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# ILMIY AXBOROTNOMA

## НАУЧНЫЙ ВЕСТНИК
## SCIENTIFIC JOURNAL

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Matematika, Mexanika, Informatika
Fizika, Kimyo, Biologiya, Geografiya

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**Obuna indeksi** – yakka tartibdagi obunachilar uchun **- 5583,**
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**M U N D A R I J A**
**C O N T E N T S**


| № | Maqola nomi | Article title | Bet/ page |
|---|---|---|---|
| **1.** | Yuqori chastotali II-turdagi radio portlash spektral kuzatuvlaridan foydalanib magnit maydon kuchini baholash<br>**Pulatov D., Mirtoshev Z.** | Estimation Of The Coronal Magnetic Field Strength Using High-Frequency Type Ii Radio Burst Observations<br>**Pulatov D., Mirtoshev Z.** | **5-11** |
| **2.** | Rayxon (OCIMUM) o‘simligi efir moyi kimyoviy tarkibiga iqlim omillarining ta’sirini GX–MS usulida tadqiq etish<br>**Siddikova Y., Saifullaeva Sh., Mukhamadiyev A., N.Fazlieva, Nayimova B., Muhamadiyev N.** | Study of the influence of climate factors on the chemical composition of basil (ocimum) essential oil using the GH–MS method<br>**Siddikova Y., Saifullaeva Sh., Mukhamadiev A., N.Fazlieva, Nayimova B., Muhamadiev N.** | **12-20** |
| **3.** | Bentonitni montmorillonit bilan boyitishning samarali usullari va termal ishlov berishning kation almashinuvi quvvatiga ta'siri<br>**Mamadoliev I., Abdikamalova A., Ruzieva S.** | Effective methods for bentonite enrichment with montmorillonite and the impact of thermal treatment on cation exchange capacity<br>**Mamadoliev I., Abdikamalova A., Ruzieva S.** | **21-28** |
| **4.** | $KPbBr_3$ asosidagi peroled tuzilmalarida zaryad tashish mexanizmlari va energetik sathlarning moslashuvi<br>**Rahmonova M., Muxamadiyev N.** | Charge transport mechanisms and energy level alignment in $KPbBr_3$ -based peroled structures<br>**Rahmonova M., Mukhamadiev N.** | **29-36** |
| **5.** | *N*-(4-(((7-Nitroxinazolin-4-il) amino) metil)fenil) siklogeksankarboksamid sintezi<br>**Gaybullaev Sh., Takhirov Y., Chao Niu, Bozorov Kh.** | Synthesis of N-(4-(((7-nitroquinazolin-4-YL) amino) methyl) phenyl) cyclohexanecarboxamide<br>**Gaybullaev Sh., Takhirov Y., Chao Niu, Bozorov Kh.** | **37-41** |
| **6.** | 3-brom-pirido[2,3-*d*]pirimidinonlarning sintezi<br>**Khushnazarov Z., Turgunov D., Bozorov Kh.** | synthesis of 3-bromo-pyrido[2,3-d]pyrimidinones<br>**Khushnazarov Z., Turgunov D., Bozorov Kh.** | **42-46** |
| **7.** | Zarrachalar tezlatkichlarida materiallarning aktivatsiyasi va radiatsion xavflar<br>**Temirov J., Khasanov Sh., Safarov A., Karimberganova Q.** | Material activation and radiological hazards in particle accelerators<br>**Temirov J., Khasanov Sh., Safarov A., Karimberganova Q.** | **47-57** |
| **8.** | Geoinformatsion dasturlar yordamida demografik atlaslar yaratishning afzalliklariga nazar<br>**Tukhtamishev Sh., Khudoyarova Sh., Shirinboyev D.** | Advantages of creating demographic atlases using geoinformation software<br>**Tukhtamishev Sh., Khudoyarova Sh., Shirinboev D.** | **58-62** |
| **9.** | Siklopropilatsetilen asosida atsetilen spirtlari sintezi, ularning nazariy energetik xarakteristikalari va nadfoksidaza oqsili (7U8G) bilan molekulyar birikish tahlili<br>**Ziyadullaev M.E., Nurmanov S.E., Buriev F.Kh., Abdukhalikov F.J.** | Synthesis of acetylenic alcohols based on cyclopropylacetylene, their theoretical energetic characterization, and molecular docking analysis with nadph oxidase (7U8G) protein<br>**Ziyadullaev M.E., Nurmanov S.E., Buriev F.Kh., Abdukhalikov F.J.** | **63-71** |
| **10.** | Tetratsiklik tieno[3,2-*d*]pirimidinonlarning siklooksigenaza-2 ingibitorlari sifatida *in silico* tadqiqi<br>**Nasrullaev A., Buronov A., Gaybullaev Sh., Bozorov Kh.** | In silico evaluation of tetracyclic thieno[3,2-d]pyrimidinones as potential cyclooxygenase-2 inhibitors<br>**Nasrullaev A., Buronov A., Gaybullaev Sh., Bozorov Kh.** | **72-76** |
| **11.** | H3PO4, KOH va ZnCl2 yordamida olingan faollashtirilgan ko‘mirning morfologik va strukturaviy xususiyatlarining qiyosiy tahlili<br>**Ergasheva D., Mukhamadiyev A., Mukhamadiyev N., Uzokov J.** | Comparative analysis of the morphological and structural properties of activated carbon prepared using $H_3PO_4$, KOH, and $ZnCl_2$<br>**Ergasheva D., Mukhamadiev A., Mukhamadiev N., Uzokov J.** | **77-81** |
| **12.** | $CO_2$ NI quyosh nuri ta’sirida samarali konversiyalashni ta’minlovchi g-$C_3N_4$/$CoNi_2S_4$ geterotuzilmali nanomateriallar sintezi va fizik-kimyoviy xossalari<br>**Samiev A., Nizamov U.N., Mirzaev Sh., Ruzimuradov O., Nasimov A.** | Synthesis and physicochemical properties of γ-C3N4/CoNi2S4 heterostructured anomaterials providing efficient conversion of CO2 under the influence of sunlight<br>**Samiev A., Nizamov U.N., Mirzaev Sh., Ruzimuradov O., Nasimov A.** | **82-87** |

