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## Section 1. Biology

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### AN ANALYSIS OF A HALF-CENTURY SCIENTIFIC PAPERS ON LEONURUS L. GENUS IS STUDIED IN THE WORLD: A REVIEW OF PAPERS FROM THE SCOPUS DATABASE PUBLISHED IN ENGLISH FOR THE PERIOD OF 1968–2023

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#### Abstract

In this article the review of papers of the *Leonurus* L. genus in the Scopus database for a half century, that is, from 1968 to 2023 is analyzed. For 55 years, 183 articles were published by 160 authors from 36 countries on the genus *Leonurus* L. and its promising species. About the species belonging to the genus *Leonurus* L., very few articles were published between 1968–2002, and between 2003–2008, 2–5 articles were published per year. During the years 2009–2023, 163 articles were published about the *Leonurus* genus, and this figure was 89% of the publications published for 55 years worldwide. 157 articles were published in 144 scientific journals about representatives of this category. Moreover, top 10 journals that have published the most articles on *Leonurus* L. genus plant species for 55 years, analytical results on Top-cited articles on motherwort, information on 160 authors who have studied motherwort in various directions, analysis of publications by countries and their organizations explained. The results of the research shows that the Chinese state ranks are the first in terms of funding and publication of articles. It is followed by Russian Federation (27; 16.54%), United States (11; 6.75%), South Korea (9; 5.52%), Iran (7; 4.29%), Germany (6; 3.68%), Lithuania (6; 3.68%), United Kingdom (6; 3.68%), and Australia (5; 3.06%), which are the countries with the top publications in terms of number of articles.

**Keywords:** *Leonurus* L., motherwort, top journals, Scopus database, medical plants

#### Introduction

This family is one of the largest and most distinctive families of flowering plants, with about 220 genera and almost 4000 species

worldwide. The last taxonomic revision of the Lamiaceae family was published in 2004 (Harley & et al., 2004). One of the families rich in medicinal, aromatic and essential oil

plants in the flora of Uzbekistan is the family of mints (Labiatae Juss.; Lamiaceae Lindley), which consists of 3,500 species belonging to 200 genera worldwide. There are 464 species belonging to 53 genera in the flora of Central Asia. 41 genera and 206 species of plants belonging to this family grow in the flora of Uzbekistan (Arabova, 2019). According to a recent classification of flowering plants, the family is divided into 12 subfamilies (Li & Olmstead, 2017) and consists of 236 genera and 7203 species. Of those, 3675 species from 105 genera (more than 50% of the Lamiaceae family) belong to the subfamily Nepetoideae (Brahmi & et al., 2017). Plant species from the Lamiaceae The genus *Leonurus* L. (subfamily: Lamioideae) comprises 25 species (Huang & et al, 2015), and four of them are reported in Central Asia (Tulaganova, 1987). Representatives of Lamioideae are characterized by the presence of iridoid glycosides and a lower essential oil content (Erdtman, 1945). Motherwort (*Leonurus cardiaca* L.) is a plant species belonging to the order Lamiales, labia families – Labiatae. Folk names are: goose foot, lion’s tail, lion’s heart, wolf’s foot. Motherwort is a perennial, i.e., a perennial plant that grows to approx. 150 cm in height. Branched stems grow from a short horizontal rhizome, which are roughly hairy, four-angular, furrowed, red-purple in color, hollow inside. Serrated leaves with long petioles are located opposite. The top part of the leaf is dark green, while the underside is lighter, both sides are covered with hairs (Medical College, The University of Rzeszów, Rzeszów, Poland. 2021). Plants belonging to the genus *Leonurus*, also named motherwort, are traditionally used for anti-gynecological disorders in East Asia, and for sedatives in Europe. Chemical investigation of the genus *Leonurus* not only enriched the natural products library, but also enlarged the pharmacological application of this traditional herb (Zhang & et al., 2018). Leonurin increases the maturation of oocytes of large-horned cattle and the subsequent embryonic development for the reduction of oxidative stress and the increase of mitochondrial function. According to the results of scientific research conducted by Ara Tachjian and others (2010), Motherwort has a long history of use in both European and Asian tradition-

al medicine because of its purported sedative and antispasmodic properties. Traditionally, it has been used for “cardiac debility,” tachycardia, anxiety, insomnia, and amenorrhea. It is also used as a hypotensive and a diuretic. When administered intravenously, motherwort reduces platelets aggregation and fibrinogen levels. It potentiates antithrombotic and antiplatelet effects and increases the risk of bleeding. Taken with benzodiazepines, motherwort can have a synergistic sedative effect and may result in coma (Tachjian & et al., 2010).

Many types of the genus *Leonurus* L. (sem. Lamiaceae) have medicinal properties: in European medicine, the herb *Leonurus cardiaca* L. (cardiac pustyrnica) is used for nerve and heart pain, rasstroystvax pishchevarenia, amenorrhoea, and also externally (Wojtyniak, & et al., 2012). In modern medicine, preparations of the herb pustyrnica are taken as a neuro – and cardioprotective agent, the action of which is provided by a rich composition of biologically active substances (Ritter & et al., 2010; Rastogi & et al, 2016). Analogous action on the cardiovascular system is noted for the plant of Chinese folk medicine *Leonurus japonicus* Houtt (Zhao, et al., 2011). The plant of Mongolian folk medicine – *Leonurus sibiricus* L. – is used in the treatment of type 2 diabetes (Schmidt & et al, 2013), on takje obladaet antibacterial activity (Ahmed & et al, 2006). As a traditional medicine, the aerial parts of *Leonurus japonicus* Houtt. (Lamiaceae), aka motherwort, have been extensively used to treat gynecological diseases. The current study was designed to investigate the longevity properties of the methanolic extract of *L. japonicus* (MLJ) using *Caenorhabditis elegans* model system (Yang & et al., 2016).

Herba Leonuri, also named Chinese Motherwort, has been extensively investigated as an effective agent on the uterus system. Our group has been studying the natural products of Herba Leonuri for several years, and during this period, many biological activities of the drug were recognized. Leonurine (4-guanidino-Nbutyl- syringate) is an alkaloid present in Herba Leonuri. Recently, growing evidence has highlighted the therapeutic potential of leonurine in multiple diseases, especially cardiovascular. In this review, we discuss the biological activ-

ities of leonurine, also latest improvements including this alkaloid (Zhao & et al., 2022). *Leonurus japonicus* Houtt. (Motherwort) is the fresh or dried aerial part of *Leonurus japonicus* Houtt. (Labiaceae), which is widely used in clinical practice and daily life, used to treat gynecological diseases. However, the differences between different parts, single index component in Pharmacopoeias and the less stability of active ingredients affect its clinical efficacy. This study aimed to find the multi-active compounds between different parts of Motherwort to ensure its clinical efficacy, which related to stability and had pharmacokinetic behavior. Firstly, HPLC-Q-TOF-MS/MS was used to analyze the components in vitro and in vivo, as well as multivariate statistical analysis and network pharmacology analysis was conducted to find the significant different components related to activity. Secondly, the content determination methods were established to study the stability of effective components during storage in order to establish the content limit for quality control of Motherwort. Thirdly, UFLC-MS/MS was used to analyze the pharmacokinetic behavior of active components in Motherwort. The results showed that a total of 131 chemical constituents were identified in vitro and 21 prototype absorption compounds and 72 metabolites were found in vivo. Meantime, multivariate statistical analysis and network pharmacology analysis was combined to find that leonurine, stachydrine and trigonelline were activity-related substance, which could be used

as active components related to pharmacodynamics in different parts. Then the stability variation trend and content limit of three alkaloids were found, which could be used for the quality control of Motherwort. Furthermore, the results showed that three alkaloids had pharmacokinetic behavior in vivo. 3 alkaloids were screened, which could be used as active components most closely related to pharmacodynamics among different parts. The stable stage, assay tolerance and pharmacokinetic characteristics were studied by the active substances, which could provide a basis for quality control and clinical medication of Motherwort (Zhao & et al., 2022).

### Methods

In this article, we went to the selection of publications on world-wide known researches. The search collects academic literature in English and Russian languages retrieved from the Scopus database for the period of 1968–2023. 199 materials were downloaded from the Scopus database on 9.11.2023. 184 of them were in English, and the remaining 15 were in Russian. We have removed 2 identical articles (deduplication) and removed sources that are not related to our topic. That is, 15 English articles about the plant *Leonotis Leonurus*, *Leonurus* and *Leonotis* are completely different genera, *Leonurus* L series is the topic we are going to analyze. Also, 1 Russian source was removed (deduplication). As a result, we processed 183 publications.

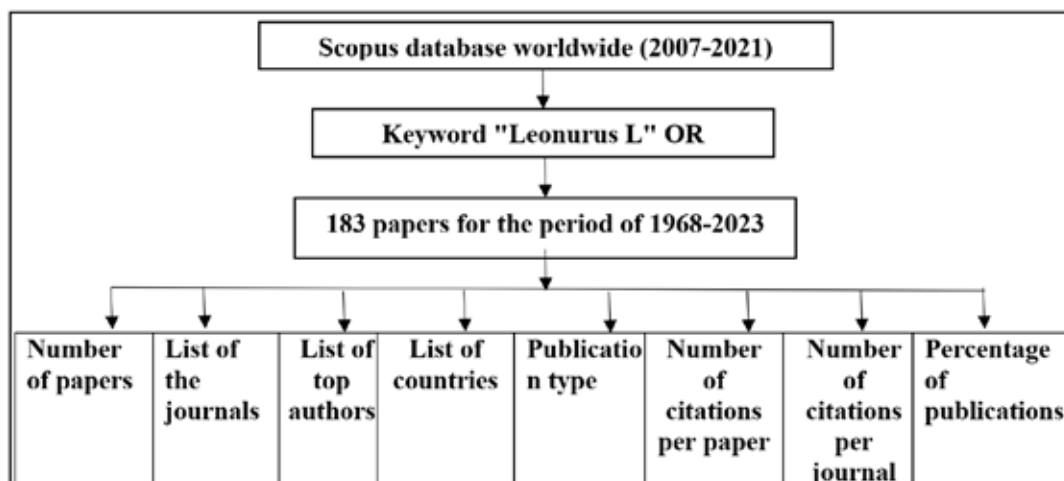
**Table 1.**

Nº	article	Conference paper	review
Doctype exclusions	14 English 13, Russian 1	1	1
Revised Doctype	157	19	6

In the next step, articles were categorized according to year of publication. A data base of all peer-reviewed papers was then created, including the year of publication, authors' names, countries, publication type, journal name, number of citations per paper, the number of citations per journal, the percentage of publications by the topic cluster name and subject area. The analysis was performed using CSV file, Microsoft Excel 2021,

RIS, VOS viewer. Figure 1 shows the flow of the selected methodology for the research. The reasons for our use of the methods mentioned above are related to Scopus, a well-known database that collects authoritative literature from around the world, especially on irrigation and drainage systems. English is a universal language, therefore, the literature in English is more standard and meaningful than literature in other languages.

**Figure 1.** Flowchart of the methodology



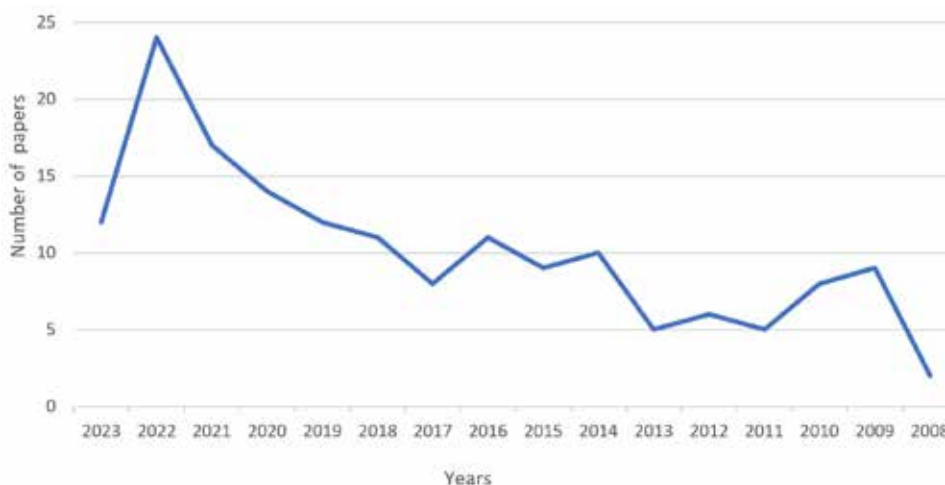
## 1. Results and discussion

### 1.1. Trends of publications on *Leonurus* genus

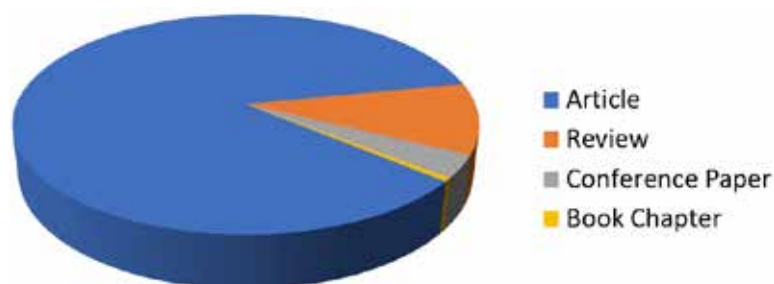
As a result of our research, 160 authors from 36 countries published 183 articles from 1968 to 2023. Between 1968 and 2002, 1 or 2 articles were published about species belonging to the genus *Leonurus*. By 2003, interest in this genus, rich in medicinal plants, began to increase, and 5 articles were published that year. During the period from 2004 to 2008, it was observed that the publication of articles decreased. Figure 2 shows the number of articles published between 2008 and 2023. When we analyze these years, 163 articles on the genus *Leonurus* were published during 16 years, which is 89% of the publications published during 55 years worldwide. 2008 was the year with the fewest articles published, 2 (163 articles taken as 100%,

1.09%), 9 (5.52%) in 2009, 8 (4.91%) in 2010, 5 (3.07%) in 2011, 6 (3.68%) in 2012, 5 (3.07%) in 2013, 10 (6.13%) in 2014, 9 (5, 52%), 11 (6.75%) in 2016, 8 (4.91%) articles by 2017, 11 (6.75%) in 2018, 12 (7.36%) in 2019, 14 (8.59%) in 2020, 17 (10.43%) in 2021, the publication of articles peaked in 2022 and reached 24 (14.72%), by 2023 the publication of articles decreased to 12 (7.36%) (Figure 2). During the years 1968–2023, 183 articles were published about the species of plants belonging to the genus *Leonurus*, of which 157 (85.79%) were articles published in journals as the results of scientific research, and 19 (10.38%) articles were reviews, (literature review) materials, 6 (3.28%) consist of conference materials, and the remaining 1 publication is covered as a Book Chapter (Figure 3). 7.65% of 183 articles are published in Russian.

**Figure 2.** Number of papers on *Leonurus* genus by the year of publication issues in the world



**Figure 3.** *Publication type on Leonurus genus issues in the world*

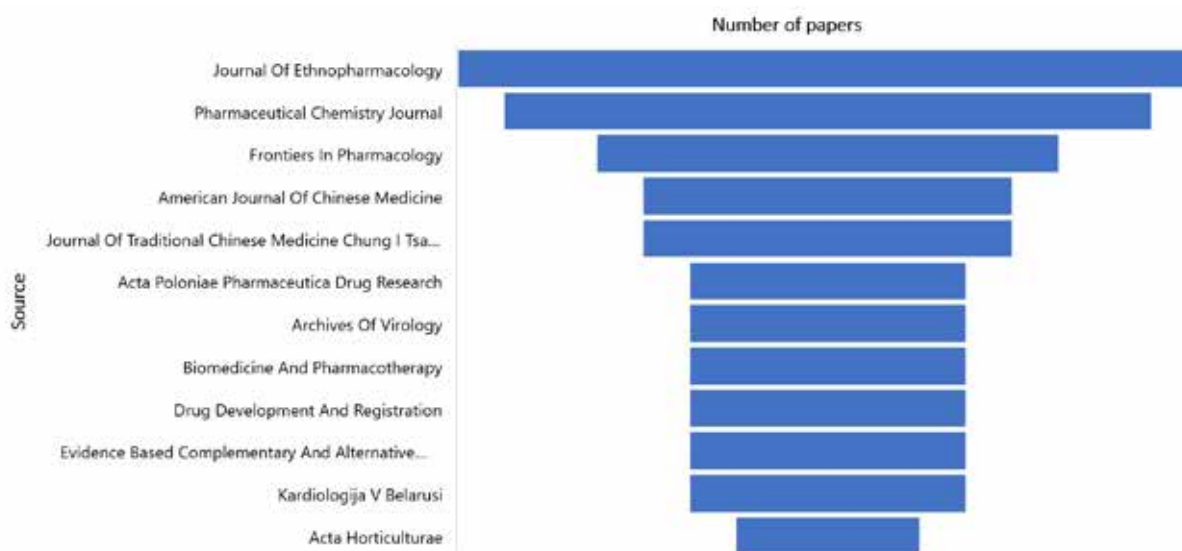


## 2. Journals on Leonurus genus

A wide range of journals in various parts of the world are used by scholars to publish their research. The communication patterns of the scholars specify that the total output was distributed across 144 journals published in 36 countries. Among them, 9

magazines published the results of scientific research in Russian. During these years, 157 (100%) articles were published in 144 journals, of which 15.29% of articles were published in 12 top journals (Figure 4) and remaining 84.71% of papers were published in other journals (Figure 4).

