying the neural network properties of hydrophobic-hydrophilic associates and their analogs will be substantiated. A neural network model of the formation of hydrophobic-hydrophilic associates and their analogs will be developed, including its applicability to carboxylic acid solutions. It will be demonstrated that this model allows for a transition to a description in terms of finite algebraic structures, particularly Galois fields. A methodology for conducting experiments to identify the properties of hydrophobic-hydrophilic associate analogs forming in carboxylic acid solutions will be developed. Experiments will be carried out, including measurements of the acidity of solutions of carboxylic acid mixtures of different molecular weights, aimed at verifying the adequacy of the developed model. By comparing experimental and theoretical results, the adequacy of the proposed neural network model for the formation

	of hydrophobic-hydrophilic associates and their analogs will be proven. It will be shown that the proposed model allows for interpretation in terms of multi-valued logic. Software algorithms will be developed for performing numerical analysis of neural networks modeling hydrophobic-hydrophilic associates and their analogs. Software algorithms will be developed for performing logical analysis of neural networks modeling hydrophobic-hydrophilic associates and their analogs, including the use of Galois fields and multi-valued logic tools. Software products will be implemented to conduct numerical and logical analysis of neural networks modeling hydrophobic-hydrophilic associates and their analogs. Numerical simulations will be carried out to demonstrate the possibility of converting the studied neural networks into programmable structures. Recommendations will be developed for the creation of programmable structures based on hydrophilic polymers, including for controlled drug delivery.
Names and Surnames of Research Group Members with Their Identifiers (Scopus Author ID, Researcher ID, ORCID, if available) and Links to Corresponding Profiles	Sherniyaz B. Kabdushev, Project Leader H-index (Scopus): 5, H-index (Web of Science): 1 ResearcherID: AEN-5981-2022 ORCID: 0000-0002-2834-883X Scopus Author ID: 57194510359 Grigoriy A. Mun, Doctor of Chemical Sciences, Professor, Academician of the National Academy of Sciences of the Republic of Kazakhstan H-index (Scopus): 28, H-index (Web of Science): 26 ORCID: 0000-0002-4984-7937 Scopus Author ID: 7006862276 Web of Science ResearcherID: I-3732-2017
Publications list with links to them	Publications of Postdoctoral Researcher Sherniyaz B. Kabdushev in Scopus-Indexed Journals Related to the Project Topic: 1 Kabdushev, S.; Mun, G.; Suleimenov, I.; Alikulov, A.; Shaikhutdinov, R.; Kopishev, E. Formation of Hydrophobic–Hydrophilic Associates in the N-Vinylpyrrolidone and Vinyl Propyl Ether Copolymer Aqueous Solutions. Polymers 2023, 15, 3578. https://doi.org/10.3390/polym15173578 2 Suleimenov, I.E., Vitulyova, Y.S., Kabdushev, S.B. and Bakirov, A.S., 2023. Improving the efficiency of using multivalued logic tools. Scientific Reports, 13(1), p.1108. (ISSN: 2045-2322, CiteScore 7.5, Q1, Multidisciplinary 97 %, https://www.scopus.com/sourceid/21100200805) 3 Ermukhambetova B.B., Mun G.A., Kabdushev S.B., Kadyrzhan A.B., Kadyrzhan K.N., Vitulyova Y.S., Suleimenov I.E., 2023. New approaches to the development of information security systems for unmanned vehicles. Indonesian Journal of Electrical Engineering and Computer Science, 31(2), pp.810-819. (ISSN: 2502-4752, CiteScore 2.9, Q3, Computer Networks and Communications 27%, https://www.scopus.com/sourceid/21100799500). 4 Kabdushev, S.B., Agibayeva, L.E., Kadyrzhan, K.N., Bakirov, A.S., Seitimova, G.A., Kolushpayeva, A.T. and Mun, A.G., 2022. New Approaches to Chemical Technologies of Plant Materials for Aromatherapy. Eurasian Chemico-Technological Journal, 24(4), pp.331-339. (ISSN: 1562-3920, CiteScore 1.4, Q4, Chemical Engineering (miscellaneous) 19%, https://www.scopus.com/sourceid/7200153124)