| № | Maqola nomi | Article title | Bet/ page |
|---|---|---|---|
| **13.** | Atrof muhitdagi ammiak mikrokensentratsiyasini monigitori uchun gibrid perovskit $MA_xFA_{1-x}PbI_3$ fluoressent sensori tayyorlash<br>**Eshmuradova G.B., Tashpulatov Kh.Sh., Khursandov J.M., Normuradov O.U., Norboyev Q.M., Toshpulatov D.T.** | Preparation of hybride perovskite $MA_xFA_{1-x}PbI_3$-fluorescent sensor for the monitoring of ammonia microconcentration in environment<br>**Eshmuradova G.B., Tashpulatov Kh.Sh., Khursandov J.M., Normuradov O.U., Norboev Q.M., Toshpulatov D.T.** | **88-92** |
| **14.** | $Al^{3+}$ bilan modifikatsiyalangan shpinel tuzilishga ega $Li_{1.33}Al_XMn_{1.67-X}O_4$ ($0 \leq x < 0.7$) tarkibli adsorbentlarning zol-gel sintezi va fizik-kimyoviy xossalari<br>**Begimkulova Sh.A., Nematova Sh.Sh., Baxriev I.S., Mirzaev Sh.E., Ruzimuradov O.N., Nasimov A.M.** | Sol-gel synthesis and physicochemical properties of adsorbents consisting of $Al^{3+}$ modified spinel structure $LI_{1.33}Al_XMn_{1.67-X}O_4$ ($0 \leq X < 0.7$)<br>**Begimkulova Sh.A., Nematova Sh.Sh., Baxriev I.S., Mirzaev Sh.E., Ruzimuradov O.N., Nasimov A.M.** | **93-99** |
| **15.** | CdCr2Se4 va CuCr4Se4 magnitli yarimo‘tkazgichda magnit-optik effektlar<br>**Dosmurodov G.**, **Kurbaniyazov A.**, **Boboqambarova G.** | Magneto-optical effects in the magnetic semiconductor CdCr2Se4 AND CuCr4Se4<br>**Dosmurodov G.**, **Kurbaniyazov A.**, **Bobokambarova G.** | **100-104** |
| **16.** | Sophora lehmanni va Cicer mogoltavikum o‘simliklari yer ustki qismilarining flavonoidlari<br>**Gafurov A.Zh, Botirov E. Kh.** | Flavonoids of aerial parts of sophora lehmannii and cicer mogoltavicum<br>**Gafurov A.Zh, Botirov E. Kh.** | **105-109** |
| **17.** | Buxoro viloyatining balneologik resurslari va ularning aholi salomatligini yaxshilashdagi ahamiyati<br>**Zaynutdinova D.K., Nematova Kh. Kh.** | Balneological resources of the bukhara region and their significance in improving public health<br>**Zaynutdinova D.K., Nematova Kh. Kh.** | **110-116** |
| **18.** | Tabiiy cho‘kuvchan gruntlarni polimer-kompozitsion eritmalar bilan inyeksion mustahkamlash texnologiyasini matematik rejalashtirish<br>**Bakhriyev N.F., Kholiqulov O.O., Nurmatova R.K.** | Mathematical planning of injection strengthening technology of natural collapsible soils using polymer-composite solutions<br>**Bakhriyev N.F., Kholikulov O.O., Nurmatova R.K.** | **117-125** |
| **19.** | Adgezion kontaktlarda ishqalanish koeffitsiyentiga geometrik parametrlar hamda tashqi yuk ta’sirining tahlili<br>**Bekmamatova G., Xoliqulov O., Tojinorov M.** | Analysis of geometric parameters and external load on the friction coefficient in adhesive contacts<br>**Bekmamatova G., Xolikulov O., Tojinorov M.** | **126-131** |
| **20.** | Markaziy Osiyo iqlim sharoitida sorbsion sovutgichlardan biogaz komplekslari bilan simbiozda foydalanish istiqbollari<br>**Abdusamiyev F., Bahriev S., Sattarov S.** | Prospects for using sorption refrigerators in symbiosis with biogas complexes in the climatic conditions of Central Asia<br>**Abdusamiev F., Bahriev S., Sattarov S.** | **132-136** |
| **21.** | Maple tizimida algebraik ko’pxilliklarni ratsional parametrlashining nazariy asoslari va kompyuterda amalga oshirilishi<br>**Usmonova N.** | Theoretical foundations and computer implementation of rational parameterization of algebraic manifolds in the maple system<br>**Usmonova N.** | **137-142** |
| **22.** | $Fe_5Ga_6Gd_2YZr$ ko‘p komponentli kristallining element tarkibi va tebranish xossalarini rentgen-fluoresans (XRF) va raman spektroskopiyasi yordamida tadqiq etish<br>**Nasirova N., Fayziyev Sh., Saidov Q., Qaxorova Sh., Sharipov M., Djuraev D.** | Investigation of the elemental composition and vibrational properties of the multicomponent crystal Fe5Ga6Gd2YZr using X-RAY fluorescence (XRF) and raman spectroscopy<br>**Nasirova N., Fayziyev Sh., Saidov Q., Qaxorova Sh., Sharipov M., Djuraev D.** | **143-152** |
| **23.** | Xofp tipidagi tenglamalar sistemasi uchun Koshi masalasi<br>**Erkinova D. A.**, **Imomnazarov Kh. Kh.** | Cauchy problem for a Hopf-type system<br>**Erkinova D. A.**, **Imomnazarov Kh. Kh.** | **153-157** |
| **24.** | Ar va HCl izotopologlari o‘rtasida hosil bo‘lgan komplekslarning kvant-kimyoviy tahlili: AIM, RDG va NCI usullari yordamida solvatatsiya effektlarini o‘rganish<br>**Khujamov U.** | Quantum-chemical analysis of complexes formed between Ar and HCL isotopologues: studying solvation effects using AIM, RDG, and NCI methods<br>**Khujamov U.** | **158-167** |

