Course Archive AY2016

Degree Completion Requirements for AY2016/2017

The OIST Graduate School offers an integrated doctoral program leading to the degree of Doctor of Philosophy (PhD). The degree of PhD is a research postgraduate degree. Such a degree shall be awarded to a candidate who

1. meets admission requirements and receives and accepts an offer of admission, and is registered as a full-time PhD student for a minimum of three years and not more than ten years; and
2. satisfactorily completes prescribed work amounting to at least 30 credits (20 from courses, 10 from research work) or alternatively, has obtained the equivalent number of credits based on prior study; and
3. presents a successful thesis representing the result of the candidate's research which should constitute an original contribution to knowledge and contain material worthy of publication; and
4. satisfies the examiners in an oral examination in matters relevant to the subject of the thesis.

Note 1: coursework credits based on prior study can be waived up to a maximum of 10 elective credits to recognise relevant prior learning, at the advice of the mentor and with approval of the graduate school. This is not a guarantee that such waiver will be made, in full or part. The amount of waiver due to prior relevant coursework is at the discretion of the mentor.

Note 2: a published paper or manuscript ready for publication from the research work presented in the thesis shall be appended to the examination version of the thesis to denote that the "material is worthy of publication".

Note 3: after successful examination of the written thesis, a thesis defence is conducted before two external examiners on-site in an oral exam. A public presentation of the thesis is required, and takes place immediately preceding the closed examination.

Note 4: paper submission of final version of thesis no longer required. Only PDF files accepted.

Courses delivered AY2016/2017

A101 Adaptive Systems

Course Coordinator:
Kenji Doya
Description:

This course aims to provide common mathematical frameworks for adaptation at different scales and to link them with biological reality of control, learning, and evolution. We will look at different classes of adaptation problems using real-world examples of robot control, web searching, gene analysis, imaging, and visual receptive fields.

Aim:

Introduction to machine learning algorithms and their application to modeling and analysis of biological systems.

Course Content:

1. Introduction: variety of learning and adaptation
2. Probability theory: entropy, information, Bayes theorem
3. Pattern classification
4. Function approximation
5. Kernel methods
6. Clustering, Mixture Gaussian, EM algorithm
7. Principal Component Analysis, Self-organizing map
8. Graphical models, Belief propagation
9. Sampling methods, Genetic algorithms
10. Kalman filter, Particle filter
11. Reinforcement learning, Dynamic programming
12. Decision theory, Game theory
13. Multiple agents, Evolutionary stable strategies
14. Communication and cooperation
15. Presentation and discussion

Course Type:
Elective
Credits:
2
Assessment:
Midterm Reports 60% (2 x 30%), Final Exam 40%.
Text Book:
Pattern Recognition and Machine Learning. Bishop (2006) Springer, New York
Reference Book:
Matlab for Neuroscientists: An Introduction to Scientific Computing in Matlab I, by Wallisch et al. (2008) Academic Press
Prior Knowledge:

Assumes good knowledge of statistics and ability to look at biological problems in a mathematical way.

OIST courses to complete beforehand: B03 Math 1, B07 Statistical Methods

A102 Mathematical Methods of Natural Sciences

Course Coordinator: Jonathan Miller

Description:

This course develops advanced mathematical techniques for application in the natural sciences. Particular emphasis will be placed on analytical and numerical, exact and approximate methods, for calculation of physical quantities. Examples and applications will be drawn from a variety of fields. The course will stress calculational approaches rather than rigorous proofs. There will be a heavy emphasis on analytic calculation skills, which will be developed via problem sets.

Aim:
To develop expertise in application of advanced mathematical methods for natural scientists

Course Content:

1. Complex Analysis I: Introduction to complex analysis: analytic functions.
2. Complex Analysis II: Cauchy Theorem and contour integration.
3. Complex Analysis III: Numerical methods in complex analysis.
4. Linear algebra I: Advanced eigenvalues and eigenvectors.
5. Linear algebra II: Numerical methods.
6. Ordinary differential/difference equations (ODDE) I: Properties and exact solutions.
7. ODDE II: Approximate solutions.
8. ODDE III: Numerical solution.
9. Asymptotic expansion of sums and integrals I: elementary methods.
10. Asymptotic expansion of sums and integrals II: steepest descents.
11. Perturbation methods.
12. Boundary layer theory.
13. WKB theory.
14. Vector fieldsStokes theorem.
15. Green's functions.

Course Type:
Elective
Credits:
2
Assessment:
Homework 60%, Midterm Exam 20%, Final Exam 20%
Text Book:
Advanced Mathematical Methods for Scientists and Engineers, Bender and Orszag (1999) Springer
A Guided Tour of Mathematical Physics, Snieder. At: http://samizdat.mines.edu/snieder/
Mathematics for Physics: A Guided Tour for Graduate Students, Stone and Goldbart (2009) Cambridge.
Reference Book:
Basic Training in Mathematics. R. Shankar. Plenum, 1995.
Geometrical methods of mathematical physics. B. Schutz. Cambridge, 1999.
Statistical Field Theory. G. Mussardo. Oxford, 2009.
Statistical Mechanics: Entropy, Order Parameters and Complexity J.P. Sethna. Oxford, 2008

A201 Quantum Mechanics

Course Coordinator: Denis Konstantinov
Description:

Basic course in non-relativistic quantum mechanics. Wave functions and the Schrödinger Equation; Hilbert space; central forces and angular momentum; one-dimensional problems including particle in box, tunneling, and harmonic oscillator; hydrogen atom; Pauli principle; scattering; electron spin; Dirac notation; matrix mechanics; the density matrix; time-independent perturbation theory; Heisenberg picture; time-dependent perturbations; degenerate harmonic oscillators; electrons in a uniform magnetic field; quantized radiation field; absorption and emission of radiation; symmetry principles, entanglement.

Aim:
To introduce students to basic concepts and techniques in quantum mechanics
Course Content:

1. Quantum description of a particle, Schrödinger equation, notations

2. The Heisenberg picture and implications
3. Spin ½ particles, magnetic field effects and resonance
4. One-dimensional harmonic oscillators, Hamiltonians
5. Particle in a box; tunneling, coupled oscillators
6. Coherent states; phonons and photons
7. Angular momentum, spherical harmonics
8. Approximation methods
9. Electrons in a uniform field
10. Time-independent perturbation theory
11. Fine and hyperfine structure of the Hydrogen atom
12. Time-dependent perturbation theory
13. Scattering theory
14. Radiation and absorption
15. Entanglement and information transfer

Course Type:
Elective
Credits:
2
Assessment:
Homework: 20%, Midterm Exams: 2 x 30%, Final Exam, 20%.
Text Book:
Quantum Mechanics: Vol I & II, by Cohen-Tannoudji, Diu, Laloe (1977). Wiley-Interscience
Reference Book:
Principles of Quantum Mechanics 2 edn, by Shankar (1994) Springer
Atom-Photon Interactions, by Cohen-Tannoudji, Dupont-Roc, Grynberg (1998) Wiley-Interscience
Statistical Mechanics, 3 edn, by Pathria and Beale (2011) Academic Press

A202 Fluid Dynamics

Course Coordinator: Satoshi Mitarai
Description:

This course introduces students to the fundamental laws that characterize fluids at rest and in motion. The equations for the conservation of mass, for momentum balance, and for conservation of energy are analyzed in control volume and, to some extent, in differential form. Students will learn to select appropriate models and solution procedures for a variety of problems. Flow phenomena that occur in actual flow situations are also illustrated, so that students will learn to assess the strengths and limitations of the models and methods.

Aim:
To introduce basic fluid dynamics skills that may be applied to problems in the life sciences and environmental sciences. The course is aimed at biologists rather than physicists, although physicists interested in a refresher course in basic fluid dynamis may apply.

Course Content:

1. Introduction (Background, Definitions, general concepts, etc)
2. Fluid Statics (Hydrostatic balance, pressure forces on objects)
3. Fluid Statics (Effects of constant acceleration or rotation)
4. Bernoulli Equation (Use of Newton's second law)
5. Bernoulli Equation (Pressure and its measurement)
6. Fluid Kinematics (Description of velocity field)
7. Fluid Kinematics (Control volume, system representations)

8. Fluid Kinematics (Reynolds transport theorem)
9. Control volume Analysis (Conservation laws)
10. Control volume Analysis (Many applications)
11. Dimensional Analysis (Dynamic similarity)
12. Dimensional Analysis (Pi theorem, Applications)
13. Flow in Pipes, Ducts, Etc. (Laminar and turbulent pipe flow, etc)
14. Flow Around Objects (Boundary layers & potential flow, etc)
15. Compressible Flow (Mach number, sound speed, etc)

Course Type:
Elective
Credits:
2
Assessment:
Homework: 20%, Midterm Exams: 2 x 30%, Final Exam, 20%.
Text Book:
Fundamentals of Fluid Mechanics, by Munson, Young, Okiishi and Huebsch (6th Edition)
Reference Book:
Multi-Media Fluid Mechanics, by G. M. Homsy et al., Cambridge University Press.
An Album of Fluid Motion by Milton van Dyke, Parabolic Press.

A203 Advanced Optics

Course Coordinator: Síle Nic Chormaic

Description:

Review of geometrical optics; wave properties of light and the wave equation; Helmholtz equation; wave optics, including Fresnel and Fraunhofer diffraction, transfer functions, coherence, auto and cross-correlation; Gaussian and non-Gaussian beam profiles; quantum optics and photon statistics; spin squeezing; applications of optics including fiber optics, laser resonators, laser amplifiers, non-linear optics, and optical trapping; quantum properties of light; interaction of photons and atoms.

Aim:
To introduce students to fundamental and advanced topics in modern optics and photon physics.

Course Content:

1. Review of classical optics
2. Ray and wave optics
3. Laser optics and Gaussian beams
4. Non-Gaussian beam optics
5. Fourier optics
6. Electromagnetic optics
7. Nonlinear optics
8. Lasers, resonators and cavities
9. Photon optics
10. Photon statistics and squeezed light
11. Interaction of photons with atoms
12. Experimental applications: Optical trapping
13. Experimental applications: Laser resonator design

14. Experimental applications: Light propagation in optical fibers and nanofibers
15. Experimental applications: laser cooling of alkali atoms
16. Laboratory Exercises: Mach-Zehnder & Fabry-Perot Interferometry; Fraunhofer & Fresnel Diffraction; Single-mode and Multimode Fiber Optics; Polarization of Light; Optical Trapping & Optical Tweezers

Course Type:
Elective
Credits:
2
Assessment:
Continuous Assessment: 60%, Final Exam, 40%.
Text Book:
Fundamentals of Photonics, by Saleh and Teich (2007) Wiley
Reference Book:
Quantum Optics, an Introduction, by Mark Fox (2006) Oxford University Press
Optics, by Eugen Hecht (2001) Addison Wesley

A205 Quantum Field Theory

Course Coordinator: Shinobu Hikami

Description:

This course covers quantum electrodynamics and chromodynamics. Topics include canonical quantization, Feynman diagrams, spinors, gauge invariance, path integrals, identical particles and second quantization, ultraviolet and infrared divergences, renormalization and applications to the quantum theory of the weak and gravitational forces, spontaneous symmetry breaking and Goldstone bosons, chiral anomalies, effective field theory, non-Abelian gauge theories, the Higgs mechanism, and an introduction to the standard model, quantum chromodynamics and grand unification.

Aim:
To introduce students to basic concepts and techniques in relativistic quantum field theory.

