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| **UČNI NAČRT PREDMETA / COURSE SYLLABUS** | | | | | | | | | | | | | | | | |
| **Predmet:** | | | Mikrobioelektromagnetika | | | | | | | | | | | | | |
| **Course title:** | | | Microbioelectromagnetics | | | | | | | | | | | | | |
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| **Študijski program in stopnja**  **Study programme and level** | | | | | **Študijska smer**  **Study field** | | | | | | | **Letnik**  **Academic year** | | **Semester**  **Semester** | | |
| doktorski študijski program tretje stopnje Elektrotehnika | | | | | Ni smeri | | | | | | | **1** | |  | | |
| 3rd cycle: doctoral study programme Electrical Engineering | | | | |  | | | | | | |  | |  | | |
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| **Vrsta predmeta / Course type** | | | | | | | | | | | Izbirni/elective | | | | | |
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| **Univerzitetna koda predmeta / University course code:** | | | | | | | | | | | 64880 | | | | | |
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| **Predavanja**  **Lectures** | **Seminar**  **Seminar** | | | **Vaje**  **Tutorial** | | | **Klinične vaje**  **work** | | | **Druge oblike študija** | | | **Samost. delo**  **Individ. work** | |  | **ECTS** |
| **30** | **15** | | | **15** | | |  | | |  | | | **65** | |  | **5** |
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| **Nosilec predmeta / Lecturer:** | | | | | prof. dr. Tadej Kotnik | | | | | | | | | | | |
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| **Jeziki /**  **Languages:** | | **Predavanja / Lectures:** | | | | slovensko (angleško) / Slovenian (English) | | | | | | | | | | |
| **Vaje / Tutorial:** | | | | slovensko (angleško) / Slovenian (English) | | | | | | | | | | |
| **Pogoji za vključitev v delo oz. za opravljanje študijskih obveznosti:** | | | | | | | |  | **Prerequisites:** | | | | | | | |
| Obveznih pogojev ni. Priporočeno predznanje obsega osnovno poznavanje navadnih in parcialnih diferencialnih enačb (npr. Matematika 1-4 z univerzitetnega programa prve stopnje Elektrotehnika) in osnovno poznavanje biologije celice (gimnazijska raven). | | | | | | | |  | There are no compulsory prerequisites. Recommended prior knowledge comprises basic familiarity with ordinary and partial differential equations (e.g. Mathematics 1-4 from 1st cycle academic programme Electrical Engineering) and basic knowledge of cell biology (secondary school level). | | | | | | | |

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| **Vsebina:** |  | **Content (Syllabus outline):** |
| 1. Biološke celice v električnem polju, mirovalna in vsiljena membranska napetost. Napetostno odvisni membranski kanali, elektrostimulacija vzdražnih celic. Elektroporacija celične membrane. 2. Analitično izvajanje vsiljene membranske napetosti v statičnem električnem polju: okrogle celice (Schwanova enačba), cilindrične, sferoidne in elipsoidne celice. 3. Analitično izvajanje vsiljene membranske napetosti v časovno spremenljivih elektromagnetnih poljih. Razširjena Schwanova enačba prvega in drugega reda. Analiza absorpcije energije polja v celici in njeni membrani. 4. Analitično izvajanje vsiljene napetosti na membranah znotrajceličnih organelov. Razmerje med vsiljeno napetostjo na zunanji in notranjih membranah celice. 5. Numerični izračun vsiljene membranske napetosti v statičnem polju: goste suspenzije okroglih celic, celice nepravilnih oblik, skupki električno izoliranih celic, skupki električno povezanih celic. 6. Numerični izračun vsiljene membranske napetosti v časovno spremenljivih elektromagnetnih poljih. Numerično modeliranje elektroporacije in transporta skozi elektroporirano membrano. 7. Simulacije molekularne dinamike: lipidni dvosloj v električnem polju, nastajanje in zapiranje por v membrani. 8. Eksperimentalno določanje membranske napetosti. Potenciometrična barvila, zajemanje slik in obdelava podatkov. Eksperimentalno spremljanje odpiranja in zapiranja napetostno odvisnih membranskih kanalov ter transporta skoznje. Eksperimentalno spremljanje elektroporacije in transporta skozi elektroporirano membrano. 