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# SOL-GEL SYNTHESIS AND PHYSICOCHEMICAL PROPERTIES OF ADSORBENTS CONSISTING OF $Al^{3+}$ MODIFIED SPINEL STRUCTURE $LI_{1.33}Al_XMn_{1.67-X}O_4$ ($0 \leq X < 0.7$)

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**Abstract.** In this work, samples with spinel structure $Li_{1.33}Al_xMn_{1.67-x}O_4$ ($0 \leq x < 0.7$) modified with $Al^{3+}$ were synthesized by sol-gel method. Conversion of $Li_{1.33}Al_xMn_{1.67-x}O_4$ samples to H-form was carried out in 0.1 M HCl solution (80.6 ml) at 25 °C and contact time of 24 h. The H-forms of the obtained adsorbents were washed with distilled water until neutral pH value was reached. $H_{1.33}Al_xMn_{1.67-x}O4$ samples showed conversion degree from 53 % to 79 %. X-ray diffraction analysis showed that doping with $Al^{3+}$ ions in the range ($0 \leq x < 0.5$) does not cause distortion of the crystal structure, and the diffraction patterns obtained after conversion to the H-form show a slight broadening of the peaks, indicating that the crystal structure is preserved. Doping with $Al^{3+}$ ions led to an increase in the lattice parameter α from 8.20 to 8.16Å.

**Keywords.** Spinel. H-form, adsorbent, Li ion, sol-gel, conversion rate.

## $Al^{3+}$ bilan modifikatsiyalangan shpinel tuzilishga ega $Li_{1.33}Al_XMn_{1.67-X}O_4$ ($0 \leq x < 0.7$) tarkibli adsorbentlarning zol-gel sintezi va fizik-kimyoviy xossalari

**Annotatsiya.** Ushbu ishda zol-gel usulida $Al^{3+}$ bilan modifikatsiyalangan shpinel tuzilishga ega $Li_{1.33}Al_xMn_{1.67-x}O_4$ ($0 \leq x < 0.7$) tarkibli namunalar sintez qilindi. $Li_{1.33}Al_xMn_{1.67-x}O_4$ namunalarini H-shakliga o‘tkazish 0,1 M HCl eritmasida (80,6 ml) 25 °C haroratda va 24 soatlik aloqa vaqtida amalga oshirildi. Olingan adsorbentlarning H-shakllari neytral pH qiymatiga yetguncha distillangan suv bilan yuvildi. $H_{1.33}Al_xMn_{1.67-x}O_4$ namunalari 53 % dan 79 % gacha konversiya darajasini ko‘rsatdi. Rentgen difraksiya tahlili shuni ko‘rsatdiki, ($0 \leq x < 0.5$) oralig‘ida $Al^{3+}$ ionlari bilan qo‘shilish kristall tuzilishining buzilishiga olib kelmaydi, H-shakliga o‘tkazilgandan so‘ng olingan difraksiya naqshlari cho‘qqilarning biroz kengayishini ko‘rsatadi, bu esa kristall tuzilishining saqlanib qolganligini ko‘rsatadi. $Al^{3+}$ ionlari bilan qo‘shilish panjara parametri a ning 8,20 dan 8,16 Å gacha oshishiga olib keldi.

**Kalit so‘zlar:** Shpinel. H-shakl, adsorbent, Li ion, zol-gel, konversiya darajasi.

## Золь-гель синтез и физико-химические свойства адсорбентов, состоящих из модифицированной $Al^{3+}$ шпинельной структуры $Li_{1.33}Al_XMn_{1.67-X}O_4$ ($0 \leq x < 0.7$)

**Аннотация.** В данной работе методом золь-геля были синтезированы образцы со шпинельной структурой $Li_{1.33}Al_xMn_{1.67-x}O_4$ ($0 \leq x < 0.7$), модифицированные $Al^{3+}$.

Превращение образцов $Li_{1.33}Al_xMn_{1.67-x}O_4$ в Н-форму проводилось в 0,1 М растворе HCl (80,6 мл) при 25 °C и времени контакта 24 ч. Н-формы полученных адсорбентов промывали дистиллированной водой до достижения нейтрального значения pH. Образцы $H_{1.33}Al_xMn_{1.67-x}O_4$ показали степень превращения от 53 % до 79 %. Рентгенодифракционный анализ показал, что легирование ионами $Al^{3+}$ в диапазоне ($0 \leq x < 0,5$) не вызывает искажения кристаллической структуры, а дифракционные картины, полученные после преобразования в Н-форму, показывают небольшое расширение пиков, что указывает на сохранение кристаллической структуры. Легирование ионами $Al^{3+}$ привело к увеличению параметра решетки α с 8,20 до 8,16 Å.