Course Content:

1. An electron in a uniform electromagnetic field: Landau levels
2. Canonical Quantization
3. Antiparticles
4. Particle decay
5. Feynman rules and the S-matrix
6. Weyl and Dirac spinors
7. Gauge Theories
8. Quantization of the electromagnetic field
9. Symmetry breaking
10. Path integrals
11. Aharonov-Bohm effect
12. Renormalization
13. Quantum chromodynamics
14. Nuclear forces and Gravity
15. Field unification

Course Type:
Elective
Credits:
2
Assessment:
Homework: 60%, Final Exam, 40%
Text Book:
A First Book in Quantum Field Theory, by Lahiri and Pal (2005) Alpha Science International
A Modern Introduction to Quantum Field Theory, by Michele Maggiore (2005) Oxford University Press.
Reference Book:
Quantum Field Theory, by Michio Kaku (1993) Oxford University Press.
An Introduction to Quantum Field Theory, by Peskin and Schroder (1995) Westview Press.
Gauge Theories in Particle Physics, Vol. I and II, by Aitchison and Hey (2004) Institute of Physics

A206 Analog Electronics

Course Coordinator:
Yabing Qi
Description:

A practical course to train students in the design and construction of analog electronic circuits, based on the classic text The Art of Electronics. Conceptual understanding of the key elements of analog circuits will be reinforced by significant project work in the electronics workshop.

Although very little device physics will be taught, the course provides sufficient theory to design and analyze analog electronic circuits, with extensive project work to enable students to become familiar with circuit construction.
Aim:
A project-based course to provide theory and practice in design, analysis, and construction of modern analog electronic circuits

Course Content:

1. Passive components. Current and voltage sources, Thevenin and Norton equivalent circuits. Diodes. (Ebers Moll equation)
2. The bipolar transistor, transconductance and its use in making efficient current and voltage sources.
3. Common emitter, common base, amplifiers. Differential amplifiers, current mirrors.
4. Push pull and other outputs, as well as some other useful circuits. Miller effect.
5. Thermal behavior of transistors; circuit temperature stability.
6. Field effect transistors and analog switches.
7. Operational Amplifiers and basic op amp circuits.
8. Negative feedback.
9. Sample and hold, track and hold, circuits. Further applications of op amps.
10. Filters
11. Voltage Regulators
12. Noise, noise reduction, transmission lines, grounding, shielding,
13. Lock in amplifiers.
14. Instrumentation amplifiers.
15. Analog to Digital conversion.

Course Type:
Elective

Credits:
2
Assessment:
Projects 3 x 25% ; final exam 25%
Text Book:
The Art of Electronics, 2 edn, Horowitz and Hill (1989) Cambridge University Press
The Art of Electronics Laboratory Manual, Horowitz and Robinson (1981) Cambridge University Press
Reference Book:
The Art of Electronics Student Manual, Hayes and Horowitz (1989) Cambridge
Analysis and Design of Analog Integrated Circuits, 5 edn, Gray, Hurst, Lewis and Meyer (2009) Wiley
The Electrical Engineering Handbook, 2 edn, Richard C Dorf (1997) CRC Press

A207 Nanotechnology

Course Coordinator: Mukhles Ibrahim Sowwan

Description:

This course covers the Nanotechnology revolution in science and engineering that is leading to novel ideas about the way materials, devices, and systems are designed, made and used in different applications. We cover the underlying principles of the multidisciplinary and very diverse field of nanotechnology, and introduce the concepts and scientific principles relevant at the nanometer scale. Then we provide a comprehensive discussion of the nanomaterials, including characterization techniques and the effect of size on their structural, physical, and chemical properties and stability. In addition we discuss the current and future applications of Nanotechnology in different fields such as materials engineering, medicine, electronics, and clean energy.

Aim:
Advanced course in the science and applications of nanomaterials and nanoengineering.

Course Content:

1, 2. Introduction to Nanotechnology and its applications (2 lectures)
History, State of the art nanotechnology, applications in different fields
3, 4. Surface imaging and visualizations (2 lectures)
SPM, SEM, TEM
5, 6. Conventional Nanofabrication (2 lectures)
Microfabrication, e-beam lithography, photolithography, micro and nanoelectronics
7, 8. Non-conventional nanofabrication (2 lectures)
Nanoimprint lithography, bottom top fabrication
9 – 13. Nanomaterials: Synthesis, properties and application (5 lectures)
Nanoparticles, nanorods, nanocrystals, nanobiomaterials , nanostructured thin films
14, 15. Nanosystems and self-assembly (2 lectures)
Self assembly of hybrid systems, bioorganic/inorganic inspired nanodevices

Course Type:
Elective
Credits:
2
Assessment:
Participation and Homework 10%; Presentations 30%; Project 60%.
Text Book:

Handbook of Nanoscience Engineering and Technology, Edited by Goddard, Brenner, Lyshevski, Iafrate (2003) CRC press
Reference Book:
Nanotechnology: A Gentle Introduction to the Next Big Idea, by Ratner and Ratner (2002) Prentice-Hall
Nanostructures & Nanomaterials: Synthesis, Properties & Applications, Cao and Wang (2004) Imperial College Press
Encyclopedia of Nanotechnology, Edited by Bhushan and Bharat (2012) Springer

A208 Bioorganic Chemistry

Course Coordinator: Fujie Tanaka

Description:

This course covers essential concepts and recent advances in the design and synthesis of functional molecules used for understanding and controlling biological systems. Topics of this course include design and synthesis of small organic molecules, organic reactions, methods for controlling reaction pathways, asymmetric synthesis, mechanisms of catalysis and molecular recognition, and creation of designer proteins and peptides.

Aim:
To discuss design and synthesis of functional molecules used for understanding and controlling biological systems.

Course Content:

1. Methods of chemical transformations to access designer molecules
2. Strategies for the development of new reaction methods including stereoselective reaction methods
3. Asymmetric reactions and asymmetric catalysis
4. Catalytic enantioselective reactions: Carbon-carbon bond forming reactions
5. Catalytic enantioselective reactions: hydrolysis, reduction, dynamic kinetic resolutions, etc.
6. Design and synthesis of functional molecules
7. Chemical mechanisms of bioactive molecules including chemistry of enzyme inhibitors
8. Molecular recognition and non-covalent bond interactions
9. Enzyme catalysis and catalytic mechanisms
10. Enzyme catalysis and small organic molecule catalysis
11. Enzyme kinetics and kinetics of non-enzymatic reactions
12. Strategies for the development of new designer catalysts
13. Methods in identification and characterization of organic molecules
14. Strategies for the development of designer functional proteins and peptides
15. Chemical reactions for protein labeling; chemical reactions in the presence of biomolecules

Course Type:
Elective
Credits:
2
Assessment:
Exercises 50%, reports 50%
Text Book:
Advanced Organic Chemistry, Part A: Structures and Mechanisms, Part B: Reactions and Synthesis, 5th edn, Carey and Sundberg (2007)
Reference Book:

Modern Physical Organic Chemistry, Anslyn and Dougherty (2005)
The Organic Chemistry of Drug Design and Drug Action, 2nd edn, Silverman (2004)
Organic Chemistry, 7th Edition, McMurry (2008)

A209 Ultrafast Spectroscopy

Course Coordinator: Keshav Dani

Description:

This course will be an introductory graduate level course to initiate students into the techniques of ultrafast spectroscopy. They will be introduced to the basic concepts underlying sub-picosecond phenomena in nature (ultrafast chemical processes, femtosecond electron dynamics in materials, etc.) and the tools used to study such phenomena (pump-probe spectroscopy, Terahertz Time Domain Spectroscopy, etc.).

Course Content:

1. Introduction, History and Development:
2. Basic Concepts
3. Understanding Ultrafast Pulses: Spectrum, Fourier Transform, Uncertainty Principle, wavelength, repetition rate
4. Understanding Ultrafast Pulses & Capabilities: Time Resolution, Nonlinearities,
5. Ultrafast pulse measurement: Spectrum, Phase, Amplitude, Intensity
6. Ultrafast pulse measurement: AutoCorrelation, FROG, SPIDER
7. Ultrafast Techniques: Pump Probe, Four-Wave Mixing, or others.
8. Ultrafast Techniques: Time Resolved Fluorescence, Up-converstion, or others.
9. Ultrafast Techniques: THz-TDS, Higher Harmonic Generation, or others.
10. Ultrafast Techniques: Single Shot Measurements, etc.
11. Applications: e.g. Condensed Matter Physics
12. Applications: e.g. Chemistry and Materials Science
13. Applications: e.g. Biology

Aim:
This course provides an overview of the modern methods and applications in ultrafast spectroscopy.
Course Type:
Elective
Credits:
2
Assessment:
Homework and Exercises, 80%; End of Class Presentation, 20%
Text Book:
No text set, students will work from primary sources that will be advised

A210 Advanced Quantum Mechanics

Course Coordinator: Thomas Busch

Description:

Advanced course in Quantum Mechanics, based on recent theoretical and experimental advances. Evolution in Hilbert space and quantum bits; conditional quantum dynamics; quantum simulations; quantum Fourier transform and quantum search algorithms; ion-trap and NMR experiments; quantum noise and master equations; Hilbert space distances; Von Neumann entropy; Holevo bound; entanglement as a physical resource; quantum cryptography; lab: quantum eraser, interaction free measurement.

Aim:
To introduce students to advanced and recent concepts and techniques in quantum mechanics

Course Content:

1. Quantum Mechanics: Mathematical Framework
2. Quantum Mechanical Postulates
3. Quantum Measurements
4. Quantum Algorithms
5. Quantum Computing: Physical Realisations
6. Quantum Noise
7. Entropy and Information
8. Quantum Statistical Mechanics
9. Quantum Information Theory

Course Type:
Elective
Credits:
2
Assessment:
Homework: 20%, Midterm Exams: 2 x 20%, Journal Club: 30%, Lab: 10%
Text Book:
Quantum Computation and Quantum Information, by M.A. Nielsen and I.L. Chuang (2010). Cambridge University Press
Reference Book:
Quantum Information and Coherence, by E. Andersson and P. Ohberg (2014) Springer
Modern Quantum Mechanics, by J.J. Sakurai and J.J. Napolitano (2010) Addison-Wesley
Quantum Information Theory, by M.M. Wilde (2013) Cambridge University Press
Prior Knowledge: A201 Quantum Mechanics, companion course to A204 Condensed Matter

A212 Microfluidics

Course Coordinator: Amy Shen

Description:

The interface between engineering and miniaturization is among the most intriguing and active areas of inquiry in modern technology. The aim of this course is to illuminate and explore microfluidics as an interdisciplinary research area, with an emphasis on emerging microfluidics disciplines, including molecular assembly to bulk and device level scales, with applications in novel materials synthesis, bio-microtechnology and nanotechnology.

The course will begin by highlighting important fundamental aspects of fluid mechanics, scaling laws and flow transport at small length scales. We will examine the capillary-driven, pressure-driven, and electro-kinetic based microfluidics. We will also cover multi-phase flow, droplet-based microfluidics in microfluidics. This course will also illustrate standard microfabrication techniques, micro-mixing and pumping systems.

Aim:
To introduce students to fundamental fluid transport physics at the micron and nanometer scale for applications in micro/nanofluidic devices. This course will also illuminate and explore microfluidics as an interdisciplinary research area, with an emphasis on emerging microfluidics disciplines.