	5 Suleimenov, I.E., Mun, G.A., Kabdushev, S.B., Kadyrzhan, K.N., Alikulov, A., Shaltykova, D.B. and Moldakhan, I., 2022. The design of viscometer with smartphone controlling. Indonesian Journal of Electrical Engineering and Computer Science, 27(1), pp.366-374. (ISSN: 2502-4752, CiteScore 2.9, Q3, Computer Networks and Communications 27%, https://www.scopus.com/sourceid/21100799500) Publications of the Project's Scientific Advisor Since 2018 in Web of Science and Scopus Indexed Journals Related to the Project Topic: 1 Mun G.A., Bekbassov T., Beksultanov Zh., Yermukhambetova B.B., Azhgaliyev B., Azhgaliyev n., dergunov s.a. their effect on the rheological properties of oil // journal of petroleum science and engineering, 213 (2022), 110298, P. 1-10. https://doi.org/10.1016/j.petrol.2022.110298; Q1 (WoS and Scopus), If=4,436 (WoS); percentile 78 (scopus). 2 Sedlacek O., Bardoula V., Vuorimaa-Laukkanen E., Gedda L., Edwards K., Radulescu A., Mun, G.A., Guo Y., Zhou J., Zhang H., Nardello-Rataj V., Filippov S., Hoogenboom R. Influence of Chain Length of Gradient and Block Copoly(2-oxazoline)s on Self-Assembly and Drug Encapsulation // Small 2022, 2106251 P. 1-10. https://doi.org/10.1002/smll.202106251; Q1 (Wos and Scopus), IF=13,281 (WoS); Percentile 90 (Scopus). 3 Nakan U., Bieerkehazhi S., Tolkyn B., Mun G.A., Assanov M., Nursultanov M.E., Rakhmetullayeva, R.K., Toshtay, K., Negim, E.-S., Ydyrys A. Synthesis, characterization and antibacterial application of copolymers based on n,n-dimethylacrylamide and acrylic acid // Materials, (2021) 14 (20), 6191, P. 1-12. https://doi.org/10.3390/ma14206191. Q2 (Wos and Scopus), IF=3,623 (WoS); Percentile 51 (Scopus). Citations 1. 4 Ermukhambenova B.B., Suleimenov I.E., Alikulov A.Zh., Moldakhan I., Baipakbayeva S., Mun G.A. On Procedure for Determining Critical pH during formation of complexes between nonionic polymers and polyacid in aqueous solutions // Polymer Science, Ser. A, 2021, Vol. 63, No. 1, P.8-10. DOI: 10.1134/S0965545X20060024, Q3 (Wos and Scopus), IF=1,206 (WoS); Percentile 38 (Scopus). 5 Nakan U., Mun G.A., Rakhmetullayeva R.K., Tolkyn B., Bieerkehazhi Sh., Yeligbayeva G.Ye., Negim El-S. Thermosensitive N-isopropylacrylamide -CO-2-hydroxyethyl acrylate hydrogels interactions with poly(acrylic acid) and surfactants // Polym. Adv. Technol. – 2020. – 32 (7). - P. 2676-2681. https://doi.org/10.1002/ pat.5070. Q2 (Wos and Scopus), IF=3,665 (WoS); Percentile 69,44 (Scopus). Citations 5. 6. Nakan U., Mun G.A., Shaikhutdinov Ye.M., Yeligbayeva G.Ye., Bieerkehazhi Sh., Negim El-S., Selenova B.S., Nauryzova S.Z. Hydrogels based on N-isopropylacrylamide and 2-hydroxyethylacrylate: synthesis, characterization and investigation of their antibacterial activity // Polym. Int. – 2020. – 69 (12). - P. 1220-1226 (Wiley Online Library). DOI 10.1002/pi.6065. Q2 (Wos and Scopus), IF=2 990 (WoS); Percentile 63,30 (Scopus). Citations 4. 7 Agibayeva L., Kaldybekov D.B., Porfiryeva N.N., Garipova V.C., Mangazbayeva R.A., Moustafine R.I., Semina I.I., Mun G.A., Kudaibergenov S.E., Khutoryanskiy V.V. Gellan gumanditsmethacrylated derivativesasinsitugelling mucoadhesive formulations of pilocarpine: In vitro and in vivo studies // Int. J. Pharmaceutics. - 577 (2020) 119093.