**Ключевые слова.** Шпинель, Н-форма, адсорбент, ионы лития, золь-гель, степень превращения.

**Introduction.** Today, as a result of the widespread use of high-energy devices and lithium-ion batteries in the world, the global demand for lithium in industry has increased sharply. This, combined with the limited and decreasing lithium resources in the Earth's crust, estimated at around 16.7 million tons, further increases the need to extract lithium from alternative sources. Due to the environmental and economic complexity of the lithium extraction process from traditional mines, current scientific research is aimed at developing methods for the effective extraction of lithium from saline lake waters and seawater. In particular, the use of Li-Mn-based sorption materials is considered one of the most promising technological solutions among such processes [1-2].

Inorganic adsorbents based on Li-Mn oxides are widely used for the purification of aqueous environments from heavy metal ions, radionuclides and organic pollutants. This is due to the unique and multifaceted nature of their crystal structure, which consists of layered (birnessite) and channel (cryptomelane, todorokite) structures forming $MnO_6$ octahedra with a defined void size in the range of 4-9 Å. Manganese oxides with a spinel structure have attracted particular attention as adsorbents. Among them, lithium-manganese spinels of the composition $LiMn_2O_4$, $Li_{1.6}Mn_{l.6}O_4$ and $Li_{1.33}Mn_{1.67}O_4$ are among the most promising materials for the selective adsorption of $Li^+$ ions from natural brines and process waters formed during the processing of lithium-ion batteries and supercapacitors [3-5]. Ion exchange materials based on lithium-manganese spinels are characterized by high adsorption capacity and selectivity for $Li^+$ ions. However, the low stability of the crystal structure during adsorption-desorption processes due to partial dissolution in acidic media and salinization of $Mn^{2+}$ ions into the solution is the main drawback that limits their widespread use [6-7].

According to the results of the research, $Al^{3+}$ ion is one of the most effective metal ions, because it is abundant, non-toxic, economically cheap and lighter than other transition metal elements [8]. $LiAl_xMn_{2-x}O_4$ ($x \leq 0.1$) spinel samples were synthesized by controlled crystallization and solid-phase method with a microspherical $Mn_3O_4$ precursor. It was found that the modification of $Al^{3+}$ ion does not change the spinel structure of the materials and the crystallinity of the particles is better [9]. Lin Li et al. synthesized spinel-structured $LiAl_xMn_{2-x}O_4$ by rheological phase reaction method [10]. Analysis of the X-ray diffraction results of the samples revealed that $LiAl_xMn_{2-x}O_4$ has better crystal parameters than pure $LiMn_2O_4$. Z. Cai et al. dissolved Mn, Li, and Al precursors with different stoichiometric ratios in alcohol and obtained Al-modified $LiAl_xMn_{2-x}O_4$ (x = 0.05, 0.10, and 0.16) spinel-structured materials [11]. In the studies, the morphological structure and physicochemical properties of Al-doped LMO samples were described in detail using X-ray diffraction (XRD) and scanning electron microscopy (SEM) methods. As a result of the studies, the bond lengths in the octahedral coordinated structures around the Al and Mn elements were determined, and the corresponding geometric parameters were calculated based on them. In the course of the calculations, light pseudopotential methods were used in the interaction zone to accurately reflect the nuclear and internal electronic states. This approach made it possible to accurately determine the electronic structure and bonding characteristics of the material. In our republic, scientific research is also being conducted on the synthesis of $Li_{1.33}Mg_xMn_{(1.67-x)}O_4$ ($0 \leq x < 0.8$) spinels using the sol-gel method and the study of the effect of modification with $Mg^{2+}$ ions on their textural properties [12-15].

The aim of this work is to study the synthesis patterns of Al-ion-modified $Li_{1.33}Mn_{1.67}O_4$ spinel and to identify the main factors affecting the phase composition, structure and adsorption properties of lithium-manganese adsorbents. $Li_{1.33}Mn_{1.67}O_4$ and $Li_{1.33}Al_xMn_{1.67-x}O_4$ spinel were prepared by sol-gel synthesis. All samples were calcined at 800°C for 6 hours to form the spinel structure.

**Research methodology.** $Li_{1.33}Al_xMn_{1.67-x}O_4$ samples were synthesized by the sol-gel method (Fig.1). The determined stoichiometric mass ratio of $LiNO_3$, $Al(NO_3)_3{\cdot}9H_2O$ and $Mn(NO_3)_2{\cdot}4H_2O$ salts was dissolved in 80 ml of distilled water (Table 1). In the next stage of the experimental process, a predetermined amount of citric acid ($C_6H_8O_8{\cdot}H_2O$) was completely dissolved in 80 ml of distilled water, and the prepared solution was added to the main mixture under uniform stirring conditions. The process was carried out for two hours with constant stirring.

**Table 1**

Masses of initial precursors in the formation of $Li_{1.33}Al_xMn_{1.67-x}O_4$ spinel samples (g).

| Sample | $LiNO_3$ | $Mn(NO_3)_2{\cdot}4H_2O$ | $Al(NO_3)_3{\cdot}9H_2O$ | $C_6H_8O_7{\cdot}H_2O$ |
|---|---|---|---|---|
| $Li_{1.33}Al_{0.1}Mn_{1.57}O_4$ | 0,734 | 3,052 | 0,260 | 5,04 |
| $Li_{1.33}Al_{0.3}Mn_{1.37}O_4$ | 0,734 | 2,663 | 0,780 | 5,04 |
| $Li_{1.33}Al_{0.5}Mn_{1.07}O_4$ | 0,734 | 2,081 | 1,302 | 5,04 |
| $Li_{1.33}Al_{0.7}Mn_{0.97}O_4$ | 0,734 | 1,886 | 1,822 | 5,04 |

This step is important to ensure a complete and efficient reaction between the reactants, as well as to maximize the stabilizing and temperature-increasing functions of citric acid.