Course Content:

1. Introduction to microfluidics; Scaling analysis
2. Low Reynolds number flows
3. Pressure-driven microfluidics
4. Capillary-driven microfluidics
5. Microfabrication
6. Diffusion in microfluidics
7. Mixing in microfluidics
8. Droplet microfluidics and 2-phase flows
9. Bio-MEMs

Course Type:
Elective
Credits:
2
Assessment:
Homework: 20%, Midterm Exam: 30%, Lab: 20%, Course Project: 30%
Text Book:
Introduction to Microfluidics by Patrick Tabeling, 2010, Oxford University Press
Reference Book:
Fundamentals and Applications of Microfluidics by Nam-Trung Nguyen and Steve Wereley, Artech House; 2002.
Micro- and Nanoscale Fluid Mechanics: Transport in Microfluidic Devices, by Brian Kirby, Cambridge University Press, 2013.
Prior Knowledge: Either A202 Fluid Dynamics or B13 Fluid Mechanics

A213 Inorganic Electrochemistry

Course Coordinator:
Julia Khusnutdinova
Description:

In this course, students will learn basic principles of electrochemistry with a particular focus on redox behavior of transition metals including metalloproteins. Modern research in application of transition metal complexes for renewable energy storage and production will be highlighted and discussed in detail, including metal-catalyzed water oxidation, proton reduction and CO2 reduction processes. The course will provide practical training in voltammetric techniques and spectroelectrochemistry, and analysis and simulation of cyclic voltammetry data.

Aim:
This course introduces basic principles of electrochemistry, and discusses modern research in the application of transition metal complexes in electrocatalysis for renewable energy storage and production.

Course Content:

1. Basic aspects of electrochemistry
2. Electrochemical instrumentation
3. Cyclic voltammetry: Reversible, irreversible and quasireversible processes
4. Cyclic voltammetry: Effect of coupled chemical reactions; Digital simulation of cyclic voltammograms
5. Bulk electrolysis and pulsed voltammetric techniques
6. Hydrodynamic techniques: application for studying reaction intermediates and mechanisms.
7. Electrochemical behavior of transition metal complexes.
8. Redox-active metalloproteins
9. Redox-induced structural reorganization of metal complexes
10. Electrocatalysis by transition metals for renewable energy production and storage: water splitting to $O_2$and H_2
11. Transition metal-catalyzed electroreduction of CO_2 and dehydrogenation of formic acid and alcohols: application for hydrogen storage
12. Immobilization of metal catalysts on electrode surface
13. Photoelectrochemistry
14. Application of electrochemical processes in chemical industry

Course Type:
Elective
Credits:
2
Assessment:
Laboratory reports: 25%; Homework: 25%; Presentation: 25%; Final exam: 25%
Text Book:
"Inorganic Electrochemistry: Theory, Practice and Application", Pierro Zanello (2003), RSC.
Reference Book:
Original papers and review articles will be supplied as required.

A214 Nucleic Acid Chemistry and Engineering

Course Coordinator: Yohei Yokobayashi

Description:

In this course, students will learn basic principles of nucleic acid chemistry and engineering through lectures and discussions. The students will then use the basic knowledge to deepen their understanding of the current research in the field of nucleic acid chemistry and engineering. Finally, the students will design, construct, and characterize functional nucleic acids in the laboratory while learning basic experimental skills to manipulate nucleic acids.

Aim:
This course introduces the basic principles and current research in nucleic acid chemistry and engineering through lectures, discussions and laboratory sessions.

Course Content:

Basic nucleic acid chemistry (3 hr)

1. Structure (DNA, RNA, unnatural nucleic acids, secondary/tertiary structures)

2. Thermodynamics (hybridization)

Synthesis of nucleic acids (4.5 hr)

1. Chemical synthesis (solid phase synthesis)
2. Biochemical synthesis (PCR, in vitro transcription, gene synthesis, biological synthesis, etc.)

Analysis of nucleic acids (4.5 hr)

1. Chemical analysis (UV, electrophoresis, CD, nuclease probing, SHAPE, etc.)
2. Sequence analysis (Sanger, Illumina, PacBio, nanopore, etc.)

Nucleic Acid Engineering (12 hr)

- Synthetic nucleic acids

1. Unnatural bases and backbones
2. Self-assembly, materials
3. Nucleic acid amplification and detection
4. Therapeutics
5. Aptamers
6. Catalytic nucleic acids
7. In vitro selection, in vitro evolution
8. Molecular computation

- Biological nucleic acids

1. Riboswitches
2. Ribozymes

Laboratory: Design, construction, and characterization of functional nucleic acids (12-16 hr labs)

Course Type:
Elective
Credits:
2
Assessment:
Reports 40%; Presentations 40%; Exam 20%
Text Book:
None
Reference Book:
original papers will be supplied as required

A215 Advanced Experimental Chemistry

Course Coordinator: Ye Zhang

Description:

Materials chemistry is emerging as an interdisciplinary field that involves knowledge from diverse science and engineering research fields. The recent public attention and enthusiasm on nanoscience and nanotechnology not only underscores the importance of interdisciplinary research, but also highlights the promises of materials chemistry. The development of modern chemistry allows chemists to precisely control the three-dimension arrangement of many atoms for developing novel materials. In this laboratory course, we will discuss the development and applications of five kinds of materials and synthesize them using classical chemical reactions through modern techniques. The course is a combination of basic theoretical study, and hands on experimental practice, following with further discussions on modern applications and self-designed possible applications as the after class challenge. The course is designed to be accessible to students from a wide range of educational backgrounds.

Aim:
The aim of the course is to teach students to be able to grasp the fundamental concepts of materials chemistry and gain intuition for developing novel materials for a variety of applications.

Course Content:

Experiment 1: Temperature-sensitive Polymeric Hydrogel

Experiment 2: Magnetic Nanoparticles/Ferrofluids

Experiment 3: Lyotropic Liquid Crystals

Experiment 4: Gold Nanoparticles

Experiment 5: Supramolecular Nanofibers/Hydrogels

(Each experiment runs up to 10 hours over 2 weeks)

Course Type:
Elective
Credits:
2
Assessment:
Performance on experiments 40%, Experiment reports 30%, Presentation on designed application 30%
Text Book:
Lab manual will be supplied.
Reference Book:
Nanomaterials: An Introduction to Synthesis, Properties and Applications, 2nd Edition, Dieter Vollath
Soft Condensed Matter (Oxford Mater Series in Condensed Matter Physics, Vol 6), Richard A. L. Jones
Polymer Chemistry, 2nd Edition, Paul C. Hiemenz and Timothy P. Lodge

A303 Developmental Biology

Course Coordinator: Ichiro Masai

Description:

This course introduces fundamental principles and key concepts in the developmental processes of animal organisms, by focusing on Drosophila embryonic development and vertebrate neural development as models, and will facilitate graduate students to reach a professional level of understanding of developmental biology. Furthermore, genetic tools for live imaging of fluorescence-labeled cells using Drosophila and zebrafish embryos will be introduced as practical exercises. The course also includes debate on specific topics in developmental biology by students and a writing exercise of mock-grant application. Some lecturers outside OIST will be invited to present particular special topics.

Course Content:

1. Basic concepts of developmental biology, and introduction of model systems
2. Development of the Drosophila embryonic body plan
3. Organogenesis
4. Patterning of vertebrate body plan
5. Morphogenesis
6. Cell fate decision in the vertebrate nervous system
7. Current topics of neuronal specification and multipotency of neural stem cells
8. Axon guidance, target recognition
9. Synaptogenesis
10. A model for neurodegeneration in Drosophila
11. Debate of topics of developmental biology by students
12. Debate of topics of developmental biology by students
13. Debate of topics of developmental biology by students
14. Genetic tools for live imaging of fluorescence-labeled cells using Drosophila
15. Genetic tools for live imaging of fluorescence-labeled cells using zebrafish

Aim:
This lecture series will introduce fundamental principles governing development of animal organisms and current research topics
Course Type:
Elective
Credits:
2
Assessment:
Participation 20%; Written Report 40%; Presentation 40%
Text Book:
Principles of Development 2 edn, Lewis Wolpert (2010) Oxford University Press
Developmental Biology 9 edn, Scott F. Gilbert (2010) Sinauer
Development of the Nervous System 3 edn, Sanes, Reh, Harris (2011) Academic Express

A304 Evolutionary Developmental Biology

Course Coordinator: Noriyuki Satoh

Description:

The course presents the most recent theory and techniques in evolutionary and developmental biology with an emphasis on the underlying molecular genomics. Recent advances in decoding the genomes of various animals, plants and microbes will be followed, with a discussion on comparative genomics, the evolution of transcription factors and signal transaction molecules and their relation to the evolution of the various complex body plans present through history.

Course Content:

1. Introduction (background, general concepts, etc)
2. History of animals (fossil records, phylogenic tree)

3. History of animals (genomics, molecular phylogeny)
4. Genetic toolkits (developmental concepts)
5. Genetic toolkits (Hox complex)
6. Genetic toolkits (genetic toolkits, animal design)
7. Building animals (lower metazoans)
8. Building animals (protostomes)
9. Building animals (deuterostome and vertebrates)
10. Evolution of toolkits (gene families)
11. Diversification of body plans (body axis)
12. Diversification of body plans (conserved and derived body plans)
13. Evolution of morphological novelties
14. Species diversification
15. Phylum diversification

Aim:
To introduce basic concepts of Evo-Devo that are essential to understand the diversity of animal body plans.
Course Type:
Elective
Credits:
2
Assessment:
Homework (20%), Written reports (4 x 20%).
Text Book:
From DNA to Diversity, 2 edn, by Carroll, Grenier and Weatherbee (2005) Blackwell.

A306 Neuroethology

Course Coordinator:
Yoko Yazaki-Sugiyama
Description:

The course provides an understanding of the neuronal mechanisms that underlie animal behavior. We will study the neuronal mechanisms for specialized animal behaviors such as sensory processing, motor pattern generation, and learning by reading original papers, which also provide an understanding of experimental technique. The course further discusses the evolutionary strategy and the biological ideas of animal behavior and underlying neuronal mechanisms.

Course Content:

1. Introduction (Basic Neurophysiology and neuronal circuits)
2. Sensory information I: Visual and Auditory (map formation, plasticity and critical period, etc.)
3. Sensory information II: Olfactory (Chemical) and other senses
4. Sensory perception and integration I (Echolocation, Sound localization, etc.)
5. Sensory perception and integration II (Sensory navigation, etc.)
6. Motor control I (Stereotyped behavior)
7. Motor control II (Central pattern generator)
8. Sexually dimorphic behavior
9. Learning I (Learning and memory)
10. Learning II (Associative learning)
11. Learning III (Sensory motor learning during development)
12. Learning VI (Spatial navigation)
13. Behavioral plasticity and the critical period

14. Recent techniques in neuroethology

Aim:
To introduce an understanding of the neuronal mechanisms that control complex animal behavior.
Course Type:
Elective
Credits:
2
Assessment:
Homework, 20%; Written reports, 4 x 20%.
Text Book:
Behavioral Neurobiology, by Thomas J Carew (2000) Sinauer

A307 Molecular Oncology and Cell Signalling

Course Coordinator: Tadashi Yamamoto

Description:

This course consists of lectures and exercises. First, students learn, through lectures, recent progress in cancer research and the mechanism of carcinogenesis based on the molecular and cellular functions of oncogenes and anti-oncogenes. Further, students will learn the relevance of signal transduction, cell cycle progression, cell adhesion, and gene regulation to tumor development and are encouraged to simulate effective methods of diagnosis and treatment of cancer. Further, through exercises, students will consider the relevance of genome sciences and systems biology to cancer research. Students are encouraged to refer to the textbook and to papers from the current literature. The course will also present special novel and important topics from year to year.

