January 2022

Yuri Fedkovych Chernivtsi National University
Physical Technical and Computer Science Institute

SYLLABUS
EDUCATIONAL DISCIPLINE
"TOPOLOGICAL METHODS IN OPTIC"

selective discipline

Educational and professional program - "Physics and Astronomy"
Specialty - № 104 "Physics and Astronomy"
Field of knowledge - № 10 "Natural Sciences"
The level of higher education is the third
Physical Technical and Computer Science Institute
The language of instruction is Ukrainian
Developer - Professor of Correlation Optics, Professor, Doctor of Physics and Mathematics, Igor Mokhun
Teacher's profile - http://ptcsi.chnu.edu.ua/teachers/мохунь-ігор-іванович/
Contact phone - 0972193715
E-mail - i.mokhun@chnu.edu.ua
Moodle course page - https://moodle.chnu.edu.ua/course/view.php?id=833
Consultations: online consultations, Monday from 14.00 to 15.00.

Summary

The aim of the course is get to know the graduate student with a new direction of modern Optics - Singular Optics, examples of new types of devices, which may be formed on the basis of Singular Optics algorithms, algorithms for restoring field characteristics by singularities networks, using topology methods in analyzing the structure of optical fields.

The course is one of the final training courses for a specialist in "Physics and Astronomy" of the third education level.

Content modules*: Basic concepts of Singular Optics (SO)*. The concept of SO. Basic concepts of elementary topology. Special points. Conservation law of topological charges and indices. Networks of singular and stationary points, connection between their elements. Singularities in scalar fields. Isolated singularities. Isotropic and anisotropic vortices. Propagation of singular structures. Interference patterns of singular structures. Generation of optical vortices using computer generated holograms. The formation of vortices due to the interference of a small number of beams. Birth and annihilation of vortices. Topological reactions. Micro-object control devices. Optical tweezers and molecular motors. Sign principle. Fine structure of the field and the network of singularities. Relationship between scalar field characteristics. Application of SO-principles to solve a phase problem. *Singularities in vector fields*. Paraxial case. Disclinations. Polarization singularities (PS). S- and C-singularities. Singular skeleton of vector field. Topological characteristics of polarization singularities. Relationship between PS characteristics and orthogonal component vortices. Methods of experimental analysis of vector field singularities. Phase differences vortices. Networks of PS. Sign principle for vector field. Generation of polarization singularities. Self-converging optical traps. Angular momentum of the field in the vicinity of polarization singularities. Relationship between different characteristics of vector field. Stokes formalism for polarization singularities. Poincare vortices. The relationship between the fine structure of the field and its integral characteristics. Three-dimensional polarization singularities. Formulation of the problem. Three-dimensional polarization singularities. Topological characteristics. The difference between paraxial and general cases.

1. The goal of the course: The aim of the course is get to know the graduate student with a new direction of modern Optics - Singular Optics, examples of new types of devices, which may be formed on the basis of Singular Optics algorithms, algorithms for restoring field characteristics by singularities networks, using topology methods in analyzing the structure of optical fields.

The course is one of the final training courses for a specialist in "Physics and Astronomy" of the third level of education.

The study of this discipline will contribute to the acquisition of the following competencies defined by the Educational and Scientific Program:

Integral competence:

IC Ability to solve complex problems in the field of professional and / or research and innovation activities, which involves a deep rethinking of existing and the creation of new holistic knowledge and / or professional practice.

General competencies

GC1. Ability to abstract thinking, analysis and synthesis.

GC5. Ability to generate new ideas and apply knowledge in practical situations.

GC8. Ability to work autonomously, initiate, organize and conduct comprehensive theoretical and experimental research.

GC10. Ability to identify, pose and solve problems and conduct research at the appropriate level, plan and predict results.

Professional competencies

PC1. Research abilities and competence to perform original research in the chosen field of physics and achieve scientific results that create new knowledge, paying special attention to current issues and using the latest scientific methods.

PC5. Ability to generate new ideas and solve complex problems in the chosen field of physical research.

PC6. Ability to conduct basic and applied research using modern experimental and theoretical methods.

PC7. Awareness of the goals and objectives of modern physics and astronomy, the ability to solve problems and problems of an innovative nature in one of the branches of physics or astronomy.

Program learning outcomes

PLO2. Ability to carry out a complete original study based on the use of modern methods of science.

PLO10. Be able to develop and research physical, mathematical and computer models of processes and systems, effectively use them to gain new knowledge and / or create innovative products in physics and related interdisciplinary areas.

PLO11. Plan and perform experimental and / or theoretical research in physics and related interdisciplinary fields using modern scientific methods, critically analyze the results of their own research and the results of other researchers in the context of the whole set of modern knowledge about the research problem.