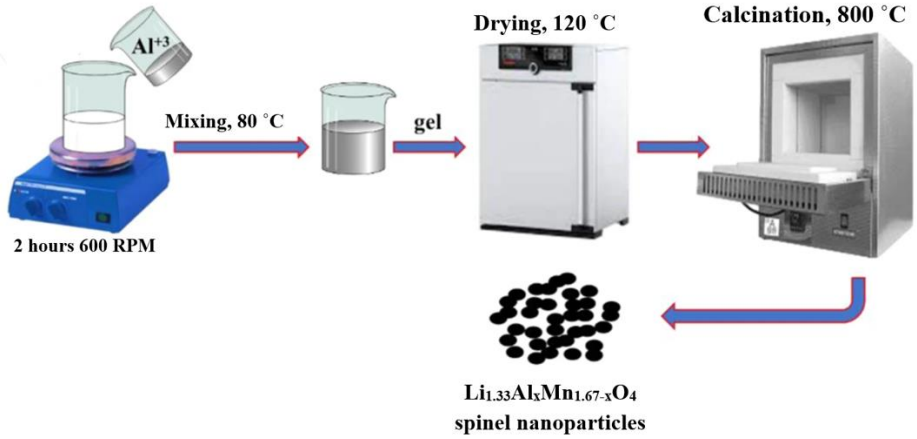


**Figure 1.** Synthesis of $Li_{1.33}Al_xMn_{1.67-x}O_4$ spinel nanoparticles by the sol-gel method.

After mixing, the solution was slowly evaporated at 80°C to remove water from the resulting solution and convert it into a denser, more concentrated phase. After the water evaporated, the remaining mixture was dried at 120°C to a dry state with a dense and uniform structure. This dried mixture was carefully ground using a mortar and pestle to a powder with uniform grain size. Then, the resulting dry powder was calcined at 800°C for 6 hours to completely remove organic components from the composition and form the desired phase. At this stage, all organic residues decomposed and the crystal structure of the product was formed. The resulting samples with a spinel structure were classified according to the formula $Li_{1.33}Al_xMn_{1.67-x}O_4$, where the x value was 0.1, 0.3, 0.5 and 0.7.

**Analysis results.** The elemental composition of the $Li_{1.33}Al_xMn_{1.67-x}O_4$ spinel samples was analyzed to show that the aluminum ion was introduced into the sample in proportion to the amount in the initial precursor (Table 2). The X-ray fluorescence spectrometer results also confirmed that the aluminum and manganese elements corresponded to the introduced ratio. In particular, the intensity of the aluminum ions was observed to be consistent with the concentration in the sample, while the Kα line of manganese ions exhibited high intensity, indicating that it quantitatively dominates the spinel composition. These results prove that the element distribution during the spinel synthesis process is precisely controlled and its final composition is close to the predetermined ratio.

**Table 2**

Al and Mn content (mass, %) in $Li_{1.33}Al_xMn_{1.67-x}O_4$ spinel samples

| Sample | Al content (mass, %) | Mn content (mass, %) |
|---|---|---|

| | | |
|---|---|---|
| $Li_{1.33}Al_{0.1}Mn_{1.57}O_4$ | 4,12 | 95,88 |
| $Li_{1.33}Al_{0.3}Mn_{1.37}O_4$ | 9,88 | 90,12 |
| $Li_{1.33}Al_{0.5}Mn_{1.07}O_4$ | 15,82 | 84,18 |
| $Li_{1.33}Al_{0.7}Mn_{0.97}O_4$ | 21,60 | 78,40 |

As can be seen from this table, the mass ratio of the initial Al and Mn precursors is almost preserved in the synthesized $Li_{1.33}Al_xMn_{1.67-x}O_4$ spinel samples. This confirms that the ratio of elements did not undergo significant changes during the synthesis process. Also, Figure 2 presents the results of X-ray fluorescence spectrometry analysis of the synthesized $Li_{1.33}Al_xMn_{1.67-x}O_4$ spinel sample, which allows for a deeper study of the elemental composition of the sample.

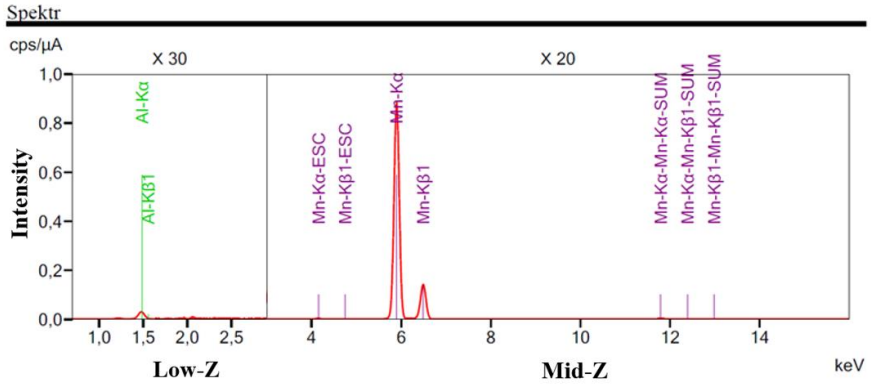


**Figure 2.** X-ray fluorescence spectrum of the $Li_{1.33}Al_{0.3}Mn_{1.37}O_4$ spinel sample.

According to the analysis results, the intensity of the Kα line of the Al element was observed in the low-energy region around 1.5 keV. Manganese appeared in the medium-energy region, and its Kα and Kβ1 lines were determined in the range of 5.0–7.0 keV. In particular, the high intensity of the Kα line of manganese is associated with the presence of this element in a high concentration in the spinel sample. These conclusions are consistent with the structural analysis data in Table 2.