**Figure 4.** *Top journals on Leonurus genus by the year of publication issues in the world*



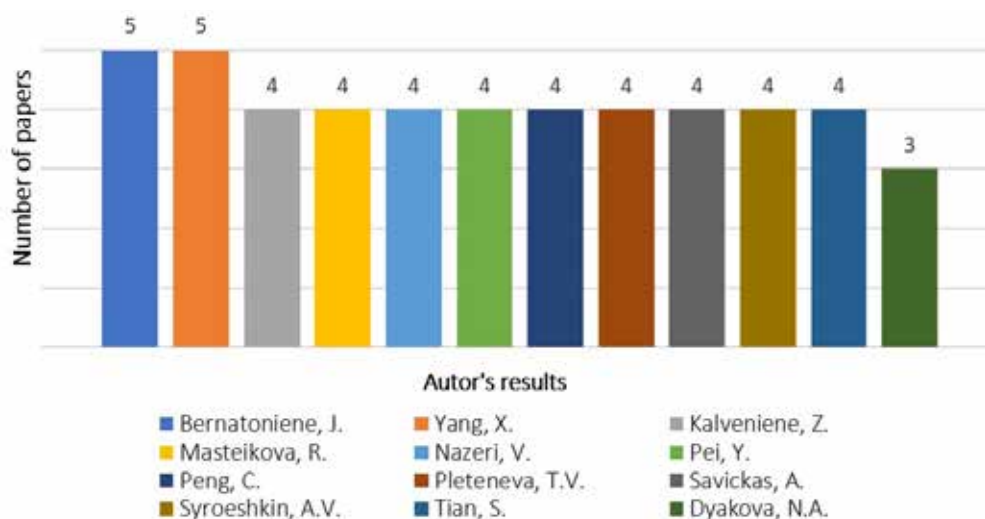
In some sense, among the top 12 journals that have published the most articles on *Leonurus* genus plant species during these 55 years, the Journal Of Ethnopharmacology takes pride of place with 8 articles, the Journal of Pharmaceutical Chemistry comes second with 7 articles, and the rest of the journals are: Frontiers In Pharmacology (5), American Journal Of Chinese Medicine (4), Journal Of Traditional Chinese Medicine Chung I Tsa Chih Ying Wen Pan sponsored by All China Association Of Traditional Chinese Medicine Academy Of Traditional Chinese Medicine (4), Acta Poloniae Pharmaceutica Drug Research (3), Archives Of Virology (3), Biomedicine And Pharmaco-

therapy (3), Drug Development And Registration (3), Evidence Based Complementary And Alternative Medicine (3), Kardiologija V Belarusi (3), Acta Horticulturae (2) (Figure 4). In addition, among these top magazines, there are 2 magazines that published articles in Russian, which accounted for 25% of the total publication (compared to 12 magazines).

## 3. Authors and their affiliated country

Our research revealed that 160 authors from 36 countries conducted research on *Leonurus* genus during 1968–2023. Figure 5 analyzes the results of scientific research of 12 authors who published the most articles.

**Figure 5.** Top authors on *Leonurus* genus by the year of publication issues in the world



Regarding top-cited articles on motherwort, the article by Ara Tachjian, Viqar Maria and Arshad Jahangir took the first place with 316 (compared to 9.11.2023) cytiruemia, Elizabeth A. Mazzio and Karam F.A. Soliman’s In vitro screening for the tumoricidal properties of international medicinal herbs article is on the 2<sup>nd</sup> place with 130

cytiruemia, Xiaofei Shang, Hu Pan, Xuezhong Wang, Hua He, Maoxing Li’s *Leonurus japonicus* Houtt: Ethnopharmacology, phytochemistry and pharmacology of an important traditional Chinese medicine is on the 3<sup>rd</sup> place with 106 cytiruemia is standing. Table 1 shows the top 10 articles and their authors.

**Table 1.** List of the Top-cited articles on motherwort

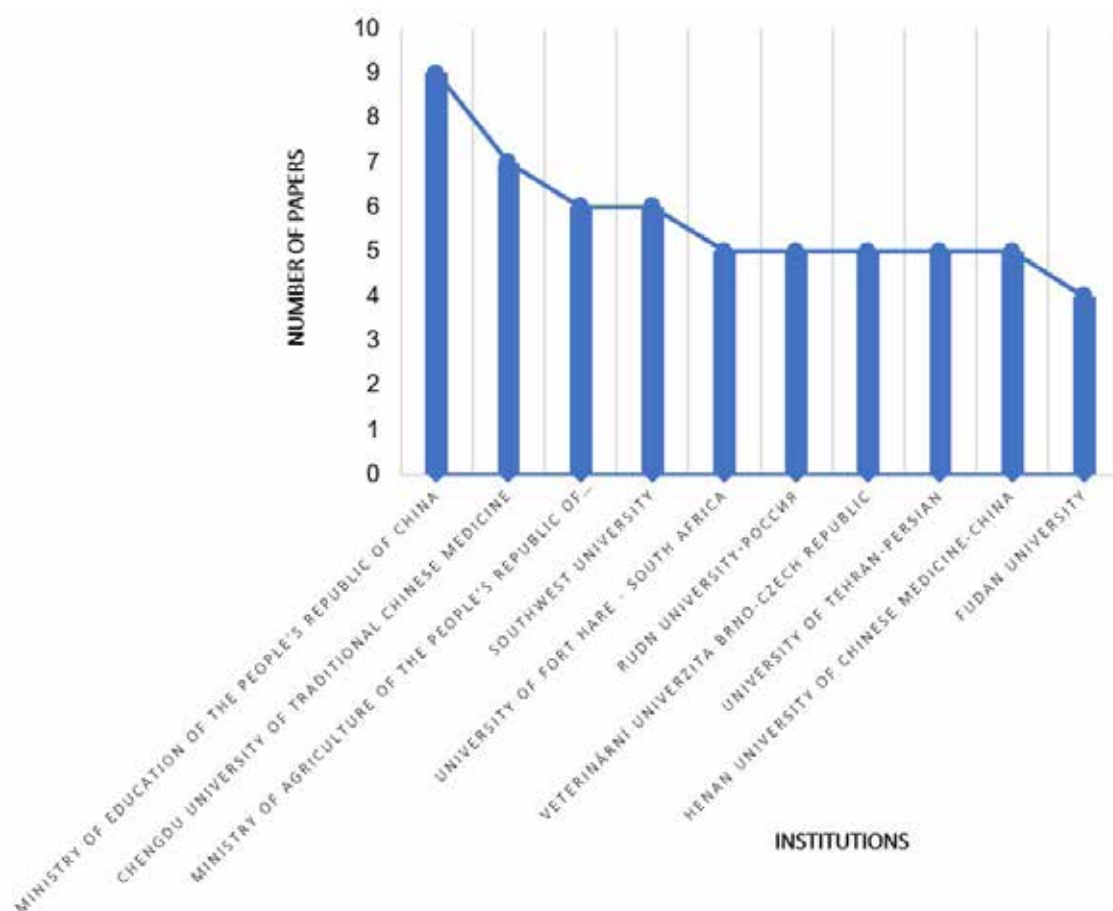
N°	Title	Authors	Citations
1.	Use of Herbal Products and Potential Interactions in Patients With Cardiovascular Diseases	Tachjian A.; Maria V.; Jahangir A.	316
2.	In vitro screening for the tumoricidal properties of international medicinal herbs	Mazzio E. A.; Soliman K. F.A.	130
3.	<i>Leonurus japonicus</i> Houtt.: Ethnopharmacology, phytochemistry and pharmacology of an important traditional Chinese medicine	Shang X.; Pan H.; Wang X.; He H.; Li M.	106
4.	Mistletoe hepatitis	Harvey J.; Colin-Jones D.G.	85
5.	<i>Leonurine hydrochloride</i> inhibits osteoclastogenesis and prevents osteoporosis associated with estrogen deficiency by inhibiting the NF-κB and PI3K/Akt signaling pathways	Yuan F.-L.; Xu R.-S.; Jiang D.-L.; He X.-L.; Su Q.; Jin C.; Li X.	84
6.	<i>Leonurus cardiaca</i> L. (Motherwort): A review of its phytochemistry and pharmacology	Wojtyniak K.; Szymański M.; Matlawska I.	83
7.	The influence of herbal medicine on platelet function and coagulation: A narrative review	McEwen B.J.	74
8.	In vitro anti-HIV activity of five selected South African medicinal plant extracts	Klos M.; van de Venter M.; Milne P.J.; Traore H.N.; Meyer D.; Oosthuizen V.	66
9.	Enhanced resistance to fungal pathogens in transgenic <i>Populus tomentosa</i> Carr. by overexpression of an nsLTP-like antimicrobial protein gene from motherwort ( <i>Leonurus japonicus</i> )	Jia Z.; Gou J.; Sun Y.; Yuan L.; Tang Q.; Yang X.; Pei Y.; Luo K.	60



The quality of papers published by researchers determines how institutions are ranked. One hundred and sixty different institutions worked in cooperation to publish 183 papers on *Leonurus* genus in the world in the period of 1968–2023. Our analysis of the top 10 institutions' publications on *Leonurus* genus allowed us to determine the

influential and productive institutions in this field. According to the results of our analysis, the country that has published the most articles about our research object is China, which ranks first with 20.22% of institutions that have published articles, followed by South Africa, the Czech Republic, and Russia (Figure 6).

**Figure 6.** List of top institutions on *Leonurus* genus issues in the world



#### 4. Top funding sponsors on *Leonurus* genus

When we analyzed the publications of the 12 authors who have published the most articles about our subject for 55 years, J. Bernatoniene and X. Yang took the proud first place out of 12 by publishing 5 articles, and the next nine authors published 4 articles each are in second place: Z. Kalveniene, R. Masteikova, V. Nazeri, Y. Pei, C. Peng, T.V. Pleteneva, A. Savickas, A.V. Syroeshkin, S. Tian. The last 12 places were taken by N.A. who published 3 articles. Dyakova occupies this place, after her 14 other authors published 3 articles each. The next places are occupied by authors who have

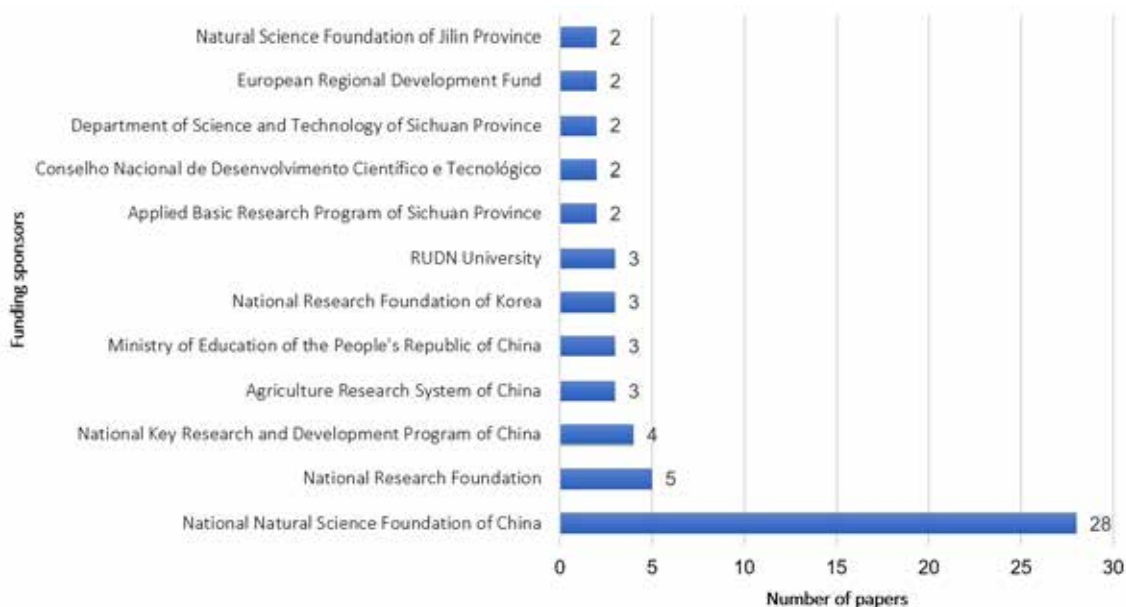
published 1–2 articles. The National Research Foundation of South Africa took the second place by sponsoring 5 articles, the National Key Research and Development Program of China took the third place by sponsoring 4 articles, the Agriculture Research System of China and the Ministry of Education of the People's Republic of China. Russia's RUDN University and Korea's National Research Foundation of Korea are in the third place, sponsoring 3 articles each. Applied Basic Research Program of Sichuan Province of China, Conselho Nacional de Desenvolvimento Científico e Tecnológico of Brazil, Department of Science and Technol-

ogy of Sichuan Province of China published 2 articles and took the fourth place (Figure 7).

When we analyzed the published articles by subject, it was found that articles were published in 22 areas. Top 6 most published articles in the field of knowledge. The major-

ity of articles were published in Pharmacology, Toxicology and Pharmaceutics, Medicine, Agricultural and Biological Sciences, Biochemistry, Genetics and Molecular Biology, Chemistry, Environmental Science.

**Figure 7.** Top funding sponsors on *Leonurus* genus issues in the world

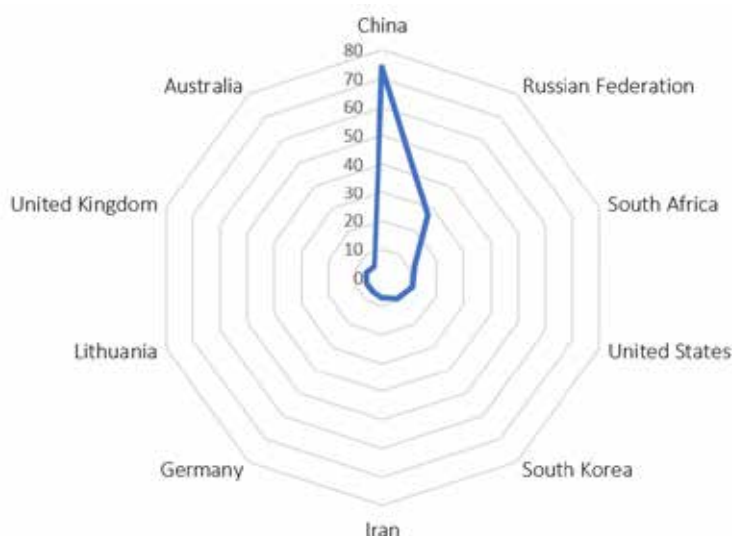


### 5. Top countries on *Leonurus* genus

Research on *Leonurus* genus was published in 36 countries around the world. Figure 8 lists 10 most prolific countries in the field of *Leonurus* genus research. Countries which published 183 research papers in last 55 years (1968–2023) have been considered as prolific countries. Figure 8 shows the top

10 countries that published the most 163 (100% of top 10 countries) articles, including China (74; 45.40%), Russian Federation (27; 16.54%), United States (11; 6.75%), South Korea (9; 5.52%), Iran (7; 4.29%), Germany (6; 3.68%), Lithuania (6; 3.68%), United Kingdom (6; 3.68%), and Australia (5; 3.06%) took the last place.