Aim:
This advanced course aims to develop a deep understanding of tumor development, based on recent research developments in the molecular and cellular biology of cancer.

Course Content:

1. Historical background of molecular oncology
2. Viruses, chemical carcinogens, and tumor development
3. RNA tumor viruses and oncogenes
4. Discovery of anti-oncogenes
5. Regulation of signal transduction and cell cycle progression by oncogenes and anti-oncogenes
6. Roles of oncogenes and anti-oncogenes in normal physiology
7. Molecular mechanisms of metastasis
8. Genome, proteome, metabolome, and cancer
9. Animal models of cancer
10. Drug development for cancer treatment
11. Cancer stem cells
12. microRNA and cancer development
13. Genome sciences in cancer research
14. Systems biology in cancer research

Course Type:
Elective
Credits:

2
Assessment:
Oral presentation of paper, 50%; Research report, 50%.
Text Book:
The Biology of Cancer, by Weinberg (2006) Garland Science
Molecular Biology of the Cell, 5 ed, by Alberts, Johnson, Lewis, Raff, Roberts and Walter (2007) Garland Science
Reference Book:
The Molecules of Life, by Kuriyan, Konforti, and Wemmer (2012) Garland Science
Biochemistry, 7 ed, by Berg, Tymoczko, and Stryer (2010) WH Freeman & Company

A308 Epigenetics

Course Coordinator: Hidetoshi Saze

Description:

Epigenetic regulation of gene activity is essential for development and response to environmental changes in living organisms. This course introduces fundamental principles and key concepts of epigenetics, and original research publications contributed to understanding the mechanism underlying the epigenetic phenomena will be reviewed. Lecturers from outside OIST may be invited for specific topics.

Aim:
This course provides an overview of the principles of epigenetics to students with background of molecular biology and genetics.

Course Content:

1. Introduction to Epigenetics
2. Histone variants and modifications
3. DNA methylation
4. RNA interference and small RNA
5. Regulation of chromosome and chromatin structure
6. Transposable elements and genome evolution I
7. Transposable elements and genome evolution II
8. Epigenetic regulation of development I
9. Epigenetic regulation of development II
10. Genome imprinting
11. Dosage compensation I
12. Dosage compensation II
13. Epigenetic reprogramming and stem cells
14. Epigenetics and disease
15. Epigenomics

Course Type:
Elective
Credits:
2
Assessment:
Participation 50%; Presentation, 50%.
Text Book:
Epigenetics, by Allis, Jenuwein, Reinberg, Caparros (2006) Cold Spring Harbor Laboratory Press

Reference Book:
Molecular Biology of the Cell, 5 edn, by Alberts et al. (2007) Garland Science
Introduction to Genetic Analysis, 10 edn, by Griffiths et al. (2010) W.H. Freeman and Company
Prior Knowledge:

Requires at least B06 Cell Biology and Genetics or similar background knowledge

A310 Computational Neuroscience

Course Coordinator: Erik De Schutter

Description:

Computational neuroscience has a rich history going back to the original Hodgkin-Huxley model of the action potential and the work of Wilfrid Rall on cable theory and passive dendrites. More recently networks consisting of simple integrate-and-fire neurons have become popular. Nowadays standard simulator software exists to apply these modeling methods, which can then be used to interpret and predict experimental findings.

This course introduces some standard modeling methods with an emphasis on simulation of single neurons and synapses and an introduction to integrate-and-fire networks. Each theoretical topic is linked to one or more seminal papers that will be discussed in class. A number of simple exercises using the NEURON simulator will demonstrate single neuron and synapse modeling.

Aim:
This course introduces basic concepts and methods of computational neuroscience based on theory and a sampling of important scientific papers.

Course Content:

1. Introduction and the NEURON simulator
2. Basic concepts and the membrane equation
3. Linear cable theory
4. Passive dendrites
5. Modeling exercises 1
6. Synapses and passive synaptic integration
7. Ion channels and the Hodgkin-Huxley model
8. Neuronal excitability and phase space analysis
9. Other ion channels
10. Modeling exercises 2
11. Reaction-diffusion modeling and calcium dynamics
12. Nonlinear and adaptive integrate-and-fire neurons
13. Neuronal populations and network modeling
14. Synaptic plasticity and learning

Course Type:
Elective
Credits:
2
Assessment:
Active participation to textbook discussions in class (40%), reports on modeling papers (40%), written exercises (20%).

Text Book:
Biophysics of Computation, by Christof Koch (1999) Oxford Press
Neural Dynamics: From Single Neurons to Networks and Models of Cognition, by Wulram Gerstner, Werner M. Kistler, Richard Naud and Liam Paninski (Cambridge University Press 2014)
Reference Book:
Computational Modeling Methods for Neuroscientists, edited by Erik De Schutter (MIT Press 2010)
Prior Knowledge:

Requires prior B03 Mathematics I, B04 Mathematics II and B05 Neurobiology or similar background knowledge.

A311 Cellular Aging and Human Longevity

Course Coordinator: Mitsuhiro Yanagida

Description:

A series of lectures and seminar (for invited lecturers) will provide basic concepts how contemporary scientists challenge the enigma of longevity and lifespan through diverse methodology. The subjects have greatly attracted mankind for thousand years. But rigorous scientific approach has been conducted for only a few decades after molecular, cellular, genetic and genome approaches to understand life mechanisms become possible. In addition, proper introduction of model organisms and detailed experimental analysis greatly helped the establishment of basic concepts on longevity and lifespan of organisms. In addition, after the entry into 21st century, developed countries have increased senior populations over 65 yr old and the financial burden for medical care and welfare is increasingly felt. Hence human longevity and lifespan have become important research themes in many countries. Healthy longevity is now the keyword for human welfare. In this series of lectures, I plan to invite a few more experts on human gerontology. It is quite important for every person to know basics of human aging and how we adapt and/or confront it.

Course Content:

January 12 (Yanagida) Introduction on cellular life span and human longevity: How I was interested in cellular and organisms lifespan after years of chromosome research.

January 19 Professor Hiroshi Kondoh (Kyoto University, School of Medicine, Gerontology) Introduction of human longevity part 1.

January 26 (Yanagida) How I started to study human aging through blood metabolites

February 2 Professor Hiroshi Kondoh (Kyoto University, School of Medicine) Human longevity part 2.

Seminar for OIST researchers and students after lecture.

February 9 (Yanagida). Measuring biological aging

February 16 Professor Takehiko Kobayashi (Univ Tokyo), Seminar, afternoon for OIST students and researchers

February 23 (Yanagida) Cellular aging

March 2 (Yanagida) Genetics of aging

March 9 (Yanagida) Genetics of aging through the study of fission yeast G0 cells

March 16 (Yanagida) Human longevity and agin.

March 23 Professor Yoichi Nabeshima (Kyoto Univ) The role of Klotho for human longevity, Seminar, afternoon for OIST students and researchers

March 30 Invited speaker (not decided)

April 6 Professor Eisuke Nishida# (Kyoto Univ, School of Biostudy) Lifespan of model organisms, Seminar, afternoon for OIST students and researchers

April 13 (reserved) a possible topic: Age-related human diseases

Aim:
This course provides a current overview of cellular aging and human longevity.
Course Type:
Elective
Credits:
2
Assessment:
TBC
Text Book:
Biology of Aging by Roger B. McDonald. Garland Science 2014

A401 Controversies in Science

Course Coordinator:
Gordon Arbuthnott
Description:

The course Controversies in Science aims to develop critical thinking and argument, essential skills for effective independent scientists. The course will be flexible in content and presentation. Invited lecturers will present topics of some controversy or recent interest in science and lead debates by the students. We will also look at some historical controversies in different fields such as neuroscience and genetics, in which we will assign students to take sides by reading only one side of a specific argument, and encourage them to discuss the issue and arrive at a resolution in class.

Aim:
This course aims to develop the argument and critical powers of scientists by examining the scientific process and its relation to knowledge, and looking at a wide range of topics of moral controversies in science.

Course Content:

1. The Scientific Method, Ockham's Razor, Basic Philosophy of Science
2. Boundaries of Science, L'Affaire Sokal, "Crackpots"
3. Science & Racism in 1940s Germany and Japan
4. Science and Capitalism: the pharmaceutical industry & biomedical science

5. Science and Communism: Lysenko
6. Scientific Misconduct I: Piltdown Man
7. Scientific Misconduct II: Recent Cases
8. Insights ahead of their time: Mendel and others
9. Paradigm shifts: the reception of evolutionary biology
10. Science and Religion: opposition to evolution
11. Science and the media: the case of the autism-vaccination link, and others
12. Science and the law: the suppression of psychedelics research
13. Science and war: the making of the nuclear bomb
14. The animal rights movement and science
15. Conclusions: science as a social enterprise

Course Type:
Elective
Credits:
2
Assessment:
Participation and contribution to discussion and debate.
Text Book:
Scientific Controversies: Case Studies in the Resolution and Closure of Disputes in Science and Technology, by Engelhardt and Caplan (1987) Cambridge University Press
Reference Book:
Doubt: A History: The Great Doubters and Their Legacy of Innovation from Socrates and Jesus to Thomas Jefferson and Emily Dickinson, by JW Hecht (2004)

A402 Computational and Mathematical Biology

Course Coordinator: Hiroaki Kitano / Igor Goryanin

Description:

Computational approaches to science in general, and particularly in biology, are an increasingly important topic. However, understanding the concepts behind such computational approaches in biology is particularly difficult due to discrepancies in the methodologies and languages that are used. This course covers basics of computational and mathematical biology with strong emphasis on understanding of computational foundation and practical modeling of metabolic networks and signal transduction networks. Students are expected to actively participate in hands-on modeling sessions. A series of numerical computation, statistical, and intelligent systems approaches will be shown in the context of computational biology. The course will introduce standards used in the field such as SBML, SBGN, BioPAX, and MIRIAM, and students will gain direct experience in modeling sessions using CellDesigner (http://www.celldesigner.org/) PhysioDesigner (http://www.physiodesigner.org/).

Course Dates: Intensive 3-week course August (Minimum 2 hours class time per day plus reading and exercises)

Course Content:

Days:

1. Course Overview and Introduction of Computational Biology (Kitano)
2. Computational Foundation of Metabolomics (Goryanin)
3. Metabolic network reconstruction (Goryanin)
4. Metabolic network modeling (Goryanin)

5. Mark up languages: SBML, SBGN (Goryanin)
6. Metabolic Database resources and development (Goryanin)
7. Metabolic Modeling and Practical applications (Goryanin)
8. Metabolic Pathways Reconstruction and Modeling: Practical Session (Goryanin)
9. Metabolic Pathways Reconstruction and Modeling: Practical Session (Goryanin)
10. Signal Transduction & Metabolic Modeling: Practical Session (Kitano & Groyanin)
11. Signal Transduction Modeling: Practical Session (Kitano)
12. Computational Foundation of Signaling (Kitano)
13. Computational Foundation of Cell Cycle (Kitano)
14. Practical applications of signal transduction modeling (Kitano)
15. Advanced topics in computational biology (Kitano)

Aim:
The goal of this course is to provide basic exposure to computational and mathematical thinking about basic biological processes and learn how to construct models and analyze them for biological studies.
Course Type:
Elective
Credits:
2
Assessment:
Written report, 50%; Project, 50%.
Text Book:
Systems Biology: A Textbook by Klipp, Liebermeister, Wierling, Kowald, Lehrach, and Herwig (2009)
An Introduction to Systems Biology: Design Principles of Biological Circuits, by Uri Alon (2006)
Kinetic Modelling in Systems Biology, by Oleg Demin and Igor Goryanin (2008)

A404 Measurement

Course Coordinator: Denis Konstantinov

Description:

Measurement is fundamental to scientists in all disciplines. This course will look at ways to make measurements and to avoid many of the pitfalls encountered in common and unusual measurements. A sound theoretical basis will be provided to allow students to go on to make their own choices with confidence and experience. Topics will include instrumentation, physical noise processes, signal transduction, models of small signal amplification, as well as modulation, detection, synchronous and lock-in detection, signal sampling techniques, digitization, signal transforms, Fourier analysis. Theoretical techniques to be presented will be centered around probability, probability theory, probability distributions, statistical inference, information theory, exact cases, and Gaussians.