The X-ray diffraction spectra of $Li_{1.33}Al_xMn_{1.67-x}O_4$ samples were compared as a function of $Al^{3+}$ concentration. The X-ray phase results of $Li_{1.33}Mn_{1.67}O_4$ and $Li_{1.33}Al_xMn_{1.67-x}O_4$ samples showed that all the diffraction peaks correspond to the cubic spinel structure of $Li_{1.33}Mn_{1.67}O_4$. All the main diffraction peaks were recorded for the (111), (311), (222), (400), (331), (511), (440), (531) planes. These results confirm that the space group of the spinel structure corresponds to Fd3m and are consistent with the standard database PDF 2 # 35-0782. No new phases were formed in the X-ray patterns as a result of the addition of $Al^{3+}$ ion to the spinel structure of $Li_{1.33}Mn_{1.67}O_4$. This indicates the structural stability of the spinel phase. Also, slight differences in unit cell parameters were observed with increasing $Al^{3+}$ concentration. This is explained by the partial substitution of $Al^{3+}$ ions for $Mn^{3+}$ or $Mn^{4+}$ ions.

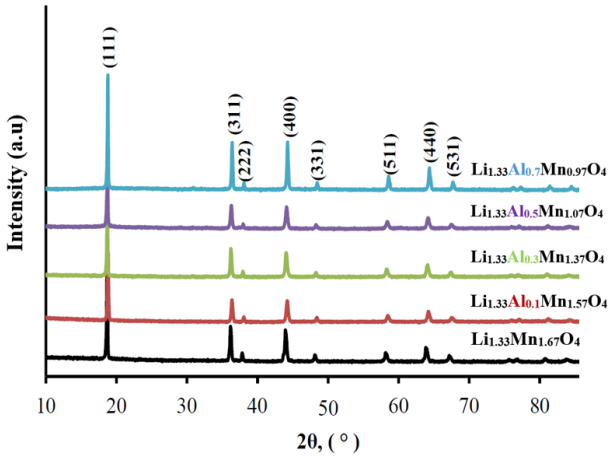


**Figure 3.** X-ray diffraction patterns of spinel samples $Li_{1.33}Mn_{1.67}O_4$ and $Li_{1.33}Al_xMn_{1.67-x}O_4$ ($0 \le x \le 0.7$).

According to the results of the study, several high-intensity vibrational bands were observed in the IR spectra of the samples before calcination in the region from approximately 1200 $cm^{-1}$ to 3500

$cm^{-1}$ (Fig. 4).

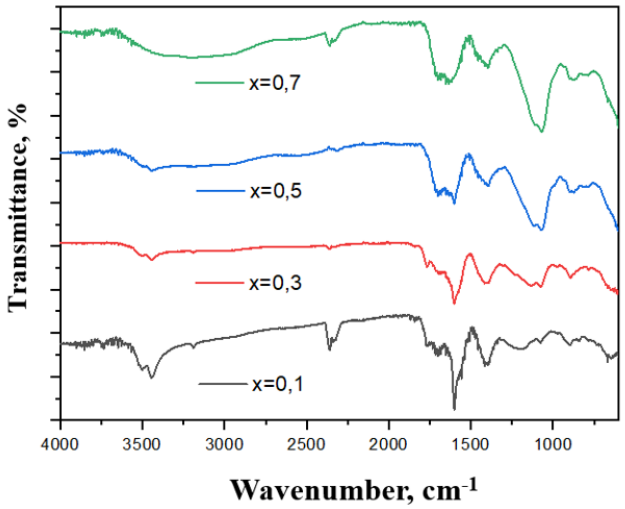


**Figure 4.** IR spectra of samples before calcination to form $Li_{1.33}Al_xMn_{1.67-x}O_4$ ($0 \leq x \leq 0.7$) spinel.

These bands indicate that the initial precursors are rich in functional groups and are important spectral features reflecting their chemical composition and bonding properties. Such vibrational frequencies can also represent the interaction of organic and inorganic components. These data also help to understand the phase changes and structural modifications that occur during the synthesis process. After the calcination process, the disappearance or significant reduction of these vibrational bands is associated with the formation of the spinel structure. The IR spectra of the samples after the calcination process to form $Li_{1.33}Al_xMn_{1.67-x}O_4$ spinels show three distinct peaks in different wavelength regions (Fig. 5).

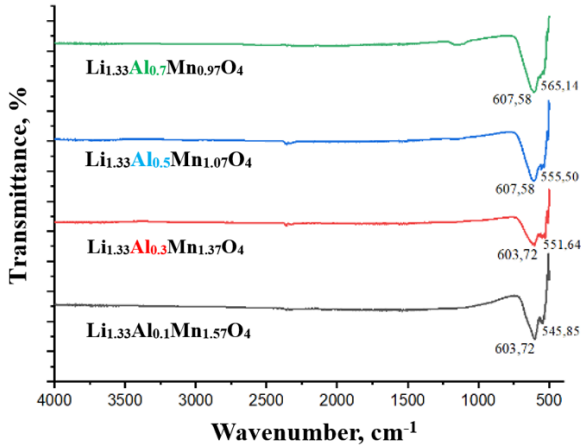


**Figure 5.** IR spectra of samples after calcination to form $Li_{1.33}Al_xMn_{1.67-x}O_4$ ($0 \leq x \leq 0.7$) spinels.