**Figure 8.** List of top countries on *Leonurus* genus matters around the world



### Conclusion

It was found that 183 articles were published by 160 authors from 36 countries during the half-century of *Leonurus* genus, that is, from 1968 to 2023. Between 1968 and 2002, very few articles were published on species belonging to the genus *Leonurus*, and by 2003, an increase in the number of articles was observed. During the period from 2004 to 2008, the number of articles published decreased. During the years 2008–2023, 163 articles were published about the *Leonurus* genus, and this figure is 89% of the publications published during 55 years worldwide. In recent years, the increased interest in the species of the genus *Leonurus* shows that this genus has important medicinal species. 157 articles were published in 144 scientific journals. For 55 years, the Journal Of Ethnopharmacology, Pharmaceutical Chemistry Journal, and Frontiers In Pharmacology have been the top 3 publications on the plant species of the genus *Leonurus*. When we analyzed the top-cited articles on motherwort, the article by Ara Tachjian, Viqar Maria and Arshad Jahangir had 316 cytotoxic cases compared to November 9 and 327 cytotoxic cases compared to December 15. In addition, Elizabeth A Mazzio and Karam F A Soliman's article In

vitro screening for the tumoricidal properties of international medicinal herbs and Xiaofei Shang, Hu Pan, Xuezhi Wang, Hua He, Maxing Li *Leonurus japonicus* Houtt.: Ethnopharmacology, phytochemistry and pharmacology of an It was noted that they occupied 2–3 places with the article “Important traditional Chinese medicine”. 160 authors who studied dragonflies in various directions were identified. Research on *Leonurus* genus had been published in 36 countries around the world. Countries which published 183 research papers in last 55 years (1968–2023) have been considered as prolific countries. According to the results of the analysis, the Chinese state is in the first place in terms of funding sponsor, publication of articles. It is followed by Russian Federation (27; 16.54%), United States (11; 6.75%), South Korea (9; 5.52%), Iran (7; 4.29%), Germany (6; 3.68%), Lithuania (6; 3.68%), United Kingdom (6; 3.68%), and Australia (5; 3.06%) are the countries with top publications in terms of number of articles. A comprehensive analysis of 55 years of scientific articles published in the Scopus database shows that species of the genus *Leonurus* are important plants, and we believe that scientific research on them will increase in the next decade.

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## PROSPECTS FOR THE FUTURE STUDY OF THE ODONATA ORDER: A REVIEW OF PUBLISHED ARTICLES FROM THE SCOPUS DATABASE 2019–2023

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### Abstract

This article analyzes the problems in the study of perspective species of the Odonata order worldwide: a review of papers from the Scopus database published in English for the period of 2019–2023. During 2019–2023, 827 articles were published about insects belonging to the Odonata order, of which 94% (776) were published in journals as scientific research results, 1% (10) articles were conference proceedings, 5% (41) and the articles were covered as a literature review. Published scientific works were analyzed in the following directions: Trends of publications on Odonata order, Journals on Odonata order, Authors and their affiliated countries, Top funding sponsors on Odonata order, Top countries on Odonata order. According to the five-year results of the Trends of publications on the Odonata order, the most articles on Odonata order were published in 2021, accounting for 217 (26%) articles, compared to 131 (16%) articles in 2022, and only 74 by 2023. (9%) articles were published. The results of analyzes of journals show that 160 journals were published in 91 countries, of which 353 (42.68%) of these papers were published in top 12 journals and remaining 57.31% papers were published in other journals. At the same time, this section presents the analytical results of 12 journals that published the most (353) articles on Odonata order. In the “Authors and their affiliated countries” section of the article, you can get acquainted with 10 major odonatologists or scientists who study Odonata order in various directions, who have published the most articles worldwide as a result of their scientific research on the Odonata order. In addition, the analytical results of the 12 most published publications of the Odonata order are presented. The top funding sponsors on Odonata order section covers the analysis of 146 different funding sponsors worked in cooperation to publish 827 papers on Odonata order over the world in the period of 2019–2023, and provides information on the 14 funding sponsors who sponsored the most in the world. Top countries on Odonata order also lists the 10 countries with the most articles on Odonata order.

**Keywords:** *Odonata order, top journals, Scopus database, insects*

## Introduction

The order of Odonata order is the most ancient representative of the class of insects and includes about 40 families and more than 6650 species. According to some sources, there are about 6,324 species of Odonata worldwide, almost all of which are distributed depending on freshwater habitats. According to Belyshev et al. (1989), dragonflies are distributed in all climatic zones of the earth and consist of about 6000 species of flowering insects. Dragonflies are one of the oldest types of insects, and they are attracting the attention of scientists even now because of their amazing adaptability. During 2019–2023, the scientific research results of scientists who studied insects belonging to the Odonata family were analyzed. Molecular-genetic analysis, fauna, ecology, distribution, adaptation, zoogeography of insects belonging to the family Odonata have been thoroughly studied by many scientists. During the study of dragonfly fauna, several new species were also discovered. More than 800 specimens of *Ceriagrion* species found in China were studied by X. Yu, C. Chen, M. Zhang, almost a quarter of which were used for molecular analysis. Nine species were identified and confirmed to occur in China. A taxonomic key of males was given. Two new synonyms (*Ceriagrion chaoi* to *Ceriagrion bellona*, *Ceriagrion olivaceum* to *Ceriagrion azureum*) were proposed, *Ceriagrion malaisei* was confirmed new to China, the distribution of *Ceriagrion rubiae* in China was eliminated, and three incorrect identifications were corrected (Yu, X., et al., 2022). D.S. Vilela & M.M. de Souza (2022) discovered a new species of dragonfly in Southeast Brazil as a result of scientific research (Vilela, D.S., & de Souza, M.M., 2022). A new genus and species of dragonflies (Odonata, Zygoptera) were discovered from the USA (Archibald, S.B., & Cannings, R.A., 2021). 250 million years ago, dragonflies and butterflies developed separately, and their current status was studied at the molecular genetic level in the scientific data of E. R. Tolman et al. (2023) (Tolman, E. R., et al., 2023) *Ischnura elegans* and *Platycnemis pennipes*, and two dragonfly species, *Pantala flavescens* and *Tanypteryx hageni*, we demonstrate that the autosomes of Odonata have undergone

few fission, fusion, or inversion events, despite 250 million years of separation. In the four genomes discussed here, our results show that all autosomes have a clear ortholog in the ancestral karyotype. Despite this clear chromosomal orthology, we demonstrate that different factors, including concentration of repeat dynamics, GC content, relative position on the chromosome, and the relative proportion of coding sequence all influence the density of syntenic blocks across chromosomes. However, these factors do not interact to influence synteny the same way in any two pairs of species, nor is any one factor retained in all four species. Furthermore, it was previously unknown whether the micro-chromosomes in Odonata are descended from one ancestral chromosome. Despite structural rearrangements, our evidence suggests that the micro-chromosomes in the sampled Odonata do indeed descend from an ancestral chromosome, and that the micro-chromosome in *P. flavescens* was lost through fusion with autosomes. © 2023 The Authors. Molecular Ecology published by John Wiley & Sons Ltd., “archive”: “Scopus”, “container-title”: “Molecular Ecology”, – DOI:10.1111/mec.17147, ISSN : 09621083 (ISSN. D. Zheng et al.’s 2019) research revealed a new dragonfly species from Northwest China from the Early Jurassic period (Zheng, D., et al., 2019). A. Zia et al., (2020) studied the fauna and ecology of dragonflies distributed in Kurram District, Pakistan. District Kurram represents an important geographical position. It shares its border with Afghanistan and possesses unlimited water resources. Due to prolonged uncertain ground conditions, this area remains unexplored for insect fauna. Present study was carried out to record richness, abundance and species complex of Odonata. It revealed four families, fifteen genera and twenty-six species. Among recorded fauna, family Libellulidae appeared to be a dominant group representing 19 species, followed by family Coenagrionidae with 5 species and family Calopterygidae and Aeshnidae representing single species each. Being a flying insect group, seasonal surveys and temporal data collection for dragonflies in this ecologically rich area can surely bring forward important information for the migratory species be-

tween Afghanistan and Pakistan (Zia, A., et al., 2019). A. Tiple, V. Sharma & S.V. Padwad, 2022) studied the odonata fauna of central India. During the study period of 2008–2019 a total of 75 species of odonates belonging to two suborders and nine families were recorded. Twenty-one new species were recorded for Jabalpur district and four for Madhya Pradesh; 37% (28) species were abundant or very common, 19% (14) were common, 16% (12) were frequent, 24% (18) rare, and 4% (3) very rare. The maximum number of odonates were found in family Libellulidae (n= 32), followed by Coenagrionidae (n=17), Gomphidae (n=09), Platycnemididae (n=06), Aeshnidae (n= 05), Lestidae (n=03), Macromiidae (n=02), and Chlorocyphidae (n=01). Of 75 species recorded from Jabalpur city, 72 come under the IUCN Red List. Among them, *Indothemis Carnatica* come under Near Threatened (NT) category, 65 species come under Least Concern (LC) Category, six species under Data Deficient (DD), and three species remain not assessed. The study supports the value of the city area in providing habitat for Odonata (Tiple, A., et al., 2022) central India. During the study period of 2008–2019 a total of 75 species of odonates belonging to two suborders and nine families were recorded. Twenty-one new species were recorded for Jabalpur district and four for Madhya Pradesh; 37% (28). Cytogenetic analysis of dragonflies is becoming one of the urgent issues in the period of rapid development of modern science. The results of the research conducted by G.K. Walia & N. Katnoria, 2021) are given below. Taxonomically, in the family Calopterygidae, 183 species under 21 genera have been reported worldwide. Out of these, cytogenetic data pertains to only 22 species which is only 12% of the known species. In India, 9 species under 6 genera are present, while only 2 species have been studied cytogenetically. The present study has been conducted to linearly characterize the chromosomes of 4 species (*Matrona nigripectus*, *Neurobasis chinensis*, *Vestalis apicalis* and *Vestalis gracilis*) of family Calopterygidae by conventional staining, C-banding, silver nitrate staining and sequence-specific staining and also compiled the cytogenetic data of the family. The species were collected from Me-

ghalaya, Goa, Kerala, Himachal Pradesh states of India. All the species possesses  $2n = 25$  m as the diploid chromosome number with XO-XX sex determination except *Neurobasis chinensis* with  $2n = 23$ , characterized by the presence of two equal sized large autosomal bivalents originated by the autosome fusion. C-banding and silver nitrate staining results depict the presence of C-bands and NOR's on the terminal positions of autosomal bivalents, while X chromosome and m-bivalent show variation in distribution of C-heterochromatin and NOR's. Sequence-specific staining represents the complement of all the species as AT-rich due to more DAPI bright signals. All the cytogenetically studied species have been catalogued including the presently studied species and the list has been updated to 23 species (Walia, G.K., & Katnoria, N., 2021) in family Calopterygidae, 183 species under 21 genera have been reported worldwide. Out of these, cytogenetic data pertains to only 22 species which is only 12% of the known species. In India, 9 species under 6 genera are present, while only 2 species has been studied cytogenetically. The present study has been conducted to linearly characterize the chromosomes of 4 species (*Matrona nigripectus*, *Neurobasis chinensis*, *Vestalis apicalis* and *Vestalis gracilis*). In the research of L. Wang et al., 2021), some species of dragonflies were analyzed molecularly (Wang, L., et al., 2021) lakes and other still water. In this study, we sequenced and analyzed the complete mitochondrial genome (mitogenome). In the article "Evolutionary history of a beautiful damselfly, *Matrona basilaris*, revealed by phylogeographic analyses: the first study of an odonata species in mainland China" published in 2018 by J. Xue et al., by molecular genetic study of several specimens of *Matrona basilaris* Selys, 1853 phylogeographic origin and demographic dynamics were analyzed (Xue, J., et al., 2019) 1853 is a damselfly distributed mainly in mainland China. A total of 423 individuals from 48 populations covering almost the entire range were sampled to explore the genetic diversity, phylogeographic structure, and demographic dynamics of the species using sequences of three mitochondrial genes (COI, COII, and ND1). D.S. In Vilela et al.'s, 2019) data, some

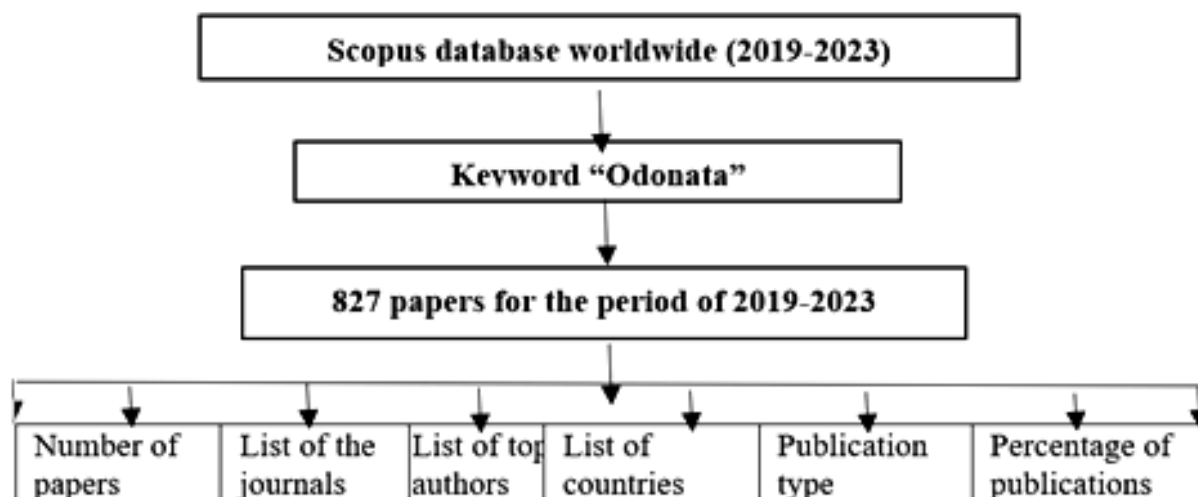
dragonfly species were studied in depth by morphological comparison (Vilela, D.S., et al., 2019). The scientific research conducted by I. Almudi & others (2020) is dedicated to the study of the adaptation of insects to water and land environment in relation to their genotype (Almudi, I., et al., 2020). I. E. Alvia & other scientists (2019) studied the genetic and morphological differentiation of the cosmopolitan dragonfly isolated on a special island (Alvia, I.E., et al., 2019) geographical and/or ecological factors can limit species distributions and promote population structure and morphological differentiation. In order to determine the effects of geographical isolation on population genetic structure and wing morphology, 281 individuals of the cosmopolitan odonate *Pantala flavescens* were collected from four continental (Central and South America. In the article “Similar Response of a Range Expanding Dragonfly to Low-and High-Elevation Predators” published by R. Zebsa, H. Mahdjoub, R. Khelifa (2022), the research results of the dragonfly *Sympetrum striolatum* were published. These authors tried to practically prove the

idea that “Recent range expansion of many species northward and upward in elevation suggests that the expanding species are able to cope with new biotic interactions in the leading edge” (Zebsa, R., et al., 2022).

### Methods

In this article, we went to the selected publications on worldly knowledge from the research done. The search collects the English-language academic literature retrieved from the Scopus database for the period 2019–2023. The analysis was carried out in November 2023. A total of 827 publications were downloaded with the keyword “Odonata”. In the next step, articles were categorized according to year of publication. A database of all peer-reviewed papers was then created, including the year of publication, authors’ names, countries, publication type, journal name, the percentage of publications by the topic cluster name and subject area. The analysis was performed using CSV file, Microsoft Excel 2021, RIS, VOS viewer. Figure 1 shows the flow of the selected methodology for the research.

**Figure 1.** Flowchart of the methodology



The reasons for the usage of these methods mentioned above are related to Scopus, a well-known database that collects authoritative literature from around the world, especially on irrigation and drainage systems. English is a universal language, therefore, the literature in English is more common than the literature in other languages.