2. Learning Outcomes: As a result of studying the course the graduate student must:

Know:

• theoretical foundations and approaches of Singular Optics (SO);
• principles of construction and analysis of singular structures of scalar and vector optical fields;
• principles of measuring the characteristics of singular structures;
• methods of synthesis of singular structures of scalar and vector fields;
• principles of practical application of SO-algorithms, and principles of development of SO-based devices;

Be able:

• perform a singular analysis of the optical field;
• to synthesize singular structures of arbitrary type by means of holography and interferometry;
• on the basis of artificial optical singularities to form SO-systems for different purposes.

3. Description of the discipline

3.1. general information

Form of study	Year of study	Semester	Number			Number of hours						Type of final control
			Credits	Hours	Content modules	lectures	practical training	seminars	laboratory classes	Individual work	Individual tasks	
Full-time education	1	1	4	120	3	30				90		exam

The structure of the discipline

Names of content modules and topics	Number of hours					
	total	lec-tures	pr.tr.	lab. cl.	Ind. work	Ind. tasks
1	2	3	4	5	6	7
Content module 1. Basic concepts of Singular Optics						
Topic 1. Basic concepts of Singular Optics. The conservation law of topological charges	8	2				6
Topic 2. Vortices. Identification and generation of vortices	8	2				6
Topic 3. Vortices of the scalar field and its phase structure	8	2				6
Topic 4. Birth and disappearance of vortices.	8	2				6
Topic 5. Vortices in random field. “Correlation” of phase and intensity	8	2				6
Together on the content module 1	40	10				30
Content module 2. Vortices in random fields						
Topic 6. Extrema of phase and intensity in optical field	8	2				6
Topic 7. Topological indices of the field intensity	8	2				6
Topic 8. Restoration of the field phase based on the analysis of vortex networks.	8	2				6
Topic 9. Determination of signs of vortices of a random field	8	2				6
Topic 10. Implementation of singular models. Structural stability. Genericity	8	2				6
Together on the content module 2	40	10				30
Content module 3. Polarization singularities						
Topic 11. Disclinations. Polarization singularities	8	2				6
Topic 12. Methods of analysis of polarization singularities.	8	2				6
Topic 13. Phase difference vortices. Sign principle for vector field	8	2				6
Topic 14. "Anticorrelation" between the intensity and polarization of the vector field.	8	2				6
Topic 15. Elementary polarization structures. Singular structure of a vector field and averaged characteristics of a vector field.	8	2				6
Together on the content module 3	40	10				30
Total hours	120	30				90

3.3. Topics of seminars
Seminars are not provided

3.4. Topics of practical classes
Practical classes are not provided

3.5. Topics of laboratory classes
Laboratory classes are not provided

3.6. Topics of individual tasks
Individual tasks are not provided

1. 3.7. Individual work

№ з/п	Name topics
1	Poynting vector singularities (P-singularity) and structure of optical fields
2	Instantaneous scalar field singularities. The averaged singularities of the Poynting vector of the scalar field.
3	Poynting vector singularities in vector fields. Instant singularity vector field.
4	Gaussian optical trap.
5	Vortex optical trap.
6	Optical tweezers. Types of optical traps.
7	Orbital and spin angular moments of the optical field

* *Individual work of graduate students consists of preparation for lectures, processing of lecture material, which is 100% of the classroom load (30 hours) and mastering the topics identified for Individual study (60 hours).*

4. Criteria for evaluating learning outcomes in the discipline

Assessment scale: national and ECTS

Score on a national scale	**Assessment on the ECTS scale**	
	Score (points)	**Explanation for extended scale**
Perfectly	A (90-100)	perfectly
Okay	B (80-89)	very well
	C (70-79)	okay
Satisfactorily	D (60-69)	satisfactorily
	E (50-59)	enough
Unsatisfactorily	FX (35-49)	(unsatisfactorily) with the possibility of reassembly
	F (1-34)	(unsatisfactorily) with a mandatory repeat course

5. Assessment tools

Surveys at lectures, current and final (modular) tests, testing, exams.

5.1. Distribution of points received by graduate students

Ongoing testing and individual work															Final test (exam)	The sum
Content module 1					Content module 2					Content module 3					40	100
T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15		
4	4	4	4	4	4	4	4	4	4	4	4	4	4	4		

5.2. Questions to be taken for the exam

1. Phase vortices. Definition. Types of vortices.
2. Topological charge and topological index of singular points.
3. The conservation law of topological charges. Elementary topological reactions.
4. Experimental observation and identification of scalar field vortices.
5. Generation of vortices using computer generated holograms.
6. Sign principle for the scalar field.
7. Physical feasibility (genericity) and structural stability of field defects. The birth of vortices.
8. Occurrence of wave front dislocations due to interference of wave fronts with simple phase surfaces.
9. Topological indices of the intensity field. Extremes of phase and intensity
10. "Anticorrelation" of phase and intensity.
11. Determining the signs of random field vortices.
12. Implementation of singular models. "Absolute" ("stationary") zeros of intensity.
13. Polarization modulation of the field in the vicinity of "absolute" zero amplitudes.
14. Disclinations. Polarization singularities.
15. phase differences vortices. Sign principle for vector field.
16. Methods of research of polarization singularities.
17. Experimental determination of s-contour characteristics.
18. C-points as vortices of phase difference.
19. "Anticorrelation" between the intensity and polarization of the vector field.
20. Relationship between component vortices and C-points.
21. Polarization structures obtained by interference of linearly polarized beams. Elementary polarization singularities obtained by interference of circularly polarized beams.
22. Fine structure of inhomogeneous vector field and its averaged polarization characteristics. "Stokes-formalism" of polarization singularities. Stokes-vortices.
23. Components of the Poynting vector.
24. Poynting vector singularities in scalar fields. Instantaneous and averaged singularities of the scalar field.
25. Poynting vector singularities in vector fields. Instantaneous and averaged singularities of a vector field

