



Univerza v Mariboru

Fakulteta za naravoslovje
in matematiko

Koroška cesta 160
2000 Maribor, Slovenija

UČNI NAČRT PREDMETA / COURSE SYLLABUS

Predmet:	Elektromagnetne in optične lastnosti materialov
Course title:	Electromagnetic and optical properties of materials

Študijski program in stopnja Study programme and level	Študijska smer Study field	Letnik Academic year	Semester Semester
Fizika 2. st.		1,2	1,2,3,4
Physics 2 nd degree		1,2	1,2,3,4

Vrsta predmeta / Course type

Izbirni / Elective

Univerzitetna koda predmeta / University course code:

Predavanja Lectures	Seminar Seminar	Sem. vaje Tutorial	Lab. vaje Laboratory work	Teren. vaje Field work	Samost. delo Individ. work	ECTS
60		30			210	10

Nosilec predmeta / Lecturer:

Uroš Tkalec in Nataša Vaupotič

Jeziki /

Predavanja / Lectures:

Slovenski / Slovene

Languages:

Vaje / Tutorial:

Slovenski / Slovene

Pogoji za vključitev v delo oz. za opravljanje študijskih obveznosti:

Osnovno znanje klasične fizike in vektorske analize.

Vsaka obveznost študenta v načinih ocenjevanja mora biti opravljena s pozitivno oceno. Vse sprotne naloge morajo biti izračunane in zagovorjene pred pristopom k pisnemu izpitu.

Prerequisites:

Basic knowledge of classical physics and vector analysis.

Each student requirement within the assessment methods must be completed with a passing grade. Completion and defense of all coursework are prerequisites for taking the written exam.

Vsebina:

- Elektrostatika: Coulombov zakon; električna sila, naboji in njihove porazdelitve; silnice, polje in Gaussov izrek; Poissonova enačba; elektrostatska energija in multipolni razvoj; polarizacija v dielektrikih.
- Magnetostatika: magnetna sila in polje; magnetni potencial, dipolni moment in magnetizacija; električni tok in Amperov zakon; Biot-Savartov zakon; magnetna energija, pretok in indukcija.
- Elektromagnetno valovanje: odboj, lom, koherenca in polarizacija svetlobe; osnove

Content (Syllabus outline):

- Electrostatics: Coulomb's law; electric force, charges and their distributions; forces, field and Gauss theorem; Poisson's equation; electrostatic energy and multipole evolution; polarisation in dielectrics.
- Magnetostatics: magnetic force and field; magnetic potential, dipole moment and magnetisation; electric current and Ampere's law; Biot-Savart law; magnetic energy, flux and induction.
- Electromagnetic waves: reflection, refraction, coherence and polarisation of light; basics of

Fourierove optike; sevanje električnega dipola; antene in valovni vodniki; skalarna teorija uklona. ➤ Maxwellove enačbe: ohranitveni zakoni in primerjava enačb za elektromagnetno polje. ➤ Elektromagnetno polje v snovi: frekvenčno odvisna dielektrična funkcija in relaksacije; razširjanje svetlobe v dielektrikih, prevodnikih in optično anizotropnih materialih; dvojni lom, elektrooptični in magneoptični pojav; modulatorji, optični retarderji in konoskopija. ➤ Nelinearna optika: simetrije v kristalih, nelinearna susceptibilnost, generiranje druge harmonične frekvence, štirivalovno mešanje; prostorski in površinski plazmoni. ➤ Metamateriali, metapovršine in fotoniki kristali. ➤ Tenzorski opis elektromagnetnega polja: Lorentzove transformacije, invariantnost Maxwellovih enačb, prostor Minkowskega in povezave s posebno teorijo relativnosti. ➤ Relativistični nabiti delci v električnem in magnetnem polju: Lagrangeova gostota polja, Hamiltonova funkcija, Maxwellov napetostni tenzor.	Fourier's optics; electric dipole radiation; antennas and wave guides; scalar diffraction theory. ➤ Maxwell's equations: conservation laws and comparison of electromagnetic field equations. ➤ Electromagnetic field in matter: frequency-dependent dielectric function and relaxations; light propagation in dielectrics, conductors and optically anisotropic materials; double refraction, electro-optic and magneto-optic phenomena; modulators, optical retarders and conoscopy. ➤ Nonlinear optics: symmetries in crystals, nonlinear susceptibility, second harmonic frequency generation, four-wave mixing; spatial and surface plasmons. ➤ Metamaterials, metasurfaces and photonic crystals. ➤ Tensor description of the electromagnetic field: Lorentz transformations, invariance of Maxwell's equations, Minkowski space and connections with special relativity. ➤ Relativistic charged particles in electric and magnetic fields: Lagrange field density, Hamiltonian function, Maxwell's stress tensor.
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Temeljni literatura in viri / Readings:

➤ J. Vanderlinde, Classical electromagnetic theory, 2nd Ed. (Springer, 2005). ➤ L. D. Landau in E. M. Lifshitz, Classical theory of fields, 4th Ed. (Butterworth-Heinemann, 1998). ➤ R. Podgornik in A. Vilfan, Elektromagnetno polje (DMFA, Ljubljana, 2012). ➤ M. Ambrožič, U. Tkalec in S. Kralj, Elektromagnetno polje: učbenik za študente fizike na FNM UM (Univerzitetna založba UM, Maribor, 2019). ➤ G. R. Fowles, Introduction to Modern Optics, 2nd Ed. (Dover, New York, 1989). ➤ E. Hecht, Optics, 3rd Ed. (Addison-Wesley, 1998). ➤ M. Fox, Optical properties of solids 2nd Ed. (Oxford University Press, Oxford, 2012). ➤ M. Čopič in M. Vilfan, Fotonika (Univerza v Ljubljani, Fakulteta za matematiko in fiziko, Ljubljana, 2020). ➤ I. Drevenšek Olenik in M. Vilfan, Optika (Univerza v Ljubljani, Fakulteta za matematiko in fiziko, Ljubljana, 2023).
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Cilji in kompetence:

Študenti usvojijo napredna teoretična znanja s področja elektromagnetizma, linearne in nelinearne optike, razširjanja svetlobe skozi prazen prostor in materiale ter ta znanja uporabijo pri reševanju ustreznih problemov z uporabo matematičnih orodij.
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Objectives and competences:

Students obtain advanced theoretical knowledge of electromagnetism, linear and nonlinear optics, light propagation through empty space and different materials, and are able to apply this knowledge to tackle relevant problems by using mathematical tools.
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Predvideni študijski rezultati:

Znanje in razumevanje: Znanje in razumevanje po uspešno zaključeni učni enoti: ➤ poznavanje in uporaba osnovnih zakonov elektromagnetizma in Maxwellovih enačb ter njihovih posledic in simetrij, vključno s kovariantno formulacijo elektrodinamike in njeno povezavo s posebno teorijo relativnosti; ➤ uporaba vektorske in tenzorske analize ter parcialnih diferencialnih enačb v klasični teoriji polja;

Intended learning outcomes:

Knowledge and understanding: Knowledge and understanding after successful completion of a learning unit: ➤ knowledge and application of the fundamental laws of electromagnetism and Maxwell's equations and their implications and symmetries, including the covariant formulation of electrodynamics and its relation to special relativity;

- poznavanje osnovnih zakonov optike, optičnih pojavov in njihove uporabe, med drugim uporaba skalarne teorije uklona, Fourierove transformacije, Maxwellovih enačb za lom in odboj na meji med optično homogeno in nehomogeno snovjo, analiza širjenja svetlobe po kovinah ter dielektrikih, obravnava površinskih plazmonov, metapovršin in osnov fotonovskih kristalov ter poznavanje nelinearnih odzivov snovi na električno polje.

Prenesljive/ključne spretnosti in drugi atributi:

- uporaba vektorske in tenzorske analize v eni in več dimenzijah ter (ne)linearnih diferencialnih enačb za reševanje realnih problemov;
- analiza osnovnih enačb klasične teorije polja in optike ter njihovih posledic;
- reševanje kompleksnih problemov, ki jih je treba razstaviti na večje število enot z različnih področjih fizike;
- uporaba sodobne programske opreme kot pomoč pri kvantitativni obravnavi fizikalnih problemov;
- uporaba znanj za obravnavo dejanskih tehnoloških problemov na področju optike, fotonike, raziskavah materialov in preiskavah v medicini.

- application of vector and tensor analysis and partial differential equations in classical field theory;
- knowledge of the fundamental laws of optics, optical phenomena and their applications, including the application of scalar theory of diffraction, Fourier transform, Maxwell's equations for refraction and reflection at the boundary between optically homogeneous and inhomogeneous matter, the analysis of the propagation of light through metals and dielectrics, the description of surface plasmons, metasurfaces and the fundamentals of photonic crystals, and an understanding of the nonlinear response of matter to an electric field.

Transferable/Key skills and other attributes:

- application of one- and multi-dimensional vector and tensor analysis and (non-)linear differential equations to solve real-world problems;
- analysing the basic equations of classical field theory and optics and their consequences;
- solving complex problems that need to be decomposed into a large number of units in different areas of physics;
- the use of modern software to support the quantitative processing of physical problems;
- the application of knowledge to actual technological problems in optics, photonics, materials research and medicine.