### Results and discussion

#### 1. Trends of publications on *Odonata* order

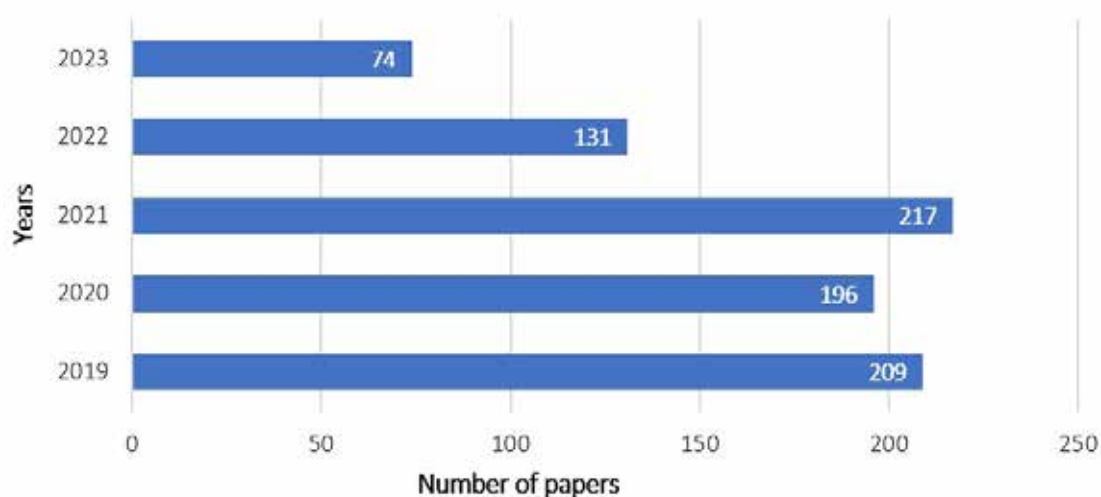
Overall, what stands out is that the number of published papers on a particular issue studied for the first time in the world. Total of 827 papers published between 2019 and 2023 on *Odonata* order issue. The number of records started to decrease between 2019 and 2023 from 209 to



74 publications. Figure 2 shows 25% (209) number of papers at the beginning in year 2019. In 2020, the highest number of publications was reached during the period of analysis 23% (196). An analysis of publications in the studied years shows that 2021 was the year with the largest number of articles published on dragonflies, with 217 articles (26%) according to the five-year

results. An analysis of the results of the last two years shows that the publication of articles on dragonflies has decreased. In 2022, 131 (16%) articles were published, but by 2023, only 74 (9%) articles were published (Figure 2). The results of the cross-year analysis show that 2021 was the year with the most articles published.

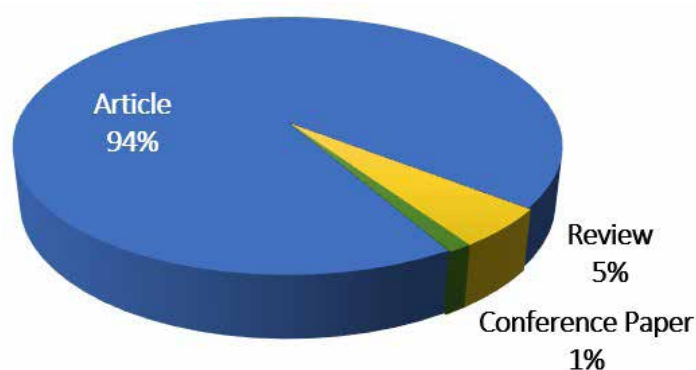
**Figure 2.** Number of papers on Odonata order by the year of publication issues in the world



During the period 2019–2023, 827 articles were published about insects belonging to the order Odonata, of which 94% (776) were articles published in journals as scientific

research results, and 1% (10) articles were conference proceedings. The remaining 5% (41) of articles are covered as a literature review (Figure 3).

**Figure 3.** Publication type on Odonata order issues in the world

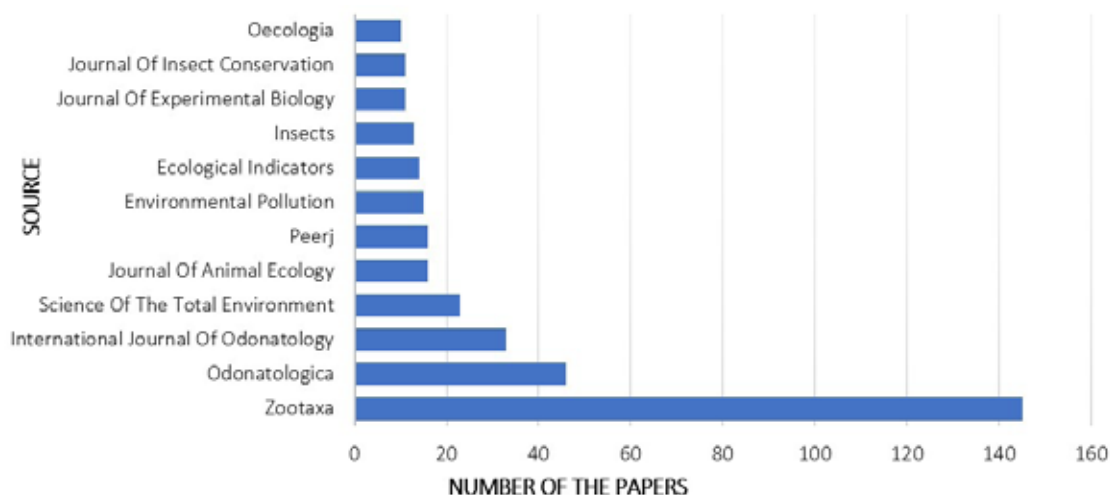


## 2. Journals on Odonata order

A wide variety of journals in different parts of the world are used by scholars to publish their research. The communication patterns of the scholars indicate that the total output was distributed across 160 journals published in 91 countries. 353 (42,68%) of these papers

were published in top 12 journals and remaining 57,31% papers were published in other journals (Figure 4). The results of scientific research on dragonflies were published in the form of 48 articles in 16 scientific journals, 72 articles in 38 journals, and 1 article each in the remaining journals.

**Figure 4.** Top journals on Odonata order by the year of publication issues in the world



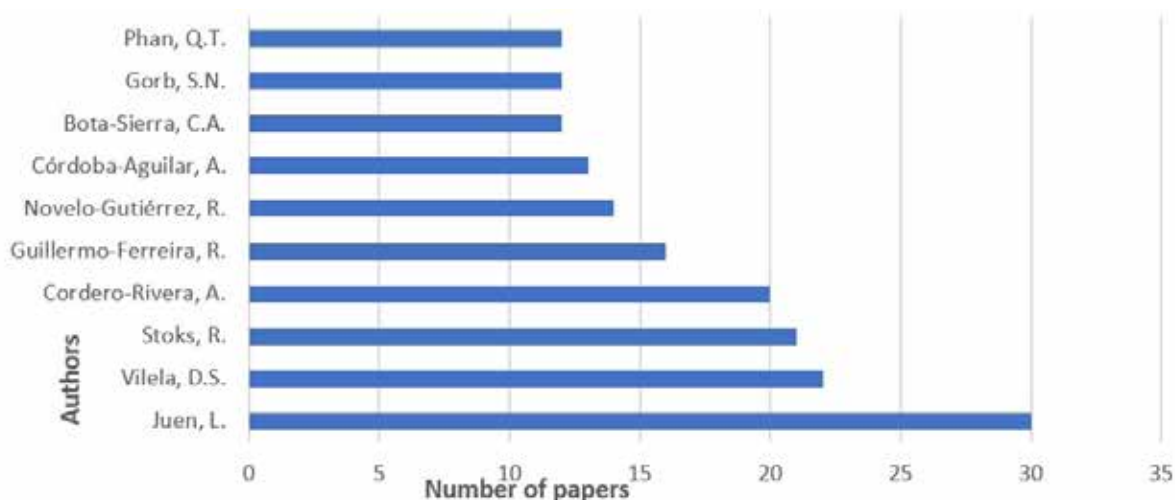
According to the analytical results of the 12 journals that published the most articles about dragonflies, 353 (100% compared to 12 journals), the first place was the Zootaxa journal, which published 145 (41%) articles about our object. Followed by Odonatologica with 46 articles (13%), International Journal Of Odonatology with 33 (9%) articles, Science Of The Total Environment with 23 articles (6%), Journal Of Animal Ecology and Peerj with 16 each (10%), Environmental Pollution 15 (4%), Ecological Indicators 14 (4%), Insects 13 (4%), Journal Of Experimental Biology and Journal Of Insect Conservation 11 articles each (6%), Oecologia and 10 (3%) articles were published (Figure 4).

### 3. Authors and their affiliated country

Our research revealed that 160 authors from 91 countries conducted research on the

Odonata order during 2019–2023. Figure 5 analyzes the results of scientific research of the 10 authors who published the most number of articles. According to it, L. Juen is in the top 10 with 30 articles published, D.S. Vilela, R. Stokes, A. Cordero-Rivera participated as authors in publishing 20 to 22 articles and took 2–4 places. R. Guillermo-Ferreira ranked fifth in the top 10 for his Odonata order with 16 published research articles, R. Novelo – Gutiérrez ranked sixth with 14 published research articles, and A. Córdoba – Aguilar ranked sixth with 13 published research articles. seventh place with the article, C.A. Botha-Sierra, S.N. Gorb & Q.T. Phan took the last places by publishing 12 articles each. According to the results of the analysis, 23.75% of the 160 authors published 4 articles, while 37.50% of the authors published the least number of 3 articles.

**Figure 5.** Top authors published on Odonata order issues in the world



The quality of articles published by researchers on the Odonata order determines how institutions are ranked. During 2019–2023, one hundred and sixty different institutions of the world published 827 articles on Odonata order in cooperation. Our analysis of the top 12 institutional publications on the Odonata order allowed us to identify the most influential and effective institutions in the field (Figure 6). According to the results of the analysis, Brazil's Universidade Federal do Pará is in first place with 35 articles, Mexico's Instituto de Ecología is in second place with 25 articles, Belgium's KU Leuven is in 24 articles, Spain's Universidade de Vigo University Press is in third place with 24 articles, followed by: The Naturalis Biodiversity Center of the Netherlands published 23 articles, the Chinese Academy of Sciences published 22 articles, the Universidad Nacional Autónoma de México of Mexico published 21 articles, and the CNRS Center National de la Recherche Scientifique of France published 20 articles.

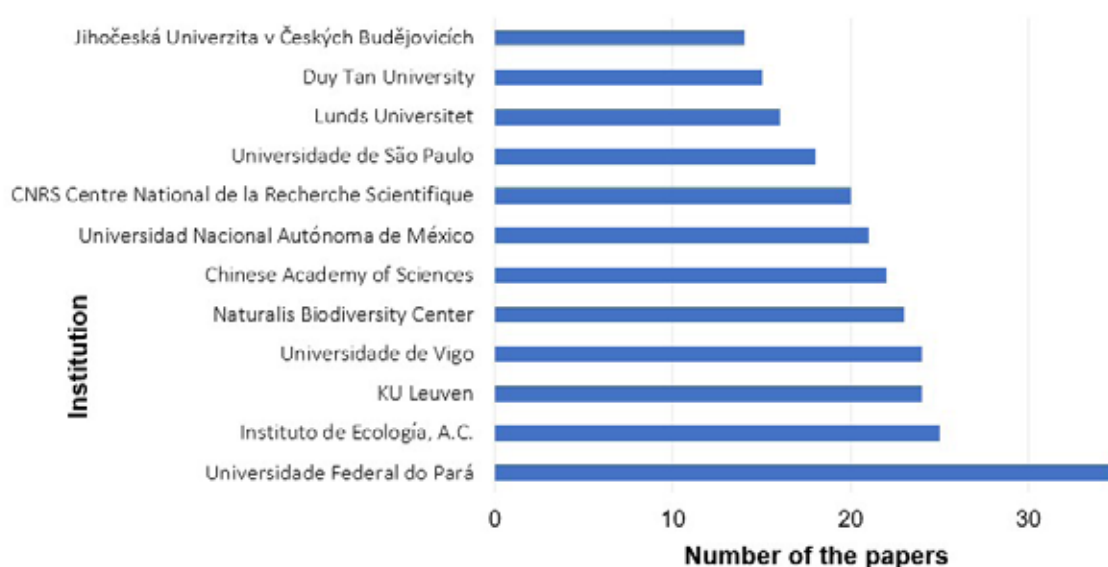
Publishing house of Universidade de São Paulo of Brazil published 18 articles, Lunds University Publishing House of Sweden published 16 articles, Duy Tan University of Vietnam published 15 articles, Jihočeská Univerzita v Českých Budějovicích published 14 articles and took 12<sup>th</sup> place. If we analyze the articles published in the top 12 institutions by country, Brazil is in the first place with 53 articles, Mexico is in the second place with 46 articles, Belgium and Spain are

in the third place with 24 articles, followed by: Netherlands (23 articles), China (22 articles), France (20 articles), Sweden (16), Vietnam (15) and the Czech Republic (14 articles) took 12 places.

#### 4. Top funding sponsors on Odonata order

There is a relationship between prevalence of affiliated countries and funding of large funding schemes and programs. 146 different funding sponsors worked in cooperation with 827 publishing papers on Odonata order over the world the period of 2019–2023. Based on our analysis of the top ten funding sponsors made publications on Odonata order, we were able to identify the most influential and productive institutions in this field. As indicated in Figure 7, of 14 funding sponsors, 72 articles were sponsored by Conselho Nacional de Desenvolvimento Científico e Tecnológico of Brazil, 47 articles were sponsored by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior of this country, 34 articles were sponsored by the National Science Foundation of the USA, 25 articles were sponsored by the Belgian Fonds Wetenschappelijk Onderzoek and the National Natural Science Foundation of China sponsored 25 articles, 19 articles under the auspices of the European Regional Development Fund and 19 articles under the auspices of KU Leuven of Belgium were published.

**Figure 6.** List of top institutions on Odonata order issues in the world

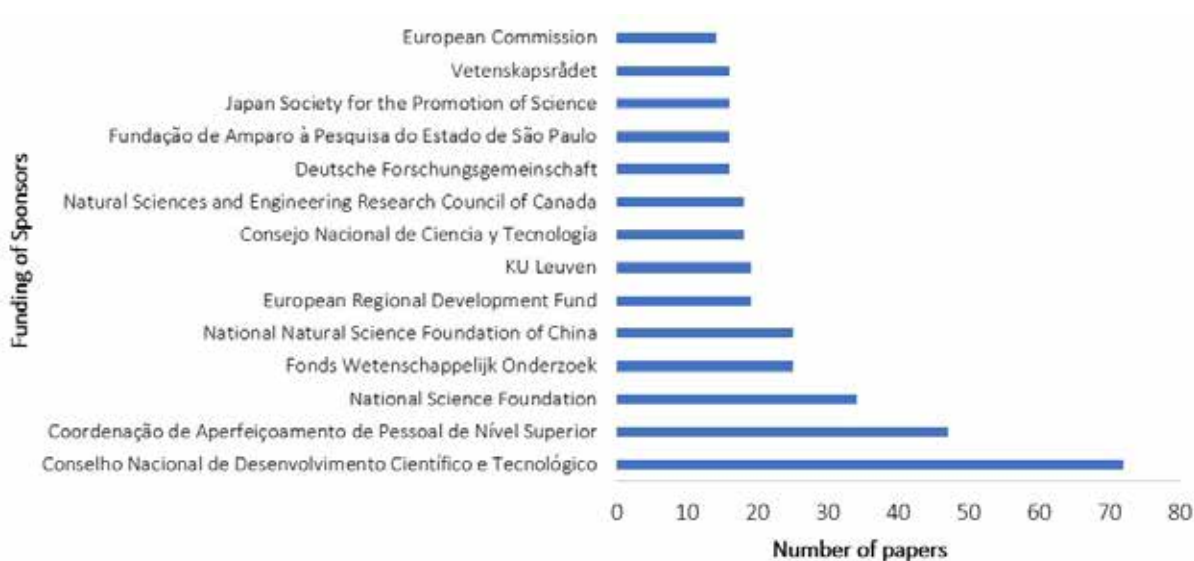


In addition to this, Mexico has 18 under the auspices of the Consejo Nacional de Ciencia y Tecnología, 18 under the auspices of the Natural Sciences and Engineering Research Council of Canada, 16 under the auspices of the German Deutsche Forschungsgemeinschaft, 16 under the auspices of the Brazilian Fundação de Amparo a Pesquisa do Estado de São Paulo, 16 articles were published under the auspices of the Japan Society for the Promotion of Science, 16 under the auspices of Sweden's Vetenskapsrådet, and 14 under the auspices of the European Commission (Figure 7).

### 5. Top countries on Odonata order

The researches on Odonata order were published in 91 countries around the world. Countries which published 827 research papers in last 5 year (2019–2023) have been considered as prolific countries. These 10 countries published more than half (79.56%) of the total output. Among them, United States dominated with (152; 23%), Brazil (99; 15%), Germany (65; 10%), Mexico (53; 8%), China (52; 8%), Canada (51; 8%), United Kingdom (50; 8%), India (47; 7%), Sweden (46; 7%), and Spain (43; 6%).