9. Elektroporacija v naravi in njena morebitna vloga v evoluciji mikroorganizmov. Trije biokemični mehanizmi horizontalnega prenosa genov. Strela kot povzročitelj izlitja DNA iz ireverzibilno elektroporiranih mikroorganizmov, gibanja izlite DNA v vodnem okolju (elektroforeze) in vnosa DNA v reverzibilno elektroporirane mikroorganizme. |  | 1. Biological cells in electric fields, resting and induced membrane voltage. Voltage-gated membrane channels, electrical stimulation of excitable cells. Electroporation of cell membrane. 2. Analytical derivation of induced membrane voltage in static electric fields: spherical cells (Schwan equation), cylindrical, spheroidal and ellipsoidal cells. 3. Analytical derivation of induced membrane voltage in time-varying electromagnetic fields. Generalized Schwan equation of the first and second order. Analysis of absorption of the field energy in the cell and its membrane. 4. Analytical derivation of voltage induced on membranes of intracellular ogranelles. Ratio between the voltage induced on the external and membrane and the internal membranes. 5. Numerical computation of induced membrane voltage in static electric fields: dense suspensions of spherical cells, irregularly shaped cells, clusters of electrically insulated and electrically connected cells. 6. Numerical computation of induced membrane voltage time-varying electromagnetic fields. Numerical modeling of electroporation and transport across the electroporated membrane. 7. Molecular dynamics simulations: lipid bilayed in the electric field, formation and resealing of transmembrane pores. 8. Experimental determination of membrane voltage. Potentiometric dyes, image acquisition and data processing. Experimental monitoring of opening and closing of voltage-gated channels and transport across them. Experimental monitoring of electroporation and transport across the electroporated membrane. 9. Electroporation in nature and its possible role in the evolution of microorganisms. Three biochemical mechanisms of horizontal gene transfer. Lightning as the cause of DNA release from irreversibly electroporated microorganisms, movement of released DNA in aqueous environment (electrophoresis) and DNA uptake by reversibly electroporated microorganisms. |

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| **Temeljni literatura in viri / Readings:** | | | | | |
| Alberts B, Bray D, Hopkin K, Johnson AD, Lewis J, Raff M, Roberts K, Walter P (2013). Essential Cell Biology, 4th edition. Garland Science, New York  Kotnik T, Pucihar G, Miklavčič D (2010) Induced transmembrane voltage and its correlation with electroporation-mediated molecular transport. J Membrane Biol 236:3-13  Tombola F, Pathak MM, Isacoff EY (2006) How does voltage open an ion channel? Annu Rev Cell Dev Biol 22:23-52  Kotnik T, Miklavčič D (2006) Theoretical evaluation of voltage inducement on internal membranes of biological cells exposed to electric fields. Biophys J 90:480-491  Kotnik T, Miklavčič D (2000) Theoretical evaluation of the distributed power dissipation in biological cells exposed to electric fields. Bioelectromagnetics 21:385-394  Delemotte L, Tarek M (2012) Molecular dynamics simulations of lipid membrane electroporation, J Membr Biol 245:531-543.  Kotnik T (2013) Lightning-triggered electroporation and electrofusion as possible contributors to natural horizontal gene transfer. Phys Life Rev 10:351-370 | | | | | |
| **Cilji in kompetence:** | |  | | **Objectives and competences:** | |
| Spoznati fizikalne osnove učinkov električnih polj na biološke celice. Pridobiti osnovno znanje za analitično, numerično in eksperimentalno obravnavanje teh učinkov. Spoznati molekularne osnove delovanja napetostno odvisnih kanalov v membranah in pojava elektroporacije membrane. | |  | | To gain the basic understanding of the effects of electric fields on biological cells. To acquire the basic knowledge of analytical, numerical, and experimental assessment of these effects. To understand the molecular basis of the functioning of voltage-gated membrane channels and the phenomenon of membrane electroporation. | |
| **Predvideni študijski rezultati:** | | |  | **Intended learning outcomes:** | |
