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 2nd 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 / Languages:		
	Predavanja / Lectures:	Slovenski / Slovene
	Vaje / Tutorial:	Slovenski / Slovene

Pogoji za vključitev v delo oz. za opravljanje študijskih obveznosti:	**Prerequisits:**
Osnovno znanje klasične fizike in vektorske analize.	Basic knowledge of classical physics and vector analysis.

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 Fourierove optike; sevanje električnega dipola; antene in valovni vodniki; skalarna teorija uklona.

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 Fourier's optics; electric dipole radiation; antennas and wave guides; scalar diffraction theory.

- 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 magnetooptični 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 fotonski 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.	- 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.

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).

Cilji in kompetence:	**Objectives and competences:**
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.	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.

Predvideni študijski rezultati:	**Intended learning outcomes:**
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; - poznavanje osnovnih zakonov optike, optičnih pojavov in njihove uporabe, med drugim uporaba skalarne teorije uklona, Fourierove	**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; - application of vector and tensor analysis and partial differential equations in classical field theory;

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 fotonskih 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.	➢ 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:	**Learning and teaching methods:**
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.	lectures with demostration experiments theoretical excercises 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.

Načini ocenjevanja:	Delež (v %) / Weight (in %)	**Assessment:**
Sprotne naloge Pisni izpit (lahko se nadomesti s 6 pisnimi kolokviji) Za uspešno zaključeno učno enoto mora vsak del posebej biti pozitiven; vse teoretične naloge morajo biti izračunane in zagovorjene.	**60** **40**	coursework written exam (it can be replaced by 6 written tests) For a successfully finished course, both parts must be positive. All the problems must be solved and defended.

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. [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. [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. [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. [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. [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. [COBISS.SI-ID 212927491]