	https://doi.org/10.1016/j.ijpharm.2020.119093. Q1 (Wos and Scopus), IF=5.875 (WoS); Percentile 73,30 (Scopus). Citations 17. 8 Mun G.A., Moldakhan I., Kabdushev Sh.B., Yermukhambetova B.B., Shaikhutdinov R., Yeligbayeva G.Zh. To the Methodology of Phase Transition Temperature Determination in Aqueous Solutions of Thermo-Sensitive Polymers // Eurasian Chemico-Technological Journal. – 2020. – Vol. 22. – P. 129-133. https://doi.org/10.18321/ectj960 (Scopus: Q3, Percentile 35). 9 Urakaev F.Kh., Abuyeva B.B.,Vorobyeva N.A., Mun G.A. Sulfur nanoparticles stabilized in the presence of water-soluble polymers // Mendeleev Commun.//- 2018.-Vol. 28.- №2. - P.161–163. https://doi.org/10.1016/j.mencom.2018.03.017 Q2 (Scopus), IF=1,806 (WoS); Percentile 52 (Scopus). Citations 6.
Patent information	1. Suleimenov I. E., Kabdushev Sh. B., Kadyrzhan K. N., Baipakbayeva S. T., Mun G. A. Rotational Viscometer. // Patent of the Republic of Kazakhstan for Invention No. 36199 dated April 28, 2023. 2. Mun G. A., Baipakbayeva S. T., Kabdushev Sh. B., Kadyrzhan K. N., Kaldybekov D. B., Suleimenov I. E. Viscometer. // Patent of the Republic of Kazakhstan for Invention No. 36267 dated June 16, 2023. 3. Suleimenov I. E., Matrasulova D. K., Kabdushev Sh. B., Baipakbayeva S. T., Kaldybekov D. B., Kadyrzhan K. N., Mun G. A. Method for Measuring the Speed/Frequency of Object Rotation. // Patent of the Republic of Kazakhstan for Invention No. 36377 dated September 22, 2023. 4. Suleimenov I. E., Mun G. A., Shaltykova D. B., Kabdushev Sh. Method for Demineralization of Solutions. // Eurasian Patent No. 031763 dated February 28, 2019, Bulletin No. 06. 5. Mun G. A., Suleimenov I. E., Kabdushev Sh. B., Baipakbayeva S. T., Vitulova E. S., Evstifeev V. N. Method for Monitoring Air Pollution Levels. // Patent of the Republic of Kazakhstan for Invention No. 34612; published October 2, 2020, Bulletin No. 08. 6. Kabdushev Sh. B., Baipakbayeva S. T., Kopishev E. E., Suleimenov I. E., Mun G. A., Shaltykova D. B. Method for Measuring the Degree of Swelling of Polymeric Hydrogels. // Patent of the Republic of Kazakhstan for Invention No. 34670, dated November 6, 2020. 7. Kabdushev Sh. B., Baipakbayeva S. T., Shaltykova D. B., Mun G. A., Suleimenov I. E. Symbolic Information Input System. // Patent of the Republic of Kazakhstan for Invention No. 34497, dated August 7, 2020.