Aim:
This course describes fundamental problems in measurement and cutting-edge solutions to them.

Course Content:

1. Information theory: signals, background and noise.
2. Probability, distributions, Gaussians, Boltzmanns
3. Sample size and Power of analysis
4. Signal sampling techniques
5. Frequency and digitization
6. Fourier and other transforms

7. Instrumentation
8. Amplifiers
9. Modulation
10. Time-locked measurements, synchronous and asynchronous events
11. Analog instruments
12. Noise reduction
13. Small signals
14. Projects
15. Projects

Course Type:
Elective
Credits:
2
Assessment:
Projects (2 x 30%) 60%; Final Exam 40%.
Text Book:
Modern Instrumentation for Scientists and Engineers, by John Blackburn (2000) Springer
Essentials of Mathematical Methods in Science and Engineering, by Selcuk Bayin (2008) Wiley-Interscience
Reference Book:
The Art of Electronics 2 edn, by Horowitz and Hill (1989) Cambridge University Press
The Electrical Engineering Handbook 2 edn, by Richard C Dorf (1997) CRC Press

A405 Emerging Technologies in Life Sciences

Course Coordinator: Ichiro Maruyama

Description:

This course is intended to provide an introduction to cutting-edge techniques that might be useful for research projects by graduate students at OIST. Such techniques include nucleotide sequencing, microarray, confocal laser scanning microscopy, microfluidics and neuroimaging. Each session will be composed of a lecture relevant to the technique. Where possible, hands-on training or research laboratory visits will also be provided, and technical presentations will be invited from leading experts. This course is intended to provide an introduction to cutting-edge techniques that might be useful for research projects by graduate students at OIST. Such techniques include nucleotide sequencing, microarray, confocal laser scanning microscopy, microfluidics and neuroimaging. Each session will be composed of a lecture relevant to the technique. Where possible, hands-on training or research laboratory visits will also be provided, and technical presentations will be invited from leading experts.

Aim:
This course introduces cutting-edge technologies in life science.

Course Content:

1. Course Introduction & Nucleotide sequencing I (Background, Basics, PCR & qPCR, etc)
2. Nucleotide sequencing II (Next generation, Genome analysis, etc)
3. Nucleotide sequencing III (RNA sequencing, ChIP, Applications, etc)
4. Microarray I (Background, Basics, DNA chips, etc)
5. Microarray II (Protein chips, Applications, Future development, etc)
6. Confocal laser scanning microscopy I (Basics, Live cell imaging, probes, etc)

7. Confocal laser scanning microscopy II (Multi-color imaging, Multi-photon, etc)
8. Confocal laser scanning microscopy III (Spectral imaging, FRAP, FRET, etc)
9. Confocal laser scanning microscopy IV (PALM, SHIM, STED, etc)
10. Microfluidics I (Background, Basics, Microfabrication, etc)
11. Microfluidics II (Applications, Devices, Future development, etc)
12. Single molecule imaging I (FCS, FCCS, etc)
13. Single molecule imaging II (TIRF、FLIM, etc)
14. Neuroimaging I (Optical, PET/CT, etc)
15. Neuroimaging II (MRI/fMRI, SPECT, etc)

Course Type:
Elective
Credits:
2
Assessment:
Midterm Reports (3 x 20%) 60%; Final Essay 40%
Text Book:
An Introduction to Genetic Analysis, 8 edn, by Lewontin, Miler, Suzuki, Gelbart, Griffiths (2004) WH Freeman
Reference Book:
Handbook of Biological Confocal Microscopy, 3 edn, Edited by JB Pawley (2006) Springer
Principles of Fluorescence Spectroscopy, 3 edn, by JR Lakowicz (2006) Springer

A409 Electron Microscopy

Course Coordinator:
Matthias Wolf
Description:

The course is designed as a mix of introductions into selected topics in the theory of transmission electron microscopy followed by practical demonstrations and hands-on exercises, which provide an opportunity to comprehend the concepts by experimenting with commonly-used image processing software. Students will be required to read and digest scientific papers for a subset of lecture topics on their own, which will subsequently be discussed jointly during student presentations with the goal to immerse them into the subject without passive consumption. The lectures cover several important concepts of the physics of image formation and analysis, which require a basic level of mathematics. An emphasis will be given to highlighting common properties between diffraction and image data and how to take advantage of tools from both techniques during the final image processing projects.

Aim:
This course provides an introduction into electron microscopy techniques and applications in biology. Participants will obtain the background knowledge for critical reading of current literature and will be exposed to practical exercises in image processing.

Course Content:

1. History of the TEM / Design of a TEM - Lecture
2. Design of a TEM (cont’d) - Lecture
3. Design of a TEM (cont’d) - Lecture
4. Demonstration of a TEM - Demo
5. Math refresher / Electron waves - Lecture
6. Fourier transforms - Lecture
7. Intro to image processing software in SBGRID - Practical

8. Image alignment - Practical
9. Contrast formation and transfer - Lecture
10. Image recording and sampling - Student presentation
11. Applications in biology - Lecture
12. Preparation of biological samples - Demo
13. Low-dose cryo-EM - Student presentation
14. 2D crystallography - Student presentation
15. Overview of the single particle technique - Lecture
16. Review of theory - Lecture
17. Electron tomography (guest lecture) - Lecture
18. Physical limits to cryo-EM - Student presentation
19. Particle picking - Practical
20. Classification techniques - Student presentation
21. 3D reconstruction - Student presentation
22. Image processing project 1 - Practical
23. Resolution-limiting factors - Student presentation
24. Refinement and sources of artifacts - Student presentation
25. Image processing project 2 - Practical
26. A sampling of original literature - Discussion

Course Type:
Elective
Credits:
2
Assessment:
Participation 30%; Presentation, 30%; Practical Exercises 30%.
Text Book:
Transmission Electron Microscopy: A Textbook for Materials Science (4-vol set), by Williams and Carter (2009) Springer
Three-Dimensional Electron Microscopy of Macromolecular Assemblies, 2 edn, by J Frank (2006) Oxford University Press
Reference Book:
Transmission Electron Microscopy: Physics of Image Formation and Microanalysis, 4th edn, by L. Reimer (1997) Springer
Introduction to Fourier Optics, 3 edn, by J Goodman (2004) Roberts & Co.
Prior Knowledge:

Ideally combined with A403 Strucutral Biology: Protein Xray Crystallography (Samatey) and A410 Molecular Electron Tomography (Skoglund)

A410 Molecular Electron Tomography

Course Coordinator: Ulf Skoglund

Description:

The course will show through theoretical and practical work how the 3D structure of a protein can be determined to about 2nm resolution directly in a buffer solution or in tissue. The students will get a direct hands-on experience of the processes involved in the practical and theoretical aspects of molecular electron tomography (MET). The students will be aware of how to carry out their own MET reconstruction and understand the limitations of the method and how to optimize its use.

Aim:

This course provides an overview of structure-function analysis of individual macromolecules.

Course Content:

1. Learning the computer
2. Learning the computer
3. Practical Aspect of sample preparation for cryo-TEM
4. Sample preparation for cryo-TEM
5. Sample preparation for cryo-TEM; data collection
6. 3D reconstruction
7. 3D reconstruction
8. 3D reconstruction
9. Generating simulation-data
10. 3D reconstruction from simulation-data
11. 3D reconstruction from simulation-data
12. Electron Microscopy: Sample Preparation

Course Type:
Elective
Credits:
2
Assessment:
Oral presentation of analyzed (cryo-)EM tomography article The major assessment is an oral presentation of a selected article in tomography. The students also have to pass the practical sessions in specimen preparations and data processing using computers
Text Book:
Basic papers will be used. There is no published book yet on low-dose cryo-electron tomography on normal sized proteins.
Reference Book:
Electron Tomography (Three-dimensional imaging with the transmission electron microscope) edited by Joachim Frank (1992) Plenum Press New York. One edition is from 1992.

B02 Biology

Course Coordinator: Alexander Mikheyev

Description:

This course will provide a practical hands-on introduction to biology for students without any background in biology, focusing on computational methods. The scope of this course will range from biological molecules, to genomes, to populations. Our goal will be to understand how computational tools may be used to answer fundamental biological problems, and, in the process of doing so, to learn what these problems might be. Although the course will aim to provide a general introduction to biology for student from other disciplines, students with an undergraduate background in biology are also welcome to attend this course for its computational aspect. The course will have a lecture component, but students will be expected to invest a significant amount of time in homework assignments, and the final research-based project.

Course Content:

1. Gene and genome structure
2. Biological databases
3. Sequence alignment and BLAST

4. Phylogeny
5. Population genetics
6. Hidden Markov Models
7. Structural bioinformatics
8. Gene expression
9. Biological networks
10. Next-generation sequencing
11. Genome assembly
12. SNPs and the human genome
13. Final presentations

Aim:
This lecture series provides an introduction to the study of life and to the biology of living organisms.
Course Type:
Elective
Credits:
2
Assessment:
Participation and attendance 1/3; homework 1/3; final project 1/3.
Text Book:
No textbook

B03 Mathematics I

Course Coordinator:
Robert Sinclair
Description:

This course introduces necessary background and fundamental mathematics for graduate biologists. The course emphasizes relevant topics in calculus, probability, and numerical methods with their applications in biology.

Aim:
Survey of basic mathematics for application to life/environmental sciences.

Course Content:

1. History of mathematics and relation to natural sciences.
2. Geometry: Distance, Euclidean and other spaces.
3. Geometry: Vectors, dot and cross products.
4. Geometry: Computation of angles and distance from a point to a line segment and a plane.
5. Geometry: Volume of a tetrahedron. Application to concept of rank.
6. Probability: Concepts (frequentist and Bayesian), independence, conditional probability, Bayes' Theorem.
7. Probability: Random walk, Bernoulli processes, Stirling's formula, normal distribution.
8. Probability: Nearest-neighbour distance distribution for randomly distributed points in a plane.
9. Calculus: Concepts of limit and slope. Application to biology.
10. Calculus: Taylor expansions. Exponential decay.
11. Calculus: Harmonic oscillator. Diffusion.
12. Numerical Methods: Roots of a quadratic polynomial.
13. Numerical Methods: Least squares curve fitting. Bisection.
14. Numerical Methods: Approximation of functions by polynomials.

15. Student presentations.

Course Type:
Elective
Credits:
2
Assessment:
Weekly written exercises, Student presentation in final week.