5.3. Criteria for evaluation of usny or letter reports of graduate students

Number of balls	Assessment criterion
1.6-2	The graduate student gives me full answer on the question, or graduate student will take an active part in the discussion of the issue and essentially adds information about the views of their comrades.
1-1.5	A graduate student gives me full answer on the question with minor inaccuracies, as they do not infuse into the essence of the opinion, but rather correctly supplement the views of his comrades by 50% of the nutrition of those.
0.6-0.9	A graduate student, gives me relatively full answer on the question, he is allowed to take insignificant pardons, since he does not add to the essence of the decision for help, but if he correctly adds 30% of the food to his comrades.
0.1-0.5	Postgraduate student for additional assistance, fragmentarily answers on the question, but has not minimal knowledge of this question
0	The graduate student cannot answer on the question and does not take the discussion on this question.

5.4. Questions for modular control of the lecture course

Module 1

1. Phase vortices. Definition. Types of vortices.
2. Topological charge and topological index of singular points.
3. The conservation law of topological charges. Elementary topological reactions.
4. Experimental observation and identification of scalar field vortices.
5. Generation of vortices using computer generated holograms.
6. Sign principle for the scalar field.
7. Physical feasibility (genericity) and structural stability of field defects. The birth of vortices.
8. Occurrence of wave front dislocations due to interference of wave fronts with simple phase surfaces.

Module 2

1. Topological indices of the intensity field. Extremes of phase and intensity
2. "Anticorrelation" of phase and intensity.
3. Determining the signs of random field vortices.
4. Implementation of singular models. "Absolute" ("stationary") zeros of intensity.
5. Polarization modulation of the field in the vicinity of "absolute" zero amplitudes.
6. Disclinations. Polarization singularities.
7. phase differences vortices. Sign principle for vector field.
8. Methods of research of polarization singularities.
9. Experimental determination of s-contour characteristics.

Module 3

1. C-points as vortices of phase difference
2. "Anticorrelation" between the intensity and polarization of the vector field.
3. Relationship between component vortices and C-points.
4. Polarization structures obtained by interference of linearly polarized beams. Elementary polarization singularities obtained by interference of circularly polarized beams.
5. Fine structure of inhomogeneous vector field and its averaged polarization characteristics. "Stokes-formalism" of polarization singularities. Stokes-vortices.
6. Components of the Poynting vector.
7. Poynting vector singularities in scalar fields. Instantaneous and averaged singularities of the scalar field.
8. Poynting vector singularities in vector fields. Instantaneous and averaged singularities of a vector field

6. Forms of current and final control

Surveys at lectures, current and final (modular) tests, testing, exams

7. Recommended literature

7.1. Main

1. I.I.Mokhun. *Introduction to linear singular optics*, Chapter 1 in the book Optical correlation techniques and applications, edited by O.V.Angelsky. – 2007. – SPIE press, Bellingham, Washington, USA.
2. J. F. Nye, *Natural focusing and fine structure of light* (Institute of Physics Publishing, Bristol and Philadelphia, 1999). (2 прим. та електронна версія, виставлена в локальній мережі ІТФ).
3. M. Soskin and M. Vasnetsov, *Singular Optics as a New Chapter of Modern Photonics: Optical Vortices Fundamentals and Applications*, Photonics Sci. News, 4, is 4 (1999) 21.
4. P. Senthilkumaran. *Singularities in Physics and Engineering*. IOP Publishing, Bristol, UK (2018).
5. Selections of articles on singular optics..

7.2. Additional

1. Born M. and Wolf E. "*Principles of optics*", sixth edition, Oxford: Pergamon, (1980).
2. R.M.A. Azzam, N.M. Bashara. "*Ellipsometry and polarized light".* North-Holland publishing company, (1977).
3. J.W. Goodman. Statistical Optics. New York, N.Y. : Wiley, (1985)
4. Франсон М. Оптика спеклов. Пер. с франц. под ред. Островского Ю.И. – М.: Мир. 1982. – 182 С.
5. *Handbook of mathematical functions*. Edited by M. Abramovvitz and Irene A. Stegun, National bureau of standards applied mathematics series – 55 (1964)

8. Information resources

1. Мохунь І.І., Вікторовська Ю.Ю. Вступ до лінійної сингулярної оптики. Чернівці: Рута, 2012. – 189 с. (Цифровий університет. ЧНУ)