Metode poučevanja in učenja:

predavanja z demonstracijskimi eksperimenti
teoretične vaje
vodeno samostojno delo
razlaga
razgovor
demonstracija
delo s tekstom
metoda pisnih in grafičnih del
uporaba simulacij
uporaba simulacijskih okolij

Poučevanje in učenje potekata z didaktično uporabo informacijsko-komunikacijske tehnologije.

Learning and teaching methods:

lectures with demonstration experiments
theoretical exercises
supervised individual work
explanation
discussion
demonstration
work with text
work with graphic elements
use of simulations
use of simulation software

Teaching and learning are done through the didactic use of ICT.

Delež (v %) / Weight (in %)		Assessment:
Načini ocenjevanja:		
Sprotne naloge	60	coursework
Pisni izpit	40	written exam

Opombe: Pisni izpit se lahko nadomesti s šestimi pisnimi kolokviji. Note: Written exam can be replaced by six written midterm examinations.

Reference nosilca / Lecturer's references:

Uroš Tkalec

1. XU, Yang, YAO, Yuxing, DENG, Weichen, FANG, Jen-Chun, DUPONT, Robert L., ZHANG, Meng, ČOPAR, Simon, TKALEC, Uroš, WANG, Xiaoguang. Magnetocontrollable droplet mobility on liquid crystal-infused porous surfaces. *Nano research*. Apr. 2023, vol. 16, iss. 4, str. 5098-5107. ISSN 1998-0124. DOI: [10.1007/s12274-022-5318-y](https://doi.org/10.1007/s12274-022-5318-y). [COBISS.SI-ID [136269571](#)]
2. YANG, Xu, RATHER, Adil M., YAO, Yuxing, FANG, Jen-Chun, MAMTANI, Rajdeep S., BENNETT, Robert K. A., ATTA, Richard G., ADERA, Solomon, TKALEC, Uroš, WANG, Xiaoguang. Liquid crystal-based open surface microfluidics manipulate liquid mobility and chemical composition on demand. *Science advances*. Oct. 2021, vol. 7, no. 40, 11 str. ISSN 2375-2548. DOI: [10.1126/sciadv.abi7607](https://doi.org/10.1126/sciadv.abi7607). [COBISS.SI-ID [79203075](#)]
3. ČOPAR, Simon, KOS, Žiga, EMERŠIČ, Tadej, TKALEC, Uroš. Microfluidic control over topological states in channel-confined nematic flows. *Nature communications*. Jan. 2020, vol. 11, art. no. 59, 10 str., ilustr. ISSN 2041-1723. DOI: [10.1038/s41467-019-13789-9](https://doi.org/10.1038/s41467-019-13789-9). [COBISS.SI-ID [3400804](#)]

Nataša Vaupotič

1. POCIECHA, Damian, VAUPOTIČ, Nataša, MAJEWSKA, Magdalena, CRUICKSHANK, Ewan, WALKER, Rebecca, STOREY, John M. D., IMRIE, Corrie T., WANG, Cheng, GÓRECKA, Ewa. Photonic bandgap in achiral liquid crystals - a twist on a twist. *Advanced materials*. [Online ed.]. 2021, vol. 33, no. 39, str. 2103288-1-2103288-7. ISSN 1521-4095. DOI: [10.1002/adma.202103288](https://doi.org/10.1002/adma.202103288). [COBISS.SI-ID [80061955](#)]
2. SZYDŁOWSKA, Jadwiga, ČEPIČ, Mojca, VAUPOTIČ, Nataša, et al. Ferroelectric nematic-isotropic liquid critical end point. *Physical review letters*. [Print ed.]. 2023, vol. 130, no. 21, str. 216802-1-216802-5. ISSN 0031-9007. DOI: [10.1103/PhysRevLett.130.216802](https://doi.org/10.1103/PhysRevLett.130.216802). [COBISS.SI-ID [153660675](#)]
3. MATKO, Vojko, GÓRECKA, Ewa, POCIECHA, Damian, MATRASZEK, Joanna, VAUPOTIČ, Nataša. Interpretation of dielectric spectroscopy measurements of ferroelectric nematic liquid crystals. *Physical review research*. 2024, vol. 6, iss. 4, [article no.] l042017, 6 str. ISSN 2643-1564. DOI: [10.1103/PhysRevResearch.6.L042017](https://doi.org/10.1103/PhysRevResearch.6.L042017). [COBISS.SI-ID [212927491](#)]