B04 Mathematics II

Course Coordinator: Robert Sinclair

Description:

The students will be introduced to some more advanced mathematical topics, but without proofs. Linear algebra, vector fields, dynamical systems, stochastic differential equations and numerical methods for these will be covered. Vector fields will be discussed with a view to motivating fluid dynamics, meaning conservation of mass, compressibility and divergence will be discussed. Systems of differential equations and their solution using Euler's and Heun's methods will be introduced. Dynamical systems will include fixed points, their stability, and bifurcation. The meaning of stochastic differential equations and their solutions will be discussed.

Aim:
An extension of the course Mathematics I for graduate biologists.

Course Content:

1. Linear Algebra: Rotations in the plane and space. Matrix representation. Matrix multiplication.
2. Linear Algebra: Solution of linear systems. Eigenproblems. Hardy-Weinberg equilibrium.
3. Linear Algebra: Change of basis, discrete Fourier transform.
4. Continuous flows: Vector fields, conservation of mass, compressibility and divergence.
5. Exercises (individual)
6. Systems of differential equations: Reduction to systems of first order. Euler's method.
7. Systems of differential equations: Reaction-diffusion equations. Heun's method.
8. Systems of differential equations: Hodgkin-Huxley equations.
9. Dynamical Systems: Linear systems, fixed points.
10. Dynamical Systems: Linearization of nonlinear systems.
11. Dynamical Systems: Predator-prey systems. Bifurcation. Chaos.
12. Stochastic differential equations: Euler-Maruyama method.
13. Student presentations: Preparation.
14. Student presentations: Preparation.
15. Student presentations: Presentation.

Course Type:
Elective
Credits:
2
Assessment:
Weekly written exercises.

B05 Neurobiology

Course Coordinator: Gordon Arbuthnott / Tomoyuki Takahashi

Description:

In this course students learn about the cellular and molecular basis of neuronal functions, and how individual electrical signals are integrated into physiological functions. The course will stress connections between information, computations, and biological mechanisms in processes underlying motivated behavior, and will be taught by discussion of physiological mechanisms that contribute to such behaviors. Students will learn how to evaluate evidence obtained in laboratory studies conducted with animals.

Aim:
This course provides an overview of cellular neurophysiology and how neuronal circuits produce behavior.

Course Content:
Organization of the nervous system
Ionic basis of excitability and voltage-gated ion channels
Action potential generation and propagation
Synaptic transmission, neurotransmitters, neuromodulators
Synaptic ion channels and receptors
Synaptic plasticity, intracellular signaling, retrograde messengers
Neural morphology, cytoskeleton, and implications for function
Neural networks, cerebral cortex, basal ganglia, cerebellum
Motor system; movement
Somatosensory systems; Whiskers
Mechanism of sensory transduction
Sensory systems Vision and hearing
Discussion of neurophysiology of brain systems with methods in the awake animal
Course Type:
Elective
Credits:
2
Assessment:
Essay 80%, Lab reports, 20%.
Text Book:
Neuroscience, 5 edn, by Dale Purves, George J. Augustine, David Fitzpatrick, William C. Hall, Anthony-Samuel LaMantia, and Leonard E. White (2012) Sinauer
Reference Book:
The Synaptic Organization of the Brain, 5 edn, Gordon M. Shepherd (2003) OUP
Fine Structure of the Nervous System, 3 edn, Peters Parlay Webster (1991) OUP
The Human Central Nervous System, 4 edn, Nieuwenhuys, Voogd, van Huijzen (2008) Springer
The Central Nervous System, 4 edn, Per Brodal (2010)
Encyclopaedia of Neuroscience (5 volumes) (2009) Springer
Principles of Neural Science, 5 edn, Kandel, Schwartz, Messel, Siegelbaum and Hudspeth (2012) McGraw-Hill
Fundamental Neuroscience 3 edn, Larry Squire, (2008) Elsevier (Academic Press)
Ion Channels of Excitable Membranes, 3 edn, Bertil Hille (2001) Sinauer

B07 Statistical Methods

Course Coordinator: Kenji Doya

Description:

This course introduces basic principles and practical methods in statistical testing, inference, validation, and experimental design. The lectures cover the following topics: What is probability: frequentist and Bayesian views; probability distributions; Statistical measures; Statistical dependence and independence; Stochastic processes; Information theory; Statistical testing; Statistical inference: maximum likelihood estimate and Bayesian inference; Model validation and selection; Experimental design. Emphasis is put on the assumptions behind standard statistical methods and the mathematical basis for finding the right one.

Aim:
This basic course will equip students with the necessary understanding and experience in statistical methods essential to modern scientific research.

Course Content:

1. What is probability: frequentist and Bayesian views
2. Statistical measures and Information theory
3. Statistical dependence and independence
4. Statistical testing
5. Random numbers, random walks, and stochastic processes
6. Regression and correlation analysis
7. Analysis of variance I
8. Analysis of variance II
9. Statistical inference: maximum likelihood estimate and Bayesian inference
10. Model validation and selection
11. Experimental design
12. Experimental design II
13. Conditional probability
14. Special probability densities and distributions
15. Revision and conclusions

Course Type:
Elective
Credits:
2
Assessment:
Problem sets, 60%; Final written test, 40%.
Text Book:
All of Statistics - A Concise Course in Statistical Inference, by Larry Wasserman (2003) Springer
All of Nonparametric Statistics, by Larry Wasserman (2005) Springer
Reference Book:
Pattern Recognition, 4 edn, by S. Theodoridis and K. Koutroumbas (2008) Academic Press
Neural Networks for Pattern Recognition, by Christopher Bishop (1996) Oxford University Press

B08 Physics for Life Sciences

Course Coordinator: Bernd Kuhn

Description:

Principles of physics of central relevance to modern biological analysis and instrumentation are introduced with an emphasis on application in practical research areas such as electrophysiology, optogenetics, electromagnetics, the interaction of light and matter, and brain recording, stimulation, and imaging.

Course Content:

1. Introduction - Physics in Biology: How physics contributes to life sciences.
2. Nature of light
3. Nature of matter
4. Fundamentals on light and matter interaction
5. Fluorescence and its applications
6. Biophotonics
7. Photosynthesis
8. The physics of optogenetics
9. Linear optics
10. Microscopy
11. Non-linear optics, lasers, two-photon microscopy, super resolution microscopy
12. The physics of electron microscopy
13. The physics of DNA, lipid membranes, and proteins
14. Bioelectricity
15. Electronics for electrophysiology
16. Magnetic resonance

Aim:
This basic course aims to introduce physical principles that are necessary in modern life sciences.
Course Type:
Elective
Credits:
2
Assessment:
Midterm presentation 35%, Final presentation 35%, participation + homework 30%
Text Book:
Atkins Physical Chemistry, by P. Atkins & J. de Paula (2006) Oxford University Press
Introduction to Biophotonics by P.N. Prasad, (2003) J. Wiley & Sons
Foundations of Cellular Neurophysiology by D. Johnston & S.M-S. Wu (1994) The MIT Press

B09 Learning and Behavior

Course Coordinator: Gail Tripp

Description:

This course aims to introduce the function of the brain at the macroscopic level, namely, the control of behaviors and the cognitive and adaptive mechanisms behind it. The topics include the following: Reflex, classical and operant conditioning. Perception, adaptation, and attention. Feedback and predictive control. Procedural and declarative memory. Motivation and emotion. Thinking and reasoning. Communication and language. Psychological disorders. Clinical and experimental neuropsychology.

Aim:

This course aims to introduce the function of the brain at the macroscopic level, namely the control of behavior and the cognitive and adaptive mechanisms behind it.

Course Content:

Research methods (I)

- Ethics
- Hypothesis testing
- Dependent and independent variables
- Reliability and validity
- Bias, blinding

Research methods (II)

- Data collection methods
- Observation
- Surveys
- Experimental and quasi experimental designs
- Data analysis

Learning and behavior (I)

- Classical, Pavlovian, respondent conditioning (elicited responses)
- Operant, instrumental conditioning (instrumental responses)

Learning and behavior (II)

- Reinforcement and punishment
- Operant schedules

Learning and behavior (III)

- Behavior modification
- Applications

Motivation and reward

- Drug addiction
- ADHD

Memory and cognition (I)

Memory and cognition (II)

Perception and attention

Behavioral neuroscience (I)

Behavioral neuroscience (II)

Genes and behaviour

Animal models

Life span

Course Type:
Elective
Credits:
2
Assessment:
Article reviews and critiques (5) each worth 5% (Total 25%), Student presentation (2) each worth 15% (Total 30%), Participation in class discussions 5%, Research grant proposal 40%
Text Book:
To be announced
Reference Book:
Attention and Associative Learning: From Brain to Behaviour, by Mitchell and Le Pelley (2010)
Handbook of Neuroscience for the Behavioral Sciences 4 edn, by Bernston and Cacioppo (2009) Wiley
Physiology of Behavior 10 edn, by Carlson (2009) Allyn and Bacon

B10 Analytical Mechanics

Course Coordinator: Mahesh Bandi

Description:

Mastery of the concepts and techniques of analytical mechanics is essential to a deep understanding of physics. This course begins with basic principles and proceeds to the Newtonian equations of motion and laws of conservation. We use the Lagrange formalism to describe particle motion in multiple modes, before covering the equations of Euler and Hamilton, and canonical transformations. The calculus of variation is used to develop Maupertuis's principle and the Hamilton-Jacobi equations, providing a starting point for the consideration of waves in later courses. This course is taught from the unifying principles of symmetry and least action.

Aim:
Covers the fundamental theories of classical mechanics, and provides a firm grounding for later studies of fluid dynamics and quantum physics.

Course Content:

1. The Principle of Least Action
2. Equations of Motion: Galileo and Lagrange
3. Equations of Motion: Newton
4. Conservation Laws: Energy, Momentum, and Angular Momentum
5. Integration of Equations of Motion
6. Breakup, Collision, and Scattering of Particles
7. Harmonic Oscillations: Free, Forced, and Damped Oscillations, Resonance
8. Rigid Body Dynamics: Angular Velocity, Inertia Tensor, Angular Momentum
9. Equations of Motion for Rigid Body
10. Euler's Equations
11. Dynamics of Rigid Bodies in Contact
12. Hamilton's Equations
13. Maupertuis' Principle
14. Canonical Transformations and Liouville's Theorem
15. Hamilton-Jacobi Equations

Course Type:
Elective
Credits:
2
Assessment:
Homework Assignments, 20%. Midterm written tests, 2 x 25%; Final written test, 30%.
Text Book:
Mechanics, 4 edn, by Landau and Lifshitz (1976) Butterworth-Heinemann
Classical Mechanics, 3 edn, by Goldstein, Poole, and Safko (2001) Addison Wesley
Reference Book:
The Variational Principles of Mechanics, 4 edn, Cornelius Lancoz (1970) Dover
The Feynman Lectures on Physics including Feynman's Tips on Physics: The Definitive and Extended Edition, 2 edn, by RP Feynman with Robert B. Leighton et al., editors (2005) Addison Wesley

B11 Classical Electrodynamics

Course Coordinator: Tsumoru Shintake

Description:

A graduate course in analytical mechanics, covering the essential equations and their applications, to prepare for later courses in electrodynamics and quantum physics. This course assumes undergraduate level knowledge of mechanics and a firm grasp of calculus and vector mathematics. An understanding of static electromagnetic fields is extended through Maxwell's equations to a discussion of dynamic vector fields and electromagnetic waves. Along the way, numerous physical and technical applications of these equations are used to illustrate the concepts, including dielectrics and conductors, wave guides, and microwave engineering. Special relativity is introduced with discussion of relativistic and non-relativistic motion and radiation, using linear accelerators and synchrotron radiation as illustrative applications.