| **Znanje in razumevanje:** Študent bo razumel fizikalne osnove učinkov električnih polj na biološke celice. Znal bo analitično, numerično in eksperimentalno obravnavati te učinke. Spoznal bo tudi molekularne osnove delovanja napetostno odvisnih kanalov v membranah in pojava elektroporacije membrane.  **Uporaba:** Samostojno razumevanje in obravnava učinkov električnih polj na ravni biološke celice, vključno s proženjem napetostno odvisnih kanalov vzdražnih celic in elektroporacijo celične membrane.  **Refleksija:** Študent bo pri poznani jakosti, trajanju in časovnem poteku električnega ali elektromagnetnega polja znal oceniti učinke izpostavitve bioloških celic takšnemu polju.  **Prenosljive spretnosti:** Znanje iz numeričnega reševanja diferencialnih enačb z metodama končnih elementov in končnih diferenc se vse več uporablja v razvoju na mnogih področjih modeliranja in simuliranja v elektrotehniki, strojništvu, analizi materialov itd. Simulacije molekularne dinamike sodijo med najhitreje razvijajoča se področja v molekularni biofiziki in biokemiji. Spremljanje napetosti na membrani in transporta prek membrane s potenciometričnimi barvili in metodo patch clamp sodita med sodobne in široko uporabljane metode v elektrofiziologiji in celični biologiji. | | |  | **Knowledge and understanding:** The students will gain the basic understanding of the effects of electric fields on biological cells. They will be able to assess these effects analytically, numerically, and experimentally. They will understand the functioning of voltage-gated channels and membrane electroporation.  **Application:** Independent understanding and analysis of effects of electric fields on the cell level, including the triggering of voltage-gated channels and cell membrane electroporation.  **Reflection:** The students will be able, for the known strength, duration and time course of the electric or electromagnetic fields, to assess the effects of exposure of biological cells to such fields.  **Transferrable skills:** Knowledge gained in numerical solving of differential equations using the finite elements and finite differences methods is of increasing use and importance in many areas of modeling and simulation in electrical and mechanical engineering, as well as in materials sciences. Molecular dynamics simulations are among the most rapidly progressing fields in molecular biophysics and biochemistry. Monitoring of membrane voltage and transmembrane transport by means of patch clamp and potentiometric methods are among the modern and widely used techniques in electrophysiology and cell biology. | |
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| **Metode poučevanja in učenja:** | | |  | **Learning and teaching methods:** | |
| V primeru zadostnega števila vpisanih študentov (vsaj trije) predavanja skozi celoten semester, sicer del semestra predavanja in zatem samostojen študij z rednimi posveti, vaje z raziskovalnim delom, seminar. | | |  | In case of sufficient number of enrolled students (at least three) lectures throughout the semester, otherwise part-time lectures and part-time self-study with regular meetings, tutorials with research work, seminar. | |
| **Načini ocenjevanja:** | Delež (v %) /  Weight (in %) | | | | **Assessment:** |
| Seminar, vaje in izpit. | Seminar 25%, vaje 25%,  izpit 50%.  /  Seminar 25%,  tutorials 25%,  exam 50%. | | | | Seminar, tutorials, and exam. |
| **Reference nosilca / Lecturer's references:** | | | | | |
| Kotnik T, Frey W, Sack M, Haberl Meglič S, Peterka M, Miklavčič D (2015) Electroporation-based applications in biotechnology. Trends Biotechnol 33:480-488  Kotnik T (2013) Lightning-triggered electroporation and electrofusion as possible contributors to natural horizontal gene transfer. Phys Life Rev 10:351-370  Kotnik T, Kramar P, Pucihar G, Miklavčič D, Tarek M (2012). Cell membrane electroporation – Part 1: The phenomenon. IEEE Electr Insul Mag 28(5):14-23  Kotnik T, Pucihar G, Miklavčič D (2010) Induced transmembrane voltage and its correlation with electroporation-mediated molecular transport. J Membrane Biol 236:3-13  Kotnik T, Miklavčič D. Theoretical evaluation of voltage inducement on internal membranes of biological cells exposed to electric fields (2006) Biophys J 90:480-491 | | | | | |