Two strong frequency bands appear between wavenumbers of approximately 540 and 600 $cm^{-1}$. These frequency bands are evidence for the formation of spinel with the $Li_{1.33}Mn_{1.67}O_4$ structure and are associated with the asymmetric stretching modes of Li–Mn–O. There is a small shift of the two peaks towards lower wavenumbers of 540 and 600 $cm^{-1}$ depending on the amount of $Al^{3+}$ ion introduced. The advantages of octahedral arrangement of the co-doped cations are clearly shown by these peaks. The decrease in wavenumber is observed to be associated with the expansion of the site radius. This shift is associated with the presence of asymmetric stretching modes in Li-Al-Mn-O. Also, the high-intensity peak observed around 1100 $cm^{-1}$ in the $Li_{1.33}Al_xMn_{1.67-x}O_4$ spinel samples is attributed to Li-O vibrations, confirming that lithium ions form strong bonds in the spinel structure.

The Raman shifts of $Li_{1.33}Al_xMn_{1.67-x}O_4$ samples synthesized by $Al^{3+}$ modification of $Li_{1.33}Mn_{1.67}O_4$ spinel samples were studied in the spectral range from 100 to 2000 $cm^{-1}$ (Fig. 6).

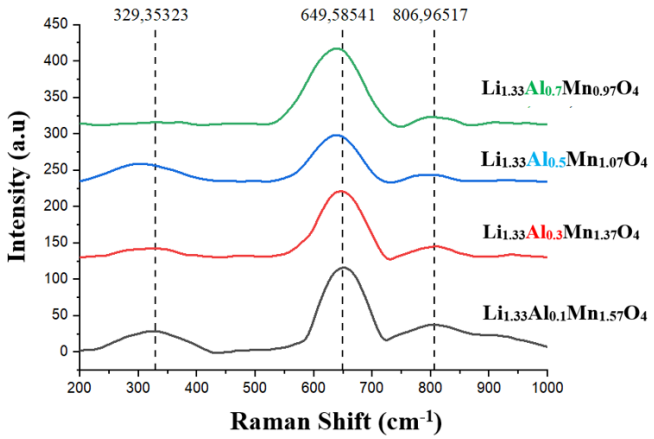


**Figure 6.** Raman shift spectra of $Li_{1.33}Al_xMn_{1.67-x}O_4$ ($0 \le x \le 0.7$) spinel samples.

The results obtained using Raman spectroscopy showed high-intensity peaks at 630-660 $cm^{-1}$, which reflect high-energy vibrations in the crystal structure of the material. These vibrations are due to changes in the Mn-O bonds, indicating a change in their arrangement and symmetry after the introduction of $Al^{3+}$ ions. Two smaller Raman shift peaks were also observed at wavenumbers of 310-370 $cm^{-1}$. These peaks represent changes in the structure of the material after the introduction of $Al^{3+}$ ions and vibrations caused by the interaction of $Mn^{3+}$ or $Mn^{4+}$ ions, which create new vibrational properties. The introduction of $Al^{3+}$ also affects the intensity and location of these shifts by changing the effects of $Mn^{3+}$ and $Mn^{4+}$ ions. In addition, the observation of a slightly higher Raman shift at 1000 $cm^{-1}$ for $Li_{1.33}Al_{0.5}Mn_{1.07}O_4$ and $Li_{1.33}Al_{0.7}Mn_{0.97}O_4$ corresponds to the vibration of the Li-O bond and reveals the high-energy vibrational properties of the $Li_{1.33}Al_xMn_{1.67-x}O_4$ spinel. This shift is associated with the structural stability of the resulting material and the improvement of its electrochemical properties.

The H-form of the obtained adsorbents was obtained by treating lithium manganese oxide with 0.1 M HCl solution at 25°C for 24 h. In $Li_{1.33}Al_xMn_{1.67-x}O_4$ oxides, a transition to the H-form was observed, while the dissolution of $Mn^{2+}$ ions exceeded 3.7%, and the dissolution of $Al^{3+}$ ions was 4.5 times lower. It should be noted that for Al-welded samples, a decrease in the H-form transition was observed in the range $0.1 < x < 0.5$, and a further increase in the H-form transition was observed at $x = 0.7$. This may be due to the disruption of the spinel structure (Fig. 7).