Aim:
Covers the theory and application of classical electrodynamics and special relativity, and provides a firm grounding for later studies of quantum physics.

Course Content:

1. Charge and Gauss's Law
2. Current and Ampere's Law
3. Divergence and Rotation
4. Induction
5. Capacitance and Inductance
6. Maxwell's Equation 1
7. Maxwell's Equation 2
8. Vector and Scalar Potentials
9. Electromagnetic Waves
10. Energy, Dispersion
11. Impedance Concept
12. Reflection and Matching Condition
13. Relativistic Equation of Motion
14. Radiation from a Moving Charge
15. Synchrotron Radiation

Course Type:

Elective
Credits:
2
Assessment:
Midterm tests, 2 x 30%; Final written test, 40%.
Text Book:
Electrodynamics of Continuous Media, 2 edn, by Landau, Pitaevskii, Lifshitz (1984)
Reference Book:
Electricity and Magnetism (Berkeley Physics Course, Vol.2) 2 edn by Edward M. Purcell (1986)
Waves (Berkeley Physics Course, Vol.3) 2 edn by Frank S. Crawford (1968) Butterworth-Heinemann
The Classical Theory of Fields, 4 edn, by DL Landau (1980) Butterworth-Heinemann
Classical Electrodynamics, 3 edn, by JD Jackson (1998) Wiley

B12 Statistical Physics

Course Coordinator: Nic Shannon

Description:

Matter can exist in many different phases. The aim of this course is to explain why, and how one phase can transform into another. Starting from the question "what is temperature?", the ideas of entropy, free energy, and thermal equilibrium are introduced, first in the context of thermodynamics, and then as natural consequences of a statistical description of matter. From this starting point, a simple physical picture of phase transitions is developed, with emphasis on the unifying concept of broken symmetry. The course is designed to be accessible to students from a wide range of educational backgrounds. It will be assessed through weekly problem sets, and a final presentation on a modern example of the application of statistical physics ideas, chosen by the student.

Aim:
This course introduces the fundamental concepts and mathematical techniques of equilibrium statistical mechanics in the context of two simple questions: Why does matter exist in different phases ? And how does it change from one phase to another?

Course Content:

1. General overview of phase transitions - what are they, and where do they happen?
2. Introduction to the basic concepts of thermodynamics - temperature, entropy, thermodynamic variables and free energy - through the example of an ideal gas.
3. Introduction to the basic concepts and techniques of statistical mechanics - phase space, partition functions and free energies. How can we calculate the properties of an ideal gas from a statistical description of atoms?
4. Introduction to the idea of a phase transition. How does an non-ideal gas transform into a liquid?
5. The idea of an order parameter, distinction between continuous and first order phase transitions and critical end points. How do we determine whether a phase transition has taken place?
6. Magnetism as a paradigm for phase transitions in the solid state - the idea of a broken symmetry and the Landau theory of the Ising model.
7. Universality - why do phase transitions in fluids mimic those in magnets? An exploration of phase transitions in other universality classes, including superconductors and liquid crystals.
8. Alternative approaches to understanding phase transitions: Monte Carlo simulation and exact solutions.

9. How does one phase transform into another? Critical opalescence and critical fluctuations. The idea of a correlation function.
10. The modern theory of phase transitions - scaling and renormalization.
11. 11.To be developed through student presentations: modern applications of statistical mechanics, with examples taken from life-sciences, sociology, and stock markets.

Course Type:
Elective
Credits:
2
Assessment:
Weekly problem sheets 75%. Final presentation 25%
Text Book:
K. Huang, “Introduction to Statistical Physics” 2nd Edition - (2009) Chapman & Hall
F. Mandl, “Statistical Physics”, 2nd Edition (1988) Wiley
M. Plischke and B. Bergersen, “Equilibrium Statistical Mechanics” 3rd edition (2006) World Scientific
Reference Book:
L. D. Landau and E. M. Lifshitz, “Statistical Physics” (1996) Butterworth-Heinermann
P. Chaikin and T. Lubensky, “Principles of Condensed Matter Physics” (2003) Cambridge University Press

B13 Theoretical and Applied Fluid Mechanics

Course Coordinator: Pinaki Chakraborty

Description:

We will introduce basic concepts of flow of fluids. We will discuss conservation laws and constitutive equations. We will derive the Navier-Stokes equations, and study its exact and approximate solutions. Last, we will introduce the theory of hydrodynamic stability and then discuss turbulent flows. Throughout the course we will discuss a wide spectrum of flows from nature and engineering.

Aim:
To introduce basic concepts, equations, and methods of the mechanics of fluids.

Course Content:

1. Overview of fluid mechanics
2. Kinematics of flow
3. Review of Tensors and the Stress Tensor
4. Conservation Laws: Mass, Momentum, and Energy
5. Constitutive Equations: the Navier-Stokes Equations, Boundary Conditions.
6. Potential Flows
7. Vortex motion
8. Dimensional analysis and similarity
9. Exact solutions of viscous flows
10. Creeping Flows
11. Boundary Layers
12. Hydrodynamic Stability
13. Turbulent flows

Course Type:

Elective
Credits:
2
Text Book:
No textbook is set.
Reference Book:
Fluid Mechanics by L. D. Landau and E. M. Lifshitz, 2 edn (1987) Butterworth-Heinemann
Vectors, Tensors and the Basic Equations of Fluid Mechanics by Rutherford Aris (1990) Dover
General Continuum Mechanics by T. J. Chung (2007) Cambridge University Press
Fluid Dynamics for Physicists by T. E. Faber (1995) Cambridge University Press
An Introduction to Fluid Dynamics by G. Batchelor (2000) Cambridge
Scaling by G. I. Barenblatt (2003)
Fluid Mechanics by P. K. Kundu and I. M. Cohen, 5 edn (2011) Academic Press

B14 Theoretical and Applied Solid Mechanics

Course Coordinator: Gustavo Gioia

Description:

Students are introduced to the concepts of stress and strain, and discuss conservation laws and constitutive equations. We derive the Navier equations of linear elasticity, introduce the Airy stress-function method, and solve problems to illustrate the behavior of cracks, dislocations, and force-induced singularities in applications relating to materials science, structural engineering, geophysics and other disciplines.

Aim:
To introduce basic concepts, equations, and methods of the mechanics of solids, including solutions of representative problems in linear elasticity.

Course Content:

(1) Mathematical Preliminaries:

- Summation convention, Cartesian, spherical, and cylindrical coordinates.
- Vectors, tensors, linear operators, functionals.
- Eigenvalues and eigenvectors of second-order symmetric tensors, eigenvalues as extrema of the quadratic form.
- Fields, vector and tensor calculus.

(2) Stress, Strain, Energy, and Constitutive Relations:

- Cauchy stress tensor, traction, small strain tensor, compatibility.
- Strain energy, strain energy function, symmetries, elastic modulii.

(3) Elasticity and the Mechanics of Plastic Deformation:

- Navier equations, problems with spherical symmetry and problems with cylindrical symmetry (tunnels, cavities, centers of dilatation).
- Anti-plane shear. Plane stress, plane strain.
- The Airy stress-function method in polar and Cartesian coordinates.
- Superposition and Green's functions.
- Problems without a characteristic lengthscale.

- Flamant's problem, Cerruti's problem, Hertz's problem.
- Load-induced versus geometry-induced singularities (unbounded versus bounded energies).
- Problems with an axis of symmetry.
- Disclinations, dislocations, Burgers vector, energetics; relation to plastic deformation in crystalline solids.

(4) Fracture Mechanics:

- The Williams expansion, crack-tip fields and opening displacements via the Airy stress-function method (modes I, II) and via the Navier equations (mode III), crack-tip-field exponents as eigenvalues, stress intensity factors.
- Energy principles in fracture mechanics, load control and displacement control.
- Energy release rate and its relation to the stress intensity factors, specific fracture energy, size effect, stability. The Griffith crack and the Zener-Stroh crack. Anticracks.

(5) Possible Additional Topics (if time allows):

- Elasticity and variational calculus, nonconvex potentials, two-phase strain fields, frustration, microstructures.
- Stress waves in solids, P, S, and R waves, waveguides, dispersion relations, geophysical applications.
- Dislocation-based fracture mechanics, the Bilby-Cotterell-Swindon solution, small- and large-scale yielding, T-stress effects, crack-tip dislocation emission, the elastic enclave model.
- Deterministic versus statistical size effects in quasibrittle materials.
- Vlasov beam theory, coupled bending-torsional instabilities.
- Dynamic forms of instability, nonconservative forces, fluttering (Hopf bifurcation).

Course Type:
Elective
Credits:
2
Text Book:
No textbook is set. Students are expected to take good notes in class. The Professor will from time to time distribute essential readings, as needed.
Reference Book:
General Continuum Mechanics by T. J. Chung (2007) Cambridge University Press
Scaling by G. I. Barenblatt (2003)

B15 Immunology

Course Coordinator: Hiroki Ishikawa

Description:

In this course, students will learn basic principles of immunology including the cellular and molecular mechanism of innate and adaptive immunity. The course also provides the clinical importance of immunology in various diseases such as HIV/AIDS, autoimmunity and allergy. Then, students will learn how the immune response can be manipulated by vaccination to combat infectious diseases and cancer.

Course Content:

1. Basic concepts in immunology

2. Innate immunity
3. Antigen recognition by B-cell and T-cell receptors
4. The generation of lymphocyte antigen receptors
5. Antigen presentation to T lymphocytes
6. Signaling through immune system receptors
7. The development and survival of lymphocytes
8. T cell-mediated immunity
9. The humoral immune response
10. Dynamics of adaptive immunity
11. The mucosal immune system
12. Failures of host defense mechanism
13. Allergy and Hypersensitivity
14. Autoimmunity and Transplantation
15. Manipulation of the immune response

Aim:
This lecture series introduces the basic principles and current research in immunology.
Course Type:
Elective
Credits:
2
Assessment:
Report 50%; Final exam 50%
Reference Book:
Immunobiology 8 edn, by Kenneth Murphy (2012) Garland Science

B16 Ecology and Evolution

Course Coordinator: Evan Economo

Description:

This course covers biological phenomena at or above the scale of a single organism. We will broadly cover topics in evolutionary biology and ecology including but not limited to population genetics, animal behavior, adaptation and natural selection, speciation, phylogenetics, population biology, community ecology, ecosystem ecology, and macroecology.

Course Content:

1. Introduction, levels of organization in biological systems.
2. Taxonomy, systematics, phylogenetics.
3. Biodiversity
4. Energy flows and transformations in biological systems.
5. Genomics and Genetics of Adaptation
6. Physiological ecology.
7. Population dynamics and regulation
8. Life histories
9. The evolution of sex and the evolution of cooperation
10. Community Ecology
11. Ecosystem Ecology
12. Global Climate system and Climate change
13. Conservation Biology

Aim:
This course provides a basic overview of modern concepts in ecology and evolution.

Course Type:
Elective
Credits:
2
Assessment:
Participation and Discussion 50%; Midterm exam 20%; Final Exam 30%
Text Book:
The Economy of Nature 6 edn, by Robert E. Ricklefs (2008) W H Freeman (Paperback)
Evolution, 3 edn, by Douglas Futuyma (2013) Sinauer

B18 Methods of Mathematical Modeling I

Course Coordinator: Eliot Fried

Description:

In this course, students will learn to formulate mathematical models leading to rate equations, transport equations, and variational principles. They will also learn techniques for extracting qualitative and quantitative information from those models. In particular, they will study phase line analysis, phase plane analysis, the method of characteristics, dimensional analysis, and methods for constructing similarity solutions.

Aim:
This is the first of a two-part series of lectures designed to provide students the ability to formulate and extract insight from basic mathematical models.

Course Content:

Rate equations

1. Particle motion
2. Chemical reaction kinetics
3. Ecological and biological models
4. One-dimensional phase-line analysis
5. Two-dimensional phase-plane analysis

Transport equations

1. Reynold’s transport theorem
2. Deriving conservation laws
3. Linear advection equation
4. Systems of linear advection equations
5. Method of characterisitcs
6. Quasilinear equations and shocks

Variational principles

1. Functionals
2. Necessary and sufficient conditions for extrema
3. Essential and natural boundary conditions
4. Application to classical mechanics
5. Treatment of constraints

Dimensional scaling analysis

1. Dimensional quantities
2. Dimensional homogeneity
3. Nondimensionalization
4. Applications
5. Buckingham Pi theorem

Self-similar solutions of partial differential equations

1. Scale-invariant symmetries
2. Similarity variables and solutions
3. Application to the heat equation
4. Application to a nonlinear diffusion equation

Course Type:
Elective
Credits:
2
Assessment:
Assignments 50%; Final exam 50%
Text Book:
Thomas Witelski & Mark Bowen, Methods of Mathematical Modelling — Continuous Systems and Differential Equations. Springer, 2015. ISBN 978-3-319-23041-2.
Reference Book:
Other readings will be supplied
Prior Knowledge: Prior knowledge of elementary calculus

B19 Methods of Mathematical Modeling II

Course Coordinator: Eliot Fried

Description:

In this course, students will learn to apply regular and singular perturbation methods to ordinary and partial differential equations. They will also be exposed to boundary-layer theory, long-wave asymptotic methods for partial differential equations, methods for analyzing weakly nonlinear oscillators and systems with multiple time scales, the method of moments, the Turing instability, pattern formation, and Taylor dispersion.

Aim:
This is the second of a two-part series of lectures designed to provide students the ability to formulate and extract insight from basic mathematical models.

Course Content:

Perturbation methods

1. Asymptotic expansions
2. Regular expansions
3. Singular perturbation problems
4. Applications of perturbation methods

Boundary-layer theory

1. Inner and outer asymptotic solutions
2. Distinguished limits
3. Matching
4. Applications of boundary-layer theory

Long-wave asymptotic solutions to partial differential equations

1. Separation of variables
2. Dirichlet problem for a slender rectangle
3. Application to wires

Weakly nonlinear oscillators

1. Linear oscillators
2. Poincare–Lindstedt expansions
3. Method of multiple time scales

Fast/slow dynamical systems

1. Strongly nonlinear oscillators
2. Chemical reactions
3. Enzyme kinetics

Reduced models for problems involving partial differential equations

1. Method of moments
2. Turing instability and pattern formation
3. Taylor dispersion and enhanced diffusion

Course Type:
Elective
Credits:
2
Assessment:
Assignments 50%; Final exam 50%
Text Book:
Witelski & Mark Bowen, Methods of Mathematical Modelling — Continuous Systems and Differential Equations. Springer, 2015. ISBN 978-3-319-23041-2.
Reference Book:
Supplemental notes will be supplied as appropriate
Prior Knowledge: B18 Methods of Mathematical Modeling I

B20 Introductory Evolutionary Developmental Biology

Course Coordinator: Hiroshi Watanabe

Description:

This course will provide an introduction to Evolutionary Biology focusing on the developmental process of multicellular organisms for students with and without an undergraduate background in this field. Two major goals in this course will be to understand evolutionary changes in development and to learn modern creatures and technologies employed for addressing issues in evolutionary developmental biology.This course presents the basic principles and recent findings in evolutionary developmental biology.

Aim:
This course presents the basic principles and recent findings in evolutionary developmental biology.

Course Content:

1. Animal phylogeny
2. Gain and loss in evolution
3. Gene homology
4. Cell homology
5. Gene expression
6. Basic body plan I: Embryogenesis
7. Basic body plan II: Main body axes
8. Basic body plan III: Main body axes
9. Signaling pathways and gene regulatory networks
10. Body axes in basal metazoans
11. Multicellularity
12. Research tools I: Genome/transcriptome analysis and molecular phylogeny
13. Research tools II: New animal models
14. Research tools III: Gene function analysis

Course Type:
Elective
Credits:
2
Assessment:
Midterm Reports 60% (2 x 30%), Final Exam 40%
Text Book:
None
original papers will be supplied as required
Reference Book:
Animal Evolution Interrelationships of the Living Phyla, 3 Edn, by Nielsen (2011) Oxford University Press
Developmental Biology, 11 Edn, by Gilbert and Barresi (2016) Sinauer
The Evolution of Organ Systems, by Schmidt-Rhaesa (2007) Oxford University Press
Evolutionary Transitions to Multicellular Life Principles and mechanisms, by Ruiz-Trillo and Nedelcu (2015) Springer
Prior Knowledge:

No prior knowledge assumed

PD1 Professional Development I for 2016 Students

Coordinator	Wickens, Jeffery
Description	This course aims to develop knowledge and skills important for leadership in scientific research and e main components of the course are (1) weekly seminars covering basic principles of research conduct

	communication, and aspects of science in society, including a visiting speaker program (2) a cross-dis (3) practical experience to develop presentation and teaching skills. Seminars Seminars are held every Friday afternoon throughout the year. It is imperative that you not only atte that you also engage by participating in discussion and asking questions. Visiting speakers will be invi seminars and lead interactive discussions. Visiting speakers will include leaders from major corporati and scientific laboratories and internationally leading researchers from different fields. This is an opp the leaders see as important during their successful careers, and also a chance to learn how to intera in ways that may lead to valuable connections for your future. Group Project. The group project component aims to develop skills required for effective teamwork, including leade management, cooperation and creative interaction, cross-disciplinary communication, and coordinat Group project work is timetabled on Friday afternoons for two hours every second week, alternating teaching skills training. Timing of project activity is flexible and different times may be decided by the component will require involvement in a student led group project. Projects will not be directly supe member, but there will be opportunities for consultation where certain expertise is required. The na will be explained in class but they may include development of new research tools and applications, i problems, field studies, or creation of resources for research and learning. There will be a self-assess group members to recognize the contributions of different members, and an overall grade based on prize will be awarded for the best project. Scientific Communication Skills Being able to deliver a clear message about your research is a valuable skill. Competition for jobs bot academia is fierce. Researchers, whether in academia or industry, need to develop their personal ski outstanding research, but also to write papers, teach and demonstrate the impact and relevance of t communication skills component of PD1 comprises a set of opportunities for students to improve ac and scientific writing skills.
Aim	The aim of this course is to provide information essential to beginning one's career as a professional develop skills fundamental to modern scientific practice.

Mandatory	
Credit	1
Assessment	Attendance and participation
Text Book	
Reference Book	

Detailed Content

Term 1 Module: Research conduct and ethics

- laboratory procedures, conduct and safety
- record keeping and data management
- plagiarism
- research misconduct
- authorship
- peer review
- conflicts of interest
- research with animals
- research with human subjects

Other Courses Offered

Special Topics

Introduction to Symmetry-Protected Topological Phases

Coordinator: Professor Nic Shannon
Lecturer: Prof. Keisuke Totsuka (Kyoto U)

Aims: To introduce the concept of a Symmetry-Protected Topological phase, and some of the mathematics need to understand it.

Description: Topological phases of matter have many exciting and unusual properties, and are an active field of research in both physics and quantum information theory. Among these, Symmetry-protected topological phases (SPT's) occupy a special place, and played an important role in the development of ideas; indeed, the first known example of an SPT, the Haldane phase found in one-dimensional spin chains, was recently celebrated in the 2016 Nobel Prize for physics. This short, intensive lecture course aims to introduce the concept of a SPT, along with some of the mathematics needed to understand their properties, in the space of six hours of lectures, with accompanying homework problems.

Cell Cycle Control

Coordinator: Professor Jeff Wickens

Main Lecturer: Sir Tim Hunt

Guest Lecturer: Professor Bela Novak

Dates: Feb 9 – April 6, 2017 (guest lectures March 27 – April 6) Teaching Sessions: twice per week. Mondays 10am – 12pm & Thursdays 2pm – 4pm

Description:
We will use primary papers to engage students in critical discussion of the cell cycle. The course will be conducted as a dialogue of mutual discovery. Starting from classic papers that provide the foundation knowledge, the course will continue to contemporary approaches. The course will conclude with integrative sessions using a systems biology approach. Students will be required to

read original papers, in preparation for small group discussions and write an essay on an agreed topic based on a literature survey.

Detailed content (arranged by class session/topics, with description):
Overview of the cell cycle: The discovery of chromosomes and their importance for development (Flemming, Boveri, 1902 (http://10e.devbio.com/article.php?id=24)). The effects of ionizing radiation on cells and the discovery of the phases of the cell cycle Howard and Pelc (1953) [See Int. J. Radiat. Biol. 1986 49:207-218 for a reprint of the hard-to-find original.]
Rao PN, Johnson RT. (1970). Mammalian cell fusion: studies on the regulation of DNA synthesis and mitosis. Nature. 225:159-64. Johnson RT, Rao PN. (1970). Mammalian cell fusion: induction of premature chromosome condensation in interphase nuclei. Nature. 226:717-22.
The growth of yeasts and the discovery and analysis of cell division cycle mutants (Hartwell and Nurse) and the regulation of cell size in fission yeast:
Hartwell, L. H., Culotti, J., Pringle, J. R. & Reid, B. J. (1974). Genetic control of the cell division cycle in yeast. Science 183:46-51.
Nurse P, Thuriaux P, Nasmyth K. (1976): Genetic control of the cell division cycle in the fission yeast Schizosaccharomyces pombe. Mol Gen Genet. 146:167-178.
or
Nurse, P. (1975). Genetic control of cell size at cell division in yeast. Nature 256:547-551.
Russell, P. & Nurse, P. (1986). cdc25+ functions as an inducer in the mitotic control of fission yeast. Cell 45:145-153.
or Russell P, Nurse P. (1987): Negative regulation of mitosis by wee1+, a gene encoding a protein kinase homolog. Cell 49: 559-567.
Early embryonic cell cycle and the discovery of MPF and first hints of the occurrence and importance of proteolysis – the discovery of cyclins. Gurdon, JB (1968). Changes in somatic cell nuclei inserted into growing and maturing amphibian oocytes. J. Embryol. Exp. Morph 20:401-414.
Masui, Y. & Markert, C. L. (1971). Cytoplasmic control of nuclear behavior during meiotic maturation of frog oocytes. J. Exp. Zool. 177:129-146.
Gerhart J, Wu M, Kirschner M. (1984). Cell cycle dynamics of an M-phase-specific cytoplasmic factor in Xenopus laevis oocytes and eggs. J Cell Biol. 98:1247-1255.
Evans, T., Rosenthal, E. T., Youngbloom, J., Distel, D. & Hunt, T. (1983). Cyclin: a protein specified by maternal mRNA in sea urchin eggs that is destroyed at each cleavage division. Cell 33:389-396.
Murray AW, Kirschner MW. (1989): Cyclin synthesis drives the early embryonic cell cycle. Nature 339:275-280
The great unification: Cdc2 meets cyclin. The regulation of MPF; tyrosine phosphorylation of Cdk1