**Figure 7.** List of top funding sponsors on Odonata order issues in the world



### Conclusion

While analyzing above mentioned issues in the study of perspective species of the order Odonata worldwide: a review of papers from the Scopus database published in English for the period of 2019–2023, trend of publications in the Odonata order, from 2019 to 2023, a total of 827 articles were published on the Odonata order, of which 94% (776) are articles published in journals as results of scientific research, 1% (10) of articles are conference proceedings, and 5% (41) of articles are literature reviews given. A five-year analysis of publications shows that 209 articles were published in 2019, 196 in 2020, 217 in 2021, 131 in 2022, and only 74 by 2023. According to the results of the cross-year analysis, the most articles were published in 2021, but by 2023, there was a

threefold decrease in scientific publications compared to the highest number of publications shows that interest in dragonflies is decreasing. According to the analytical results of journals, 160 journals were published in 91 countries, of which 353 (42.68%) of these papers were published in top 12 journals and remaining 57.31% papers were published in other journals. At the same time, Zootaxa, Odonatologica, and International Journal Of Odonatology occupy the first 3, according to the analytical results of 12 journals that published the most, 353 articles about dragonflies. According to the results of our research, 160 authors from 91 countries published 827 articles in 2019–2023. According to the published papers of the authors who published the most articles, L. Juen (published 30 articles in co-authorship 3 or more), D.S. Vilela

(22), R. Stokes (21), A. Cordero-Rivera (20), R. Guillermo-Ferreira (16), R. Novelo-Gutiérrez (14), A. Córdoba-Aguilar (13), C.A. Bota-Sierra (12), S.N. Gorb (12) and Q. T. Phan (12) are occupied by scientists working in different areas of Odonatology. In addition, the analytical results of the 12 most published articles of the Odonata order are presented. Top funding sponsors on Odonata order 146 different funding sponsors worked in cooperation to publish 827 papers on Odonata order

over the world in the period of 2019–2023. Top countries on Odonata order also lists the 10 countries with the most articles on dragonflies. Countries which published 827 research papers in last 5 years (2019–2023) have been considered as prolific countries. These 10 countries published more than half (79.56%) of the total output. If we analyze the publications about dragonflies by country, 23% of them are in the United States, 15% in Brazil and 10% in Germany.

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## Section 2. Economics and Management

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### LATEST STRATEGIES OF TRANSPORT AND LOGISTICS OF GEORGIA

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#### Abstract

The paper describes the state and current reforms of the most important sector of our country's economy – transport and transportation systems. It analyzes The transport and logistics market of Georgia. Through the comparative analysis of relevant indicators, the role of transport and logistics in improving the country's business environment and economic situation is justified. The already implemented reforms are evaluated and conclusions and recommendations are presented according to the problems identified.

**Keywords:** *Logistics systems; Transport system; Infrastructural reforms; Supply chain; Logistic hub*

#### Introduction

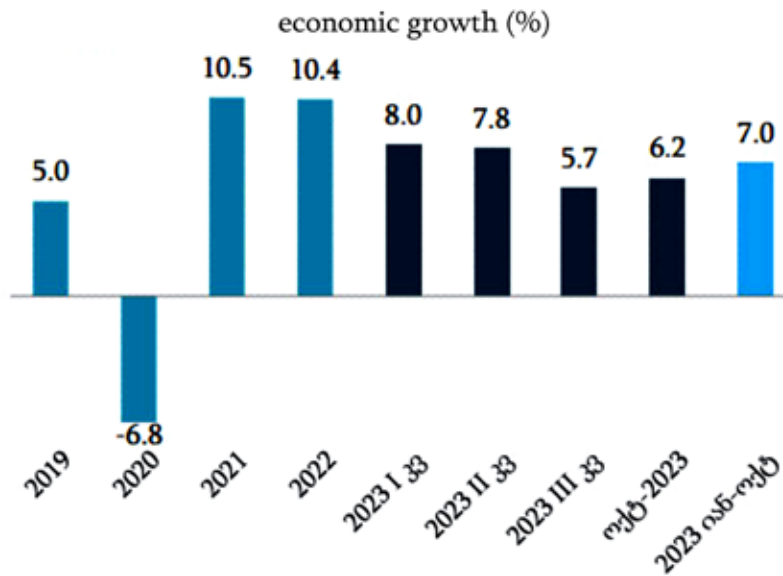
For the Country's economic and social progress, the development of such a field as a transportation, is vital. Efficient transport and logistic systems create opportunities and benefits for economic development. Infrastructure change is particularly noticeable for developing countries, including post-communist economies, to which our country belongs.

Following the global processes taking place in the world, Economic and infrastructural reforms were implemented in Georgia. which led to the development of the transport and logistics sector. Meaning: infrastructural modernization, simplification of

customs procedures and liberalization of services in the main sector of the economy. Direct foreign investments in the field of transport and logistics increased, in 2022 compared to 2020 it increased by 79,646.7 thousand US dollars, and in the III quarter of 2023 it reached 61,953.1 thousand US dollars.

The country's economy has significantly revived in the post-Covid period. The high economic growth of 2021 continued in 2022, and then the average economic growth of the ten months of 2023 amounted to 7.0%.

**Figure 1. Economic growth (%)**



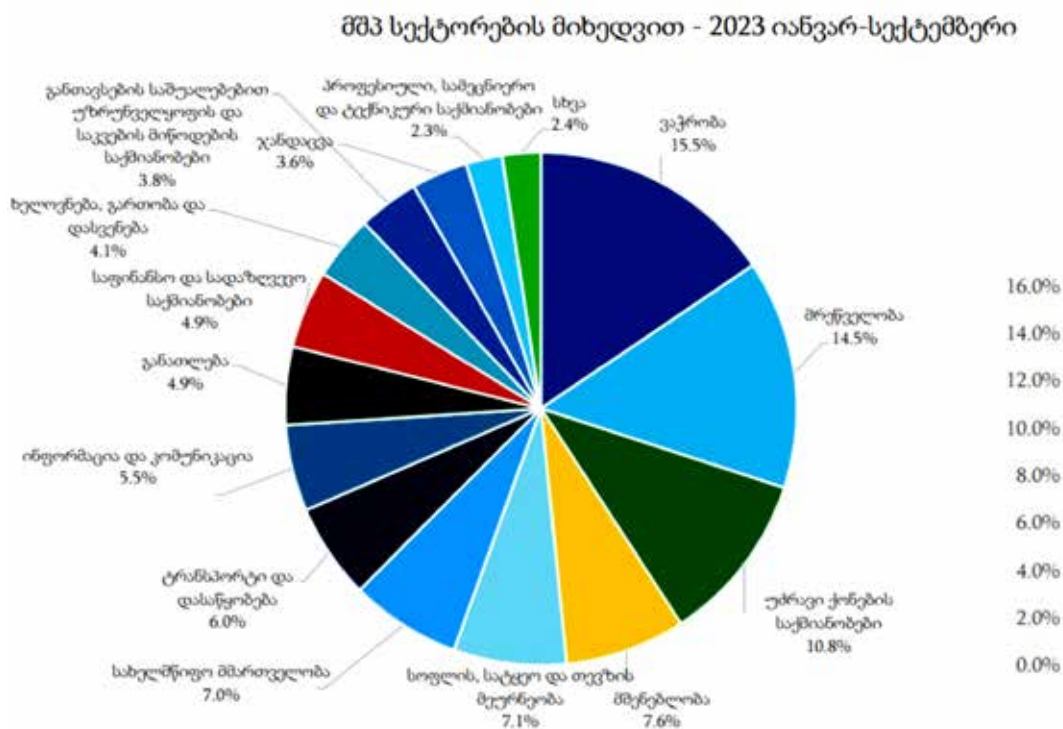
Economic growth was expressed in the growth of the Gross Domestic Product, the information about it, is presented in the table No. 1.

**Table 1. G.D.P**

	2019 Y.	2020 Y.	2021 Y.	2022 Y.	2023 Y. III Qu.
G. D. P at current prices. Billion Gel.	49.7	49.8	60.7	72.9	21.3

As can be seen in the table, GDP has a growth trend and in 2022 compared to 2019, it has increased by 46.7%.

**Figure 2.**





The share of transport and warehousing in the gross domestic product of Georgia is 6.0%. According to the data of 2021, the same indicator is in developed countries GDP of transport and warehousing was 6–12%, which naturally indicates our progress.

The transport system of our country is represented by a combination of transport networks and their management systems of the relevant infrastructure of road, marine, railway and civil aviation enterprises. There are 3 international and 4 local airports; 4 seaports/terminals and railway transport (Georgian Railway and Marabda-Kartsakhi Railway).

Today, the transportation industry is increasingly using intermodal operations to transport cargo. Which requires the connection of different types of transport, especially the establishment of hubs of international

importance with seaports and road, rail and air transport connections.

### Transport and warehousing

As the data given in the table is showing, all indicators are having a growth trend, which undoubtedly proclaims the success of the industry.

Globalization and the growing economic connection with the European Union create unique opportunities for the integration of our country in international trade, which requires the creation of an efficient transport system for each type of transport. Integration into the EU transport system will contribute the implementation of EU standards and the improvement of transport connections. Infrastructure and service quality will improve and make our country an important link in the global supply chain.

**Table 2.**

	2019 Y.	2020 Y.	2021 Y.	2022 Y.	2023 Y. III Quarter.
Turnover (Billion Gel.)	6.0	5.8	7.1	9.3	2.0
released products (Billion Gel.)	4.6	4.2	5.1	6.9	1.4
fixed assets (Billion Gel.)	5.5	5.3	6.1	6.4	
number of employees thousand persons.	61.2	56.8	62.6	66.5	58.7
Average monthly salary of employees (Gel.)	1384.7	1435.7	1479.3	1697.0	1917.6

Georgian market in the field of transport and logistics is in the process of transformation, which implies the appearance of new international participants and the expansion or maybe disappearance of the existing ones. The development of the market requires the development of passenger transportation along with freight transportation, which is impossible without improving the transportation network and increasing the level of safety.

According to the World Bank's 2023 report, Georgia ranks 79<sup>th</sup> among 139 countries in the International Logistics Performance Index (LPI). The indicator reflected by the index has improved in all components, except for infrastructure (customs, international shipments, competence logistics, traceability and time), but it is significantly below the average indicator of the Europe

and Central Asia region (3.01 points) and is 2.7 points.

Based on the situational analysis carried out in the field, the following most important problems were identified:

- Development of modern infrastructure and lack of automation systems;
- Low quality of logistics services – this refers to services such as cargo transportation and simple warehousing operations.
- Insufficient knowledge of supply chain management, which requires the implementation of international practices of supply chain management.
- Weak regulatory Authority of the logistics sector;
- the current situation of human capital;
- The current situation in the field of transport.

### **Conclusion:**

The results of the study indicate that the field is unable to use the opportunities due to lack of efficiency and reliability. According to the authors, in order for Georgia to become a logistics hub, it is necessary to correctly formulate strategic goals and develop effective strategies. Strategies should be developed

precisely to eliminate the existing problems, which results in:

1. Increasing the efficiency and competitiveness of the logistics sector;
2. Development of human capital;
3. Sustainable development of transport sectors, safe connections and transport corridors.

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## Section 3. Engineering science in general

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### MODELING AND IMPLEMENTING SPOT JAMMING WITH GNU RADIO AND HACKRF ONE

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#### Abstract

This article presents the results of simulation of spot jamming in the GNU Radio environment using various modulating signals. In addition, experimental results of spot jamming using GNU Radio software in combination with HackRF One are presented.

**Keywords:** *spot jamming, GNU Radio, HackRF One, radio systems, electronic warfare, SDR, side electromagnetic radiation, modeling, modulation*

#### Introduction

Currently, spatial noise generators are used, as a rule, to mask informative side electromagnetic radiation and interference (SERI) of personal computers, workstations of computer networks and complexes at computer facilities (Liu, T., & Li, Y., 2019; Adamy, D. L., 2015; Foziljonov, K., & Faziljanov, I., 2023). Various types of blockers can be used to suppress cellular communications that are not authorized to be used in radio microphone mode or in classrooms during an exam. Such devices are actually generators of barrage interference, blocking the frequency range of a particular cellular communication standard within a small radius. Both noise generators and signal jammers affect a wide range of frequencies,

which can lead to restrictions on the use of legitimate radio communications, access to radio frequencies and wireless networks (Liu, T., & Li, Y., 2019).

Spot jamming generators have less impact on the operation of authorized wireless technologies within a controlled area or room, since they have a relatively narrow frequency spectrum, commensurate with the bandwidth of the suppressed device. In addition, the continuous improvement of technical reconnaissance means, including in the direction of reducing the bandwidth of the frequencies used in order to reduce the likelihood of their detection, still leaves relevant issues of modernization and development of new circuits for narrow-band interference generators.

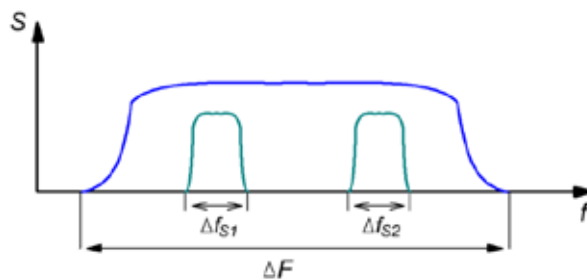
With the rapid development of communication technology, with the advantages of high flexibility, good compatibility, wide openness, and the ability to easily upgrade and expand the system at a later stage, soft radio technology has been applied to a variety of radio engineering activities, showing broad application prospects.

This paper discusses the modeling and experimental study of Spot jamming using

GNU Radio software and the HackRF One radio device.

Radio-electronic interference is electromagnetic radiation that degrades the quality of operation of radio-electronic equipment, guided weapons, and information processing, reception and transmission systems. Based on the frequency range overlap, interference is divided into barrage and Spot jamming (SJ) (Schleher, D. C., 1999; Spezio, A. E., 2002).

**Figure 1.**

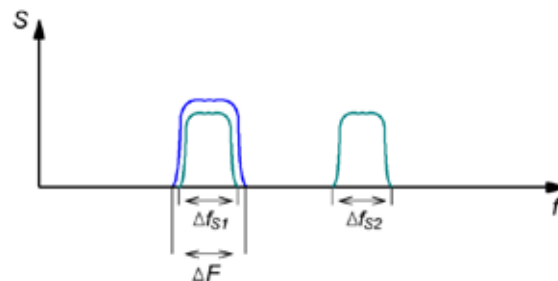


$$\Delta F \gg \Delta f_s.$$

Barrier interference has a wide range of frequencies, many times greater than the bandwidth of the suppressed receiver (Fig. 1) (Schleher, D. C., 1999).

Where  $\Delta F$  – interference signal spectrum frequency;  $\Delta f_s$  – bandwidth of the suppressed receiver or signal.

**Figure 2.**



SJ has a relatively narrow frequency spectrum commensurate with the bandwidth of the suppressed device or a spectrum width commensurate with the signal spectrum width (Fig. 2) (Spezio, A. E., 2002).

$$\Delta F \approx \Delta f_s.$$

### Simulation of Sj in the Gnu Radio Environment

GNU Radio is open source software that is a set of tools for developing software-defined radio (SDR) systems. It provides users with blocks (nodes) for signal processing that can be used to create various radio systems, ranging from conventional radio receivers to new generation communication systems (“Tutorials,” GNU Radio, 21-Jul-2022; Mi-

yashiro, H., Medrano, M., Huarcaya, J., & Lezama, J., 2017; Gummineni, M., & Polipalli, T. R., 2024).

With GNU Radio, users can develop their own radio systems using flexible and powerful signal processing tools.

GNU Radio is widely used in both academic research and commercial projects, including prototyping, educational purposes, and scientific research.

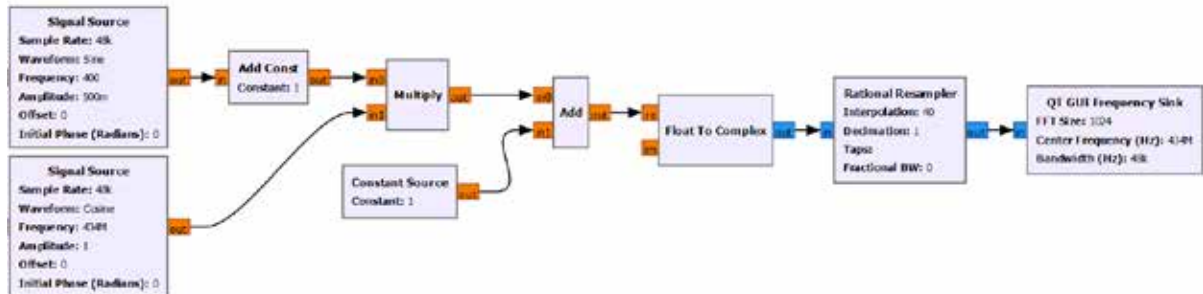
GNU Radio’s core capabilities include signal processing, filtering, modulation, demodulation, encoding and decoding, and interfacing with various hardware devices via standard interfaces such as USB and Ethernet.

In this article, two types of modulation AM and FM were chosen for the formation of

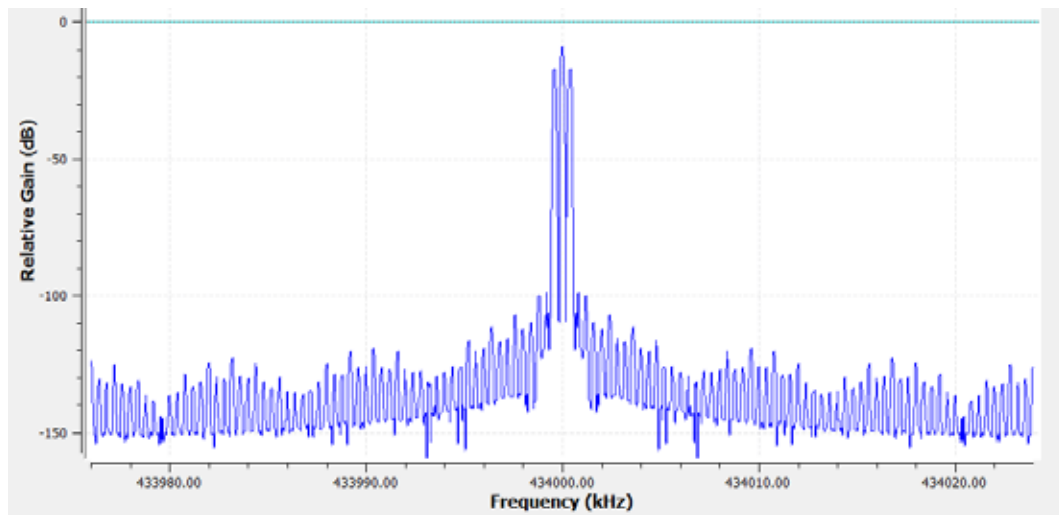
modulated PPs. Below are the AM PP simulation model (Fig. 3) (Harianto, B. B., Rifai, M., Irfansyah, A., & Suprpto, Y., 2021; Bhimavaram, K. R., Hiremath, P. S., & Kumar, S. A.,

2021). In Fig. Figure 4 shows the spectrum of the AM PP, in this case, a harmonic signal is used as a modulating signal.

**Figure 3.**



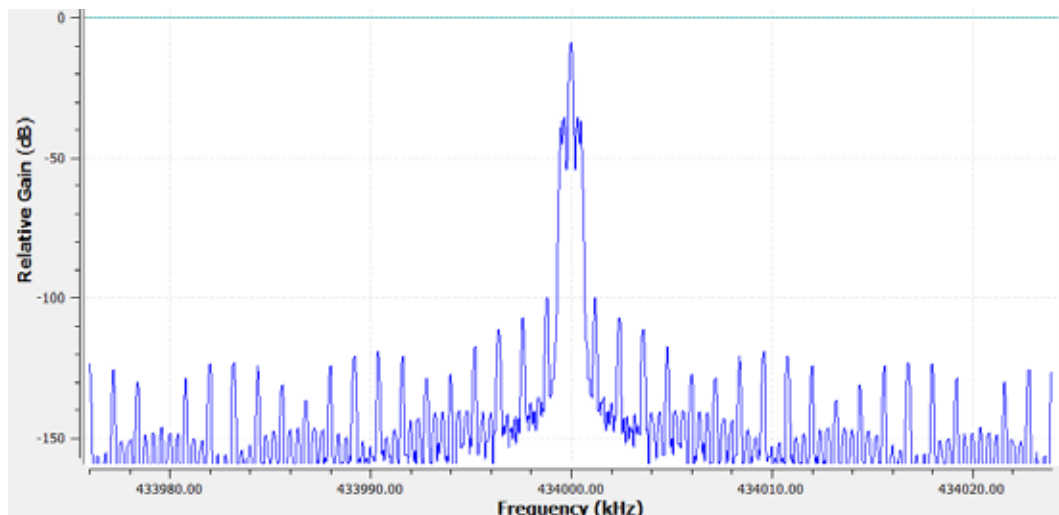
**Figure 4.**



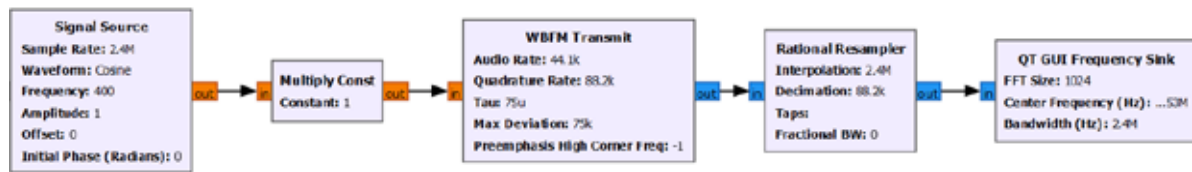
Replacing the signal source block with Wav file source makes it possible to use an audio file as a modulating signal. The result

of the simulation, the spectrum of the AM SJ is shown below (Fig. 5).

**Figure 5.**



**Figure 6.**

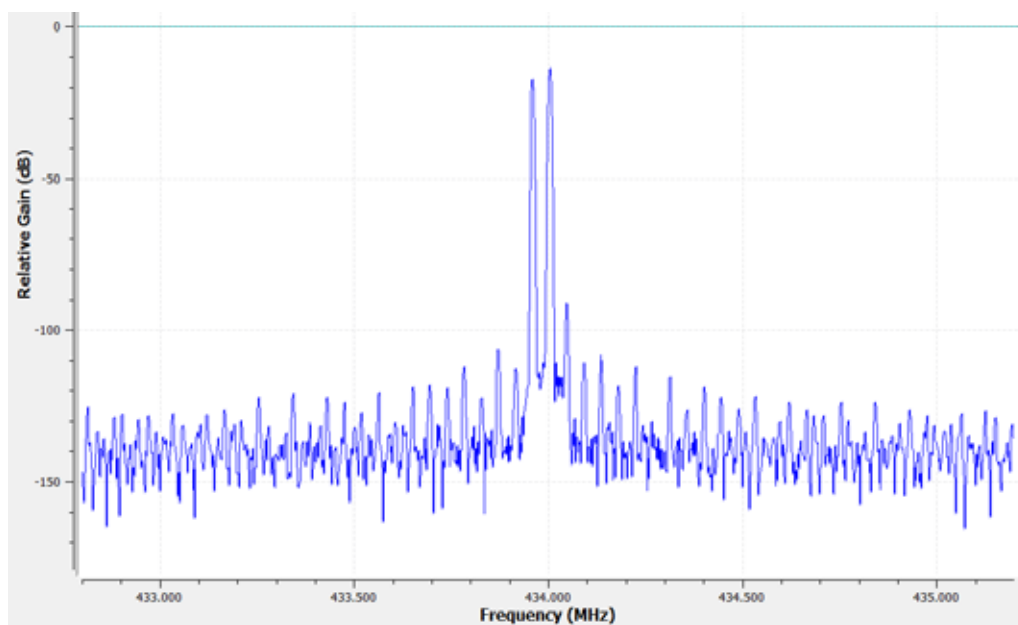


In GNU Radio, the WBFM Transmit block is provided to generate an FM signal. This block generates wideband frequency modulation (Shrivastava, A., 2018; Martoyo, I., Setiasabda, P., Kanalebe, H. Y., Uranus, H. P., & Pardede, M., 2018; Gummineni, M.,

& Polipalli, T. R., 2020). By connecting the corresponding blocks, we can obtain a simulation model of the FM SJ (Fig. 6).

In Figure 7 shows the oscillogram and spectrum of the FM SJ. In this case, a harmonic signal is used as a modulating signal.

**Figure 7.**



**Figure 8.**

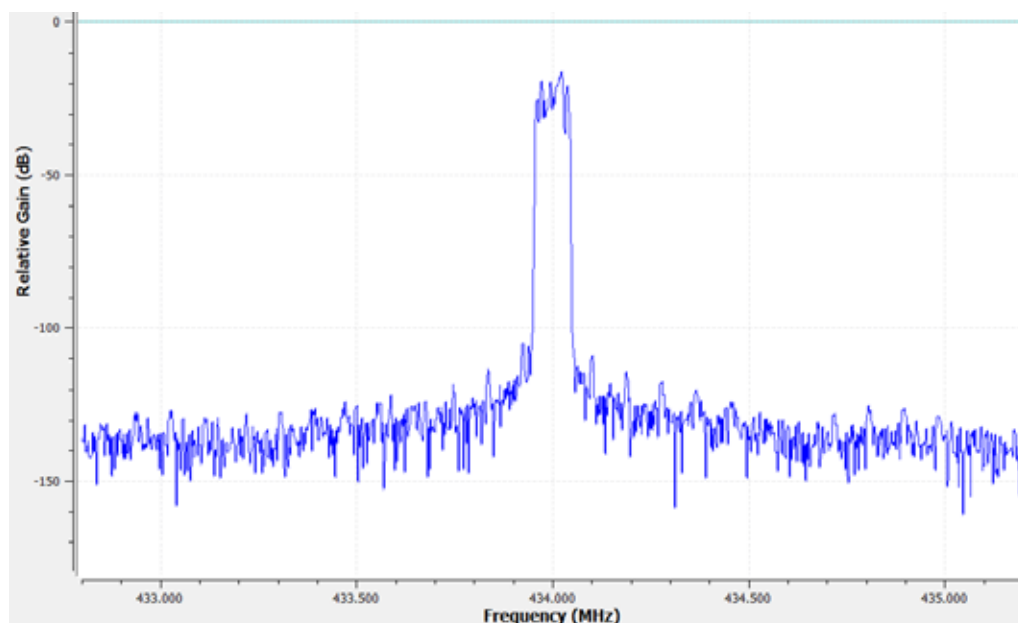


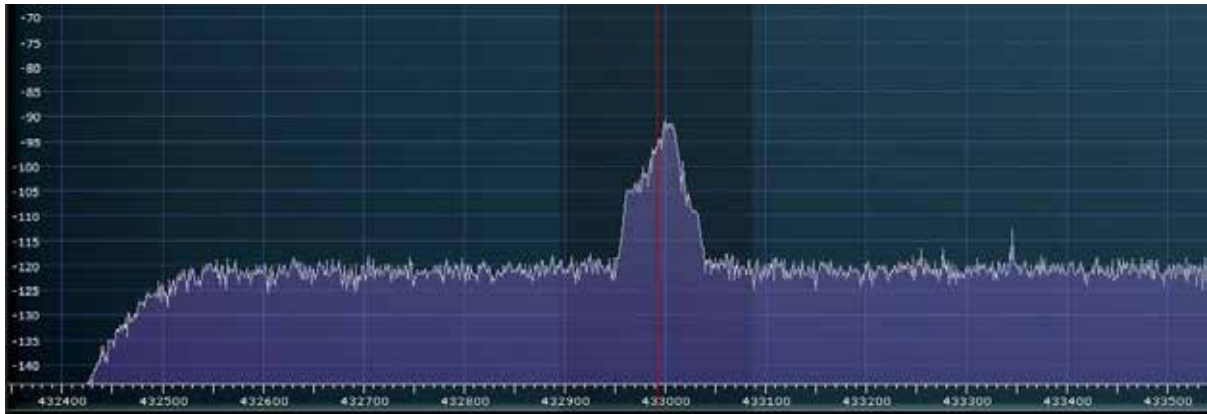
Figure 8 shows the result of the simulation, where an audio file is used as a modulating signal.

### Experimental Part

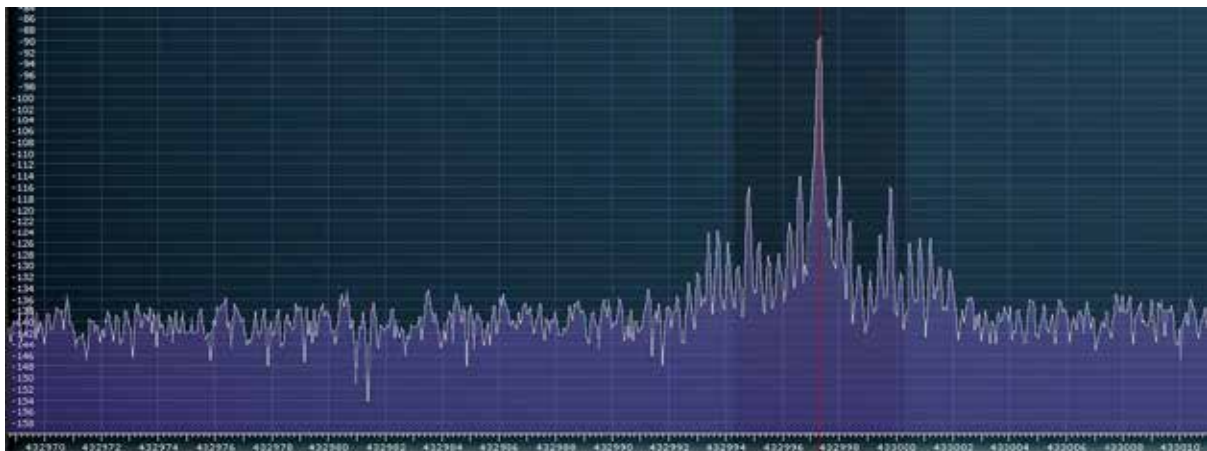
This section presents the results of AM and FM PP radiation. In the models shown in Figures 3 and 6, by replacing the QT\_GUI\_

Frequency\_Sink blocks with an Osmocom sink, it becomes possible, using the HackRF One SDR transceiver and the ANT500 antenna (Gummineni, M., & Polipalli, T. R., 2020; Davronbekov, D., & Fozilzhonov, H., 2021; SDRuno User Manual v 1.41. SD Rplay, 21-Jul-2020), to broadcast (radiate) the generated SJs at a frequency of 434 MHz.

**Figure 9.** Spectrum of the FM SJ signal using an audio file as a modulating signal



**Figure 10.** Spectrum of the FM SJ signal, a harmonic signal is used as a modulating signal



**Figure 11.** Spectrum of an AM SJ signal using an audio file as a modulating signal



The SDRplay RSPdx with the SA-7000 antenna and the SDRuno program for working with the SDR receiver were used as an SDR receiver.

Figures 9–12 show the spectrum of the emitted SJ. In Figure 9, an audio file is used as a modulator.

**Figure 12.** *Spectrum of an AM PP signal, a harmonic signalis used as a modulating signal*



Thus, based on the results of the experiment and simulation, the following conclusions can be drawn:

GNU Radio software allows you to create simulation models for generating modulated targeted interference with different modeling signals and frequencies. This makes it possible to study the effects of such interference on radio systems or electronic devices without the risk of damaging the actual equipment.

Using HackRF One in combination with GNU Radio, targeted interference can be transmitted at various frequencies. It is important to note that the interference power

will be limited by the maximum output power of the HackRF One. This approach has a wide range of applications, including testing the immunity of radio systems to interference, evaluating the effectiveness of interference detection and suppression algorithms, and in radio frequency attacks to disrupt radio systems.

The results obtained can be used to demonstrate targeted interference to military and radio engineering students. In addition, it is possible to use targeted interference to disguise SERI or to disrupt synchronization in reconnaissance receivers.

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## Section 4. Philology and linguistics

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### INTERACTIONAL POTENTIAL OF IMITATION ACTIVITIES FOR LITERATURE LESSONS

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#### Abstract

This article explores the use of interactive activities in literature lessons, with a specific focus on the pedagogical strategy of imitation. By engaging students in imitation exercises, educators can foster students' critical thinking, creativity, and language development. This article discusses a theoretical framework for realizing the role of interactive activities in literature education and provides practical examples of imitation activities for understanding the characters behaviour, writing style, and plot of the fiction. Additionally, case studies highlight the implementation and impact of these activities in literature classrooms. The discussion section analyzes the benefits and limitations of imitation activities, offers pedagogical considerations, and suggests avenues for future research in the field of study.

**Keywords:** *interactive activities, pedagogical considerations, language proficiency, critical thinking skills, cultural awareness, literary concepts, literature lessons, imitation, students' participation, language development, interpretation skills*

#### Introduction

In the faculties of foreign languages at Tashkent State Pedagogical University (TSPU) named after Nizami, literature lessons are conducted with the aim of developing students' language proficiency, critical thinking skills, and cultural awareness. However, teachers often encounter various challenges in their efforts to effectively teach literature. These challenges may include limited class time, diverse student backgrounds and abilities, and the need to engage students in meaningful and interactive ways.

Interactive activities play a crucial role in literature lessons, enhancing students' engagement and understanding of literary concepts. Among these activities, imitation has emerged as a valuable pedagogical tool. Many teachers consider that imitation does not concern the interactive nature because imitation techniques is usually used as a drill. However, they have a didactic potential in literature lesson in the context of interaction with literary text while reading and comprehension, reproduction and discussion, etc. By leveraging the interactional potential of

imitation activities, teachers can create lively and engaging literature lessons that overcome the challenges faced in the faculties of foreign languages at TSPU. These activities foster active student participation, language development, critical thinking, and interpretation skills. Furthermore, they provide a platform for collaborative learning and can be adapted to accommodate diverse student backgrounds and abilities. Ultimately, the integration of imitation activities into literature lessons can enhance students' appreciation and understanding of literary texts while promoting their language skills and engagement in the learning process.

That is why this article aims at providing insights into successful methods and activities that can enhance literature instruction to overcome the gaps in the foreign language context.

### **Challenges to literature lessons organization**

One of the key challenges in teaching at literature classes faced by teachers is the constraint of limited class time. Literature lessons often need to strike a balance between language instruction and literary analysis. To overcome this challenge, teachers can adopt efficient time management strategies, such as selecting shorter literary texts or focusing on key excerpts that encapsulate important themes or literary devices. By carefully selecting and prioritizing content, teachers can ensure that students have ample time for close reading, discussion, and reflection.

Another difficulty faced by teachers is catering to the diverse backgrounds and abilities of students. In a foreign language context, students may come from different linguistic and cultural backgrounds, which can impact their understanding and interpretation of literary texts. To address this challenge, teachers can employ differentiated instruction techniques. They can provide scaffolding and support for struggling students while also offering enrichment activities for more advanced learners. Differentiated instruction can include pre-reading activities, vocabulary support, and tailored discussion questions that cater to individual student needs.

To address the challenges faced in literature lessons within the faculties of foreign

languages at TSPU named after Nizami in Uzbekistan, one effective strategy is to leverage the interactional potential of imitation activities. A lot of studies (Smith & Johnson, 2019; Brown & Thompson, 2020; Williams & Davis, 2018) highlight the transformative potential of imitation exercises to deepen students' literary understanding and improve their overall learning experience.

### **Theoretical framework**

In literature education, interactive activities are supported by various educational theories, including constructivism, socio-cultural theory, and active learning approaches. These theories emphasize the importance of active student participation, collaboration, and hands-on learning experiences (Piaget, 1972; Vygotsky, 1978; Bonwell & Eison, 1991). Imitation, as a pedagogical strategy, aligns with these theories by encouraging students to actively engage with texts and participate in the creative process of interactive activity.

Engaging students in meaningful and interactive ways is crucial for effective literature instruction. Passive reading and lecture-style lessons may hinder student motivation and comprehension. To promote active engagement, teachers can incorporate various interactive activities and discussion-based approaches. For instance, literature circles can be implemented, where students read and discuss texts in small groups, taking on different roles and responsibilities. Socratic seminars can also be employed, encouraging students to critically analyze and debate literary themes and ideas. By fostering collaboration, critical thinking, and student-led discussions, these interactive activities create a dynamic learning environment that promotes deep understanding and engagement with the literature.

It is necessary to point out some functions of imitation activities in the literature lessons. Firstly, imitation activities provide a dynamic and interactive way for students to connect with literature. By embodying characters or performing scenes, students are actively engaged in the text, allowing them to develop a deeper understanding of the characters' motivations, emotions, and conflicts. This interactive approach brings literature to

life, making it more relatable and memorable for students.

Secondly, imitation activities promote language development and communication skills. When students imitate the language and style of a literary text, they are exposed to authentic language patterns, vocabulary, and literary devices. Through imitation, students can enhance their language proficiency and fluency, as well as gain a better grasp of the nuances and cultural elements embedded within the literature. Moreover, imitation activities encourage students to work collaboratively, fostering communication and teamwork skills as they interact and coordinate with their peers.

Furthermore, imitation activities provide opportunities for critical thinking and interpretation. By imitating characters or reenacting scenes, students are prompted to analyze and make decisions about the motivations, intentions, and emotions of the characters. This process requires students to engage in close reading, textual analysis, and interpretation, enabling them to develop their critical thinking skills and gain a deeper understanding of the literary work.

In addition, imitation activities can be adapted to address the diverse backgrounds and abilities of students. Teachers can provide scaffolding and support, such as providing model performances, guiding questions, or prompts, to assist students in their imitation tasks. This allows students to participate at their own level and pace, accommodating their individual needs and ensuring that all students can actively engage with the literature.

Moreover, technology can enhance imitation activities by providing additional resources and platforms for students to practice and showcase their imitations. Students can use digital tools to record and share their performances, allowing for peer feedback and reflection. Online platforms or videoconferencing tools can also facilitate remote or asynchronous collaboration, enabling students to engage in imitation activities beyond the confines of the physical classroom.

### **Interactive activities through imitation in literature lessons**

Imitation activities involve students imitating or reenacting literary texts, charac-

ters, or situations, which can enhance their understanding, engagement, and language skills. In particular, imitation exercises involve students emulating various literary elements, such as characters, writing styles, and plot structures. By imitating some verbal and behavioral actions described in the fiction, students can deepen their comprehension of literary techniques and develop their creative and analytical skills (Smith & Johnson, 2019; Brown & Thompson, 2020).

There are various activities through imitation, each serving its own function in literature lessons within the faculties of foreign languages at TSPU. One such activity is character role-playing, where students assume the identities of literary characters and engage in improvised dialogues or scripted scenes. This activity allows students to delve into the psyche of the characters, explore their perspectives, and gain a deeper understanding of their motivations and conflicts.

Another imitation activity is reader's theater, where students perform a script based on a literary text. This collaborative activity enables students to practice expressive reading, intonation, and dramatic interpretation. By embodying the voices and emotions of the characters, students develop their oral communication skills and bring the literature to life.

Imitation activities can also include writing exercises, such as imitating the style or voice of a renowned author. Students can experiment with different literary techniques, mimic the author's writing style, and create their own pieces inspired by the literature studied in class. This activity encourages creativity, develops writing skills, and fosters a deeper appreciation for the craft of writing.

#### ***Activity 1: Character Imitation***

Character imitation involves students creating and embodying literary characters. By assuming the roles of characters, students gain a deeper understanding of their motivations, emotions, and relationships. Through this activity, students develop their empathy, critical thinking, and interpretation skills. Furthermore, character imitation encourages students to analyze the techniques used by authors to create well-rounded characters (Smith & Johnson, 2019).

### **Activity 2: Writing Style Imitation**

Writing style imitation focuses on students emulating the writing styles of established authors. By closely examining an author's word choice, sentence structure, and tone, students gain insights into the author's craft and develop their own writing skills. This activity promotes language development, enhances students' awareness of literary techniques, and encourages creativity in writing (Brown & Thompson, 2020).

### **Activity 3: Plot Imitation**

Plot imitation involves students creating narratives inspired by existing works. By analyzing the structure, pacing, and tension-building techniques employed by authors, students learn how to construct compelling plots. This activity helps students develop their storytelling abilities, strengthens their understanding of narrative elements, and encourages imaginative thinking (Williams & Davis, 2018).

Thus, incorporating character imitation, writing style imitation, and plot imitation activities into literature lessons within the faculties of foreign languages at TSPU offers a range of benefits. These activities promote engagement, critical thinking, language development, creativity, and collaboration among students. By providing opportunities for students to actively immerse themselves in the world of literature, these imitation activities enhance their appreciation for literature, deepen their understanding of literary techniques, and strengthen their language skills.

### **Practical application through Case study**

Implementation of interactive imitation activities into literature curriculum can be achieved through a variety of approaches, such as small group work, class discussions, and individual projects. One of the ways of implementation and survey of efficacy of suggested types of activity is Case study which can be conducted in literature classrooms to demonstrate the positive impact of imitation activities on students' engagement, critical thinking, and creative expression. That is why this method was used to justify the efficacy of imitation activities in literature lessons of TSPU.

**The objective of the case study** was to examine the efficacy of implementing im-

itation activities in a literature classroom and their impact on students' engagement, critical thinking, and creative expression. Let's present all procedural elements and findings of case study conducted by the author of this article.

**Participants:** The study was conducted with a group of 30 students from the group 302 enrolled in a literature course at a university. The students had varying levels of proficiency in the target language and diverse backgrounds in literary studies.

**Implementation:** Over the course of several weeks, a series of imitation activities were integrated into the literature curriculum. The activities included character role-playing, writing style imitation exercises, and plot imitation tasks. These activities were conducted through a combination of small group work, whole-class discussions, and individual projects.

**Data Collection:** Multiple data collection methods were employed to assess the impact of the imitation activities. These included pre- and post-activity surveys to gauge students' initial perceptions and reflections on the activities, classroom observations to document student engagement and participation, and student work samples to evaluate their critical thinking and creative expression.

**Analysis:** The data collected from the case study were analyzed qualitatively. The surveys, classroom observations, and student work samples were examined to identify patterns, themes, and changes in students' attitudes, behaviors, and learning outcomes as a result of the imitation activities.

**Results:** The case study revealed several positive outcomes. Students reported increased engagement and enjoyment in the literature lessons, as the imitation activities made the texts more relatable and interactive. Classroom observations showed higher levels of participation and collaboration among students during the imitation activities compared to traditional teaching methods. Additionally, student work samples demonstrated improved critical thinking skills, language proficiency, and creative expression through their imitations of characters, writing styles, and plots.

**Implications:** The findings of this case study suggest that incorporating imitation activities in literature curriculum can enhance students' learning experience, promote active

engagement, foster critical thinking, and develop their language and creative skills. These activities provide a valuable instructional approach that can be implemented in literature classrooms to deepen students' understanding and appreciation of literary works.

The case study was conducted in English literature classes of TSPU, but the approach can be adapted and applied to literature courses in various educational settings, such as high schools or language institutes. The results of the case study provide evidence for the effectiveness of imitation activities in fostering student learning and can serve as a basis for further research and implementation in literature curricula.

### Conclusion

While imitation activities offer numerous benefits, it is essential to consider their limitations. Imitation should be used as a stepping stone towards developing students' unique voices and styles rather than stifling their creativity. Educators should provide guidance and encourage students to experiment and innovate within the framework of imitation activities. Additionally, ongoing assessment and feedback mechanisms can help monitor stu-

dents' progress and ensure the effectiveness of these activities (Lampert, 2001).

Pedagogical considerations for implementing interactive activities in literature lessons include the need for clear learning objectives, alignment with curriculum standards, and scaffolding support for students at different skill levels. Furthermore, collaboration between literature teachers and language arts specialists can enhance the integration of imitation activities into broader language and literacy development initiatives.

It was found out that interactive activities, such as imitation exercises, hold significant potential in literature education. By engaging students in character imitation, writing style imitation, and plot imitation, educators can foster critical thinking, creativity, and language development. The implementation of these activities requires thoughtful planning, consideration of pedagogical implications, and ongoing research to explore their full potential in enhancing literature lessons. Through collaborative efforts, educators can create dynamic and interactive literature classrooms that inspire students to become passionate readers, critical thinkers, and skilled communicators.

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## Section 5. Physics

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### EXCITON-TWO-PHONON RABMAN SCATTERING OF LIGHT IN A QUANTUM WELL

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#### Abstract

The theory of exciton-two-phonon resonant Raman scattering of light in a quantum well has been developed. It is shown that in the case of exciton-two-phonon Raman scattering of light, in which two-dimensional excitons appear as intermediate states, it leads to a sharp increase in scattering (in  $(\alpha_0^{-3} / \ln^2 \alpha_0)$  times (where  $\alpha_0$  – dimensionless Fröhlich constant of interaction of two-dimensional excitons with LO phonons,  $\alpha_0 \ll 1$ ) compared to the mechanism of electron-hole pairs. The amplification is due to the fact that in a quantum well, in which the energies of the electron and hole are dimensionally quantized, the process of direct creation (or direct annihilation) of an exciton and the actual emission of a second phonon by the exciton are possible. The scattering tensor at the maximum of the second phonon repetition peak is  $\alpha_0^{-1}$ .

**Keywords:** *exciton-two-phonon, resonant Raman scattering, quantum well, two-dimensional excitons, intermediate states, direct creation, phonon, scattering tensor, low dimension, electron and hole, for their potential applications in microelectronic device technology*

#### Introduction

In recent years a great deal of interest has been devoted to the study and the engineering of high-quality devices of very low dimension, essentially quantum-well, wires, or quantum-dots (QDs) semiconductors (Xiao Z., Zhu J., He F., 1995). Because of their low –dimensionality of these systems exhibit many new physical effects (Mukhopadhyay

S., 1995) which are extremely interesting from the point of view of fundamental physics and also for their potential applications in microelectronic device technology.

Consequently much effort has lately gone into understanding and exploring the physical properties of these systems both theoretically and experimentally. These studies have been performed with the proposal of understanding

the fascinating novel phenomena and of fabricating devices with new functions or to improve the performance of the existing devices (Wen Fang X. (2001). Excitons play a dominant role in their physical properties; therefore, their stability is important for possible devices requiring this characteristic (Moussaouy A. El., Bria D., Nougauoi A., Charrou R., Bouhassoune M., 2003). In semiconductor quantum wells, the electron–phonon interaction is usually much less.

As is known, multiphonon resonant Raman scattering (MRRS) is observed during monochromatic irradiation of some polar semiconductors in the fundamental absorption region (Xiao Z., Zhu J., He F., 1995; Mukhopadhyay S., 1995; Sood A.K., Mendez, J., Cardona M. & Ploog K., 1985; Meynadres M.H., Finkman E., Sturge M.D., Warlock J.M. & Tamargo M.C., 1987). The method (MRRS) has been intensively used in recent years to obtain information about both vibrational modes and electronic states and features of electron-phonon and exciton-phonon interactions in systems of reduced dimensionality (heterostructures, quantum wells, wires and points). Secondary lines glow (phonon repetitions) is observed at frequencies  $\omega_s = \omega_l - N\omega_{LO}$ , where  $\omega_l$  is the frequency of the exciting light;  $\omega_{LO}$  – frequency of bulk longitudinal (optical) phonons;  $N$  is the scattering order, i.e. those. number of  $LO$  phonons backgrounds emitted during scattering.

Theoretical studies of MRRS processes in a bulk semiconductor have shown that two types of processes contribute to the scattering cross sections: scattering through intermediate states of free electron-hole (EDH) (Goltsev A.V., Lang I.G., Pavlov S.T. Bryzhina M. F., 1983) and through excitonic states (Korovin L.I., Pavlov S. T. & Eshpulatov B. E., 1990).

Scattering with the participation of free EHPs in two-dimensional systems was studied in (Korovin L.I., Pavlov S. T. & Eshpulatov B. E., 1991), where it was shown that the MRRS cross section is enhanced in  $\alpha_0^{-1}$  times compared to the three-dimensional case. For phonon repetitions  $N \geq 2$ .

This article examines two-phonon resonant Raman scattering (RRS) in a single quantum well in the case where the intermediate states are two-dimensional excitons.

### Statement of the problem and necessary relationships

Let us consider a single quantum well with infinite potential walls located between the  $z = 0$  and  $z = d$  planes. Let us further assume that the relation

$$d \ll r_0, \quad (1)$$

$r_0 = \varepsilon \hbar^2 / \mu e^2$  – exciton Bohr radius,  $\varepsilon$  – dielectric constant of the quantum well material,  $e$  – electron charge,  $\mu$  – reduced effective mass.

Inequality (1) ensures the two-dimensionality of the exciton. We will assume that the exciton, emitting phonons, remains in the  $1S$  state all the time.

In the case of the second phonon repetition, the scattering tensor is determined by the expression (Korovin L.I., Pavlov S. T. & Eshpulatov B. E., 1988).

$$S_{\beta\gamma\beta'\gamma'} = S_{\beta\gamma\beta'\gamma'}^{(0)} (S_1 + S_2), \quad (2)$$

Where

$$S_{\beta\gamma\beta'\gamma'}^{(0)} = \left( \pi \hbar^6 \omega_s^2 \omega_l^2 \right)^{-1} (\hbar \omega_{LO})^4 (2d / \pi r_0)^4 \times \\ \times J_\beta J_\gamma J_{\beta'}^* J_{\gamma'}^* \delta(\omega_l - \omega_s - 2\omega_{LO}). \quad (3)$$

Scalar functions  $S_1$  and  $S_2$  represent one- and two-fold sums over quantum numbers of size quantization

$$S_1 = \alpha_0^2 \sum_{n=0}^{\infty} \int K dK I^2(K, n) \left[ (1+a_h)^{-3/2} - (1+a_e)^{-3/2} \right]^4 \times \\ \times |G(n, n, K, \omega_l - \omega_{LO})|^2 |G(n, n, 0, \omega_l)|^2 |G(n, n, 0, \omega_s)|^2, \quad (4)$$

Where

$$\alpha_0 = 2\hbar\omega_{LO} (\varepsilon_\infty^{-1} - \varepsilon^{-1}); a_{e(h)} = (\alpha_0 m_{e(h)} / 4m_e) K, \\ \omega_s = \omega_l - 2\omega_{LO} \\ G(n, n', \kappa, \omega) = \\ = [\omega - \omega(n, n', \kappa) - (i/2)\gamma(n, n', \kappa)]^{-1} \quad (5)$$

Green's function The expression for the Green's function (5) includes the function  $\gamma(n_e n_h, \mathbf{K}) = \tau^{-1}(n_e n_h, \mathbf{K})$ , where  $\tau(n_e n_h, \mathbf{K})$  is the lifetime of an exciton in the state  $(n_e n_h, \mathbf{K})$  The function  $\gamma$ , which has the meaning of a mass operator, is not calculated further; it is only assumed that

$$(\gamma / \omega_{LO}) \ll 1. \quad (6)$$

If we calculate  $\gamma$  to first order from the coupling constant  $\alpha_0$ , then it is obvious that  $\gamma \sim \alpha_0$ .



$$S_2 = \alpha_0^2 \sum_n \int_0^\infty K dK I^2(K, n, n') \left\{ \left| G(n, n', K, \omega_l - \omega_{LO}) \chi(n, n', \omega_l) \right|^2 \times \right. \\ \left. \times \chi(n, n', \omega_s) + \left| G(n', n, K, \omega_l - \omega_{LO}) \right|^2 \chi(n', n, \omega_l) \chi(n', n, \omega_s) \right\}, \quad (7)$$

$$\alpha_{h(e)} = (\alpha_0 m_{h(e)} / 4m_e) K, \quad \omega_s = \omega_l - 2\omega_{LO}.$$

Functions look like

$$\chi(n, n', \omega), I(K, n) u I(K, n, n') \quad \chi(n, n', \omega) = (1 + \alpha_h)^{-3} |G(n, n, 0, \omega)|^2 + \\ + (1 + \alpha_e)^{-3} |G(n', n', 0, \omega)|^2, \quad (8)$$

$$I(K, n) = \left( \frac{2}{x} + \frac{1}{b_n^2 + x^2} \right) \left\{ 1 - \frac{2b_n^2 [1 - \exp(-x)]}{x(b_n^2 + x^2)(2b_n^2 + 3x^2)} \right\}, \quad b_n = 2\pi n, \quad (9)$$

$$I(K, n, n') = \left[ \pi^2 (n - n')^2 + x^2 \right]^{-1} + \left[ \pi^2 (n + n')^2 + x^2 \right]^{-1}, \quad x = Kd. \quad (10)$$

in  $S_1$  and  $S_2$  the Green's function  $G(n, n, 0, \omega_l)$  corresponds to the direct production of an exciton, and  $G(n, u, 0, \omega_s)$  corresponds to its direct annihilation.

These processes can only take place if  $K = 0$  (the small impulse of the light wave is neglected).

$$|G(n, n, 0, \omega)|^2 = \left[ (\omega - \omega'_g - n^2 \omega_\mu)^2 + \gamma^2 \right]^{-1}, \quad \omega_\mu = \omega_{0e} + \omega_{0h} - \omega'_g = \omega_g - \Delta\omega. \quad (11)$$

The Green's function  $G(n, n', K, \omega_l - \omega_{LO})$  corresponds to the emission of a phonon by an exciton both for the case of scattering in

the same zone ( $n = n'$ ) and for the case of transition to another zone ( $n \neq n'$ ). Its square modulus is equal to

$$|G(n, n', K, \omega_l - \omega_{LO})|^2 = \left[ \left( \omega_l - \omega_{LO} - \omega'_g - \omega_{0e} n^2 - \omega_{0h} n'^2 - \frac{\hbar K^2}{2m_e} \right)^2 + \gamma^2 \right]^{-1}. \quad (12)$$

### Frequency dependence of the scattering tensor

Let us first consider the case of scattering in the same zone, described by the function  $S_1$ . At frequencies  $\omega_l < \omega'_g + n^2 \omega_\mu$  all Green's functions are non-resonant (no real transitions) and  $S_1 \sim \alpha_0^2$ , which corresponds to background scattering.

At the frequency  $\omega \omega_l^{(1)} = \omega'_g + n^2 \omega_\mu$  real direct production of an exciton becomes possible, and at this frequency  $|G(n, n, 0, \omega)|^2 \sim \gamma^2$ . Since  $\gamma \sim \alpha_0$ , then  $S_1 \sim \alpha_0^0$ . At frequency  $\omega_l^{(1)}$  there is a peak that is  $\alpha_0^{-2}$  times higher than the background. In the frequency domain background. In the frequency domain

$\omega' + n^2 \omega_\mu < \omega_l < \omega'_g - n^2 \omega_\mu + \omega_{LO}$  (13) all Green's functions are non-resonant and  $S_1 \sim \gamma^2$ . Starting from frequency

$$\omega_l^{(2)} > \omega'_g - n^2 \omega_\mu + \omega_{LO} \quad (14)$$

becomes resonant  $G(n, n, K, \omega_l - \omega_{LO})$  (real phonon emission is possible). Therefore, with sufficient accuracy we can assume that

$$|G(n, n, K, \omega_l - \omega_{LO})|^2 = \\ = \frac{2\pi}{\gamma} \delta \left( \omega_l - \omega_{LO} - \omega'_g + n^2 \omega_\mu - \frac{\hbar K^2}{2m_e} \right). \quad (15)$$

If the parameter is  $\gamma / \omega_{LO} \ll 1$ , then when integrating over the variable  $K$ , the contribution of the pole of the function  $G(n, n, K, \omega_l - \omega_{LO})$  becomes dominant. Therefore, with sufficient accuracy we can assume that

$$|G(n, n, K, \omega_l - \omega_{LO})|^2 = \\ = \frac{2\pi}{\gamma} \delta \left( \omega_l - \omega_{LO} - \omega'_g + n^2 \omega_\mu - \frac{\hbar K^2}{2m_e} \right). \quad (15)$$

Then in the frequency domain (13)

$$S_1 = \frac{2\pi a_0^2 m_e}{\gamma \hbar} \sum_n I^2(K_0, n) \left[ (1+a_h)^{-3/2} - (1+a_e)^{-3/2} \right]^4 \times |G(n, n, 0, \omega_l)|^2 |G(n, n, 0, \omega_s)|^2 \quad (16)$$

$$K_0 = \sqrt{2m_e / \hbar} \sqrt{\omega_l - \omega_{LO} - \omega'_g + n^2 \omega_m},$$

those  $S_1 \sim \alpha_0$ . If  $\omega_l = \omega_l^{(3)} = \omega'_g + n^2 \omega_{LO} + 2\omega_{LO}$  (frequency corresponding to direct annihilation), then  $|G(n, n, 0)|^2 \sim \gamma^2$  and  $S_1 \sim \alpha_0^{-1}$ .

Thus, the frequency dependence  $S_1(\omega_l)$  has two peaks: weaker  $S_1(\omega_l) \sim \alpha_0^0$ , corresponding to real direct exciton production;

$$S_1 = \frac{2\pi a_0^2}{\gamma} \left( \frac{3\alpha_0}{8} \right)^4 \frac{2m_e^3}{\hbar^3} \left( \frac{\omega_h - \omega_e}{\omega_h + \omega_e} \right)^4 \sum_n (\omega_l - \omega_{LO} - \omega'_g + n^2 \omega_\mu)^2 \times |G(n, n, 0, \omega_l)|^2 |G(n, n, 0, \omega_s)|^2, \quad (17)$$

$$\omega_l \geq \omega'_g + \omega_{LO} + n^2 \omega_\mu.$$

The frequency dependence of  $S_2$  differs from the frequency dependence of  $S_1$  in that at frequency  $\omega_l^{(1)} S_2 \sim \alpha_0^{-1}$ , while  $S_1 \sim \alpha_0^0$ . The fact is that the function  $|G(n, n, K, \omega_l - \omega_{LO})|^2$  can be approximated by the  $\delta$  - function at frequencies

$$\omega_l^{(4)} = \omega'_g + \omega_c n^2 + \omega_v n'^2 + \omega_{LO}. \quad (18)$$

$$S_2 = \frac{2\pi a_0^2 m_e}{\gamma \hbar} \sum_{n>n'} \left[ I^2(K_{01, n, n'}) c(n, n', \omega_l) c(n, n', \omega_s) + I^2(K_{02, n', n}) c(n, n', \omega_l) c(n', n, \omega_s) \right], \quad (19)$$

Where

$$K_{01} = \sqrt{2m_e / \hbar} \sqrt{\omega_l - \omega_{LO} - \omega'_g - \omega_{0e} n^2 - \omega_{0h} n'^2}, \quad K_{02} = \sqrt{2m_e / \hbar} \sqrt{\omega_l - \omega_{LO} - \omega'_g - \omega_{0e} n'^2 - \omega_{0h} n^2}. \quad (20)$$

he part of formula (19), which depends on  $K_{02}$ , is valid in a wider frequency range  $\omega_l^{(5)} = \omega'_g + \omega_{0e} n'^2 + \omega_{0h} n^2$ . approaching  $\alpha_0 K_{01(2)} \ll 1$

strong peak  $S_1(\omega_l^{(3)}) \sim \alpha_0^{-1}$ , corresponding to real direct annihilation;

In the case of equal effective masses ( $m_e = m_h$ )  $S_1$  becomes zero.

In the limiting case  $\alpha_0 K_0 \ll 1$  (usually  $\alpha_0 \cong 10^{-5} \div 10^{-6} \text{ cm}$ ,  $K_0 \cong 10^3 \div 10^4 \text{ cm}^{-1}$  formula (16) is simplified and takes the form

This frequency interval includes the frequency  $\omega_l^{(1)}$ , at which  $|G(n, n', 0, \omega_l^{(1)})| \sim \gamma^{-2}$ , if the condition  $(n = n') \omega(n^2 - n'^2) \omega_v > \omega_{LO}$  real transition between bands  $nm$  and  $mn'$  with emission of LO phonon. Replacing  $|G(n, n', K, \omega_l - \omega_{LO})|^2$  in (7) with a  $\delta$  - function and integrating over  $K$ , for  $S_2$  we obtain the expression

$$I(K_0, n, n') \rightarrow (2/\pi^2) \left[ (n^2 + n'^2) / (n^2 - n'^2)^2 \right]$$

$$I(K_0, n, n') \rightarrow (2/\pi^2) \left[ (n^2 + n'^2) / (n^2 - n'^2)^2 \right]$$

and from (7), (8) we obtain

$$S_2 = \frac{16\alpha_0^2 m_e}{\gamma \pi^3 \hbar} \sum_{n>n'} \frac{(n^2 + n'^2)^2}{(n^2 - n'^2)^2} |G(n, n, 0, \omega_l)|^2 |G(n, n, 0, \omega_s)|^2, \quad (21)$$

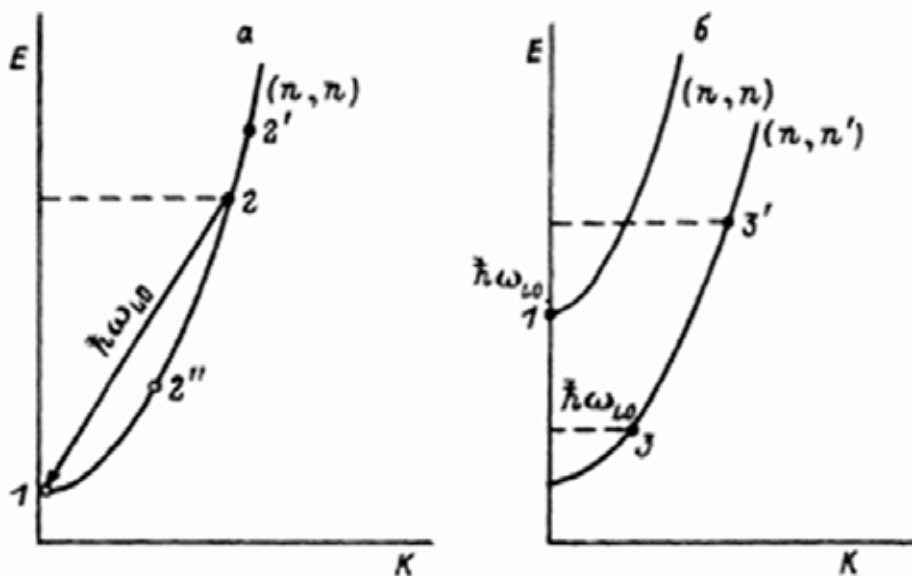
$$\omega_l \geq \omega'_g + \omega_{LO} + \omega_{0e} n^2 + \omega_{0h} n'^2.$$

#### 4. Discussion of the results obtained

When deriving formula (17), terms containing  $|G(n', n', 0, \omega_s)|^2$  are omitted, since the maxima of these functions are located outside the frequency interval  $\omega_l^{(5)}$ . Formulas (16) and (17) are valid in the vicinity of the maximum of the Green's function, which lead

to large values of  $S_1$  and  $S_2 \sim \alpha_0^{-1}$ . Function  $S_1$  contains one such maximum at  $\omega = \omega_l^{(3)}$ , corresponding to direct annihilation of excitons. Function  $S_2$  has two strong maxima: one at the frequency  $\omega_l = \omega_l^{(1)}$  (direct exciton production) and the other coinciding with the strong maximum of function  $S_1$ . Exciton transitions for the cases  $n \neq n'$  are shown in (Fig. 1).

**Figure 1.** Scheme of exciton transitions in the case of taking into account only one (a) and two (б) excitonic zones



1 – exciton energy after direct production or before indirect annihilation; 2, 2', 2'' and 3' – after indirect birth; 3 – before indirect annihilation.

$E$  is the energy of the exciton band,  $K$  is the modulus of the exciton wave vector.

The considered excitonic mechanism of two-phonon RRS leads to a sharp increase in the scattering cross section (scattering tensor  $S_{bg'b'g'} \sim a_0^{-1}$  at the resonant frequencies of the exciting light) compared to electron-hole pairs as intermediate states ( $S_{bg'b'g'} \sim a_0^2 \ln^2 a_0$ ).  $a_0^{-3} / \ln^2 a_0 a_0$ . Thus, there is an increase in scattering by  $a_0^{-3} / \ln^2 a_0 a_0$  times. From this we can conclude that in a quasi-two-dimensional electron system, the mechanism of two-phonon RSRS is predominant. This conclusion seems justified specifically for two-phonon scattering, when the exciton appears only in the act of indirect creation (or indirect annihilation) and single emission of a  $LO$  - phonon. phonons, the question of the relationship between the contribution of the exciton mechanism and the EHP mechanism to scattering becomes more complicated. This is due to the fact that when a  $LO$  - phonon is emitted by a hot exciton, it

can go into the EHP state and then phonons will be emitted by the electron and hole. Without exploring the relative roles of the two scattering mechanisms in this paper. We only note that the dependence of the scattering tensor on the coupling constant  $\alpha_0$  in the case of MFRRS with a purely exciton mechanism. Remains the same as in the case of two-phonon RSRS, since the appearance of an additional coupling constant in the numerator during the transition from  $N$  to  $N + 1$  emitted phonons will be compensated by the appearance of the constant  $\gamma \sim a_0$  in the denominator, which comes from the process of real emission of a phonon by an exciton .

The excitonic scattering mechanism in a bulk semiconductor is  $a_0^{-2}$  times weaker than scattering in a quasi-two-dimensional system. The enhancement of two-phonon scattering compared to the bulk case is explained by the fact that in a quantum well in the frequency range corresponding to direct production or direct annihilation of an exciton, real phonon emission is possible, while in a bulk semiconductor two-phonon scattering consists of two indirect processes – creation and annihilation exciton.

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