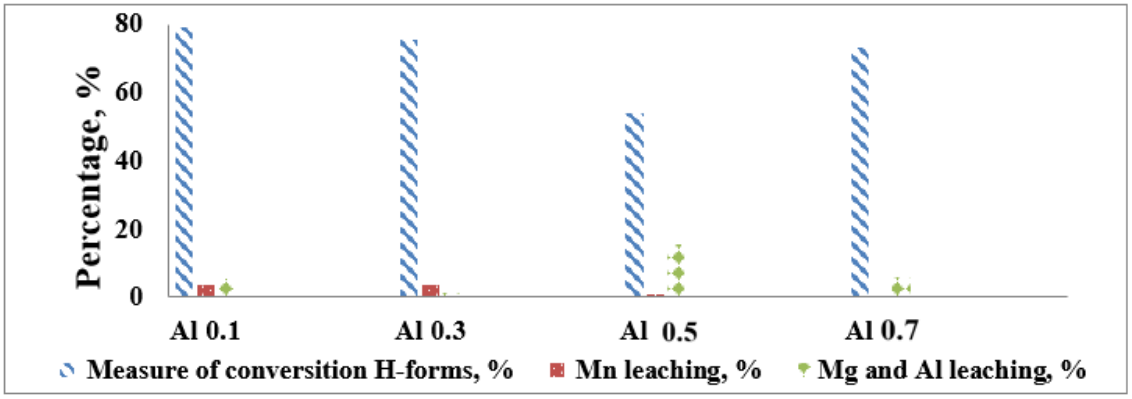


**Figure 7.** Percentage of H-form conversion and dissolution of metal ions of $Li_{1.33}Al_xMn_{1.67-x}O_4$ samples.

**Conclusions.** The effect of synthesis method and processing temperature on the crystal structure and phase composition of $Li_{1.33}Al_xMn_{1.67-x}O_4$ spinel samples was studied. The samples obtained by the sol-gel method at 800 °C were found to be single-phase. During the synthesis of Li-Mn-based spinels, an increase in the average crystal size was observed with an increase in $Al^{3+}$ ($0 \le x \le 0.7$). According to the results of X-ray phase analysis, all spinel samples had an octahedral structure and were compared with the existing database. The removal of functional groups in the initial precursor during the calcination process was proven by the absence of them in the IR spectra of Li-Mn

spinels. The fact that the amount of $Al^{3+}$ ions introduced was consistent with the amount of Mn and Al in the resulting Li-Mn spinels was proven by the results of X-ray fluorescence spectrometry analysis.

The resulting adsorbents are used in multiple cycles of adsorption-desorption of $Li^+$ ions to further substantiate the prospects for their practical use.

**References**


1. Sagzhanov D. et al. The Role of Sustainable Lithium Processing in Renewable Energy Development: A Comprehensive Review and the Potential of Kazakhstan Deposits //Sustainability. – 2025. – Т. 17. – №. 13. – P. 5903.
2. Begimqulova S. et al. Zol-gel usulida olingan $LiAl_xMn_{(2-x)}O_4$ ($0 \leq x \leq 0.7$) adsorbentlarda litiy ionlarining adsorbsiyasini o‘rganish //«ACTA NUUz». – 2024. – Т. 3. – №. 3.1. – С. 353-357.
3. Tian, L., Liu, Y., Tang, P., Yang, Y., Wang, X., Chen, T., ... & Liu, B. (2022). Lithium extraction from shale gas flowback and produced water using $H_{1.33}Mn_{1.67}O_4$ adsorbent. Resources, Conservation and Recycling, 185, 106476.
4. Weng, D., Duan, H., Hou, Y., Huo, J., Chen, L., Zhang, F., & Wang, J. (2020). Introduction of manganese based lithium-ion Sieve-A review. Progress in Natural Science: Materials International, 30(2), 139-152.
5. Begimkulova, S. A., Nasimov, A. M., Ruzimuradov, O. N., Prozorovich, V. G., & Ivanets, A. I. (2024). Sol-Gel Synthesis, Structure, and Adsorption Properties of $LiMg_xMn_{(2-x)}O_4$ ($0 \leq x \leq 0.7$) Oxides. Russian Journal of Inorganic Chemistry, 69(4), 520-527.
6. Bao, L. R., Zhang, J. Z., Tang, W. P., & Sun, S. Y. (2023). Synthesis and adsorption properties of metal oxide-coated lithium ion-sieve from salt lake brine. Desalination, 546, 116196.
7. Disu, B., Rafati, R., Sharifi Haddad, A., & Muirhead, D. (2025). Maximizing Lithium Adsorption and Selectivity on Manganese-Based Ion Sieves: Effects of Thermal Treatment, Acid Content, and Operating Conditions. Industrial & Engineering Chemistry Research, 64 (24), 11961-11980.
8. Elia, G. A., Kravchyk, K. V., Kovalenko, M. V., Chacón, J., Holland, A., & Wills, R. G. (2021). An overview and prospective on Al and Al-ion battery technologies. Journal of Power Sources, 481, 228870.
9. Tao-Xiong, X. I. E., Peng-Wen, R. E. N., Lin-Yu, Y. U., Wei, L. I., & Hao-Jie, D. E. N. G. (2022). Optimization of $Al^{3+}$ Doping on the Microstructure and Electrochemical Performance of Spinel $LiMn_2O_4$①. Chinese Journal of Structural Chemistry, 41(2), 2202168-2202175.
10. Li, L., Zheng, W., Zhao, R., & Cheng, J. (2020, February). Effect of $Al^{3+}$ Doping on the Properties of $LiMn_2O_4$ Cathode Material. In IOP Conference Series: Earth and Environmental Science (Vol. 440, No. 2, p. 022076). IOP Publishing.
11. Cai, Z., Ma, Y., Huang, X., Yan, X., Yu, Z., Zhang, S., ... & Yang, W. (2020). High electrochemical stability Al-doped spinel $LiMn_2O_4$ cathode material for Li-ion batteries. Journal of Energy Storage, 27, 101036.
12. Zhu, A., Li, D., Bao, L., Gao, Z., Xue, M., Chu, H., & Wei, H. (2026). Enhancing cyclic stability of $LiMn_2O_4$ in lithium extraction by electrosorption through synergistic doping/coating engineering. Chemical Engineering Journal, 173297.
13. Hlungwani, D., Ledwaba, R. S., & Ngoepe, P. E. (2022). First-principles study on the effect of Lithiation in spinel $Li_xMn_2O_4$ ($0 \leq x \leq 1$) structure: calibration of CASTEP and ONETEP simulation codes. Materials, 15(16), 5678.
14. Ivanets, A. I., Razumovskaya, D. V., Prozorovich, V. G., & Kouznetsova, T. F. (2024). Determination of structure stability and adsorption performance of $Li_{1.33}Mn_{1.67}O_4$ adsorbents. Mendeleev Communications, 34(3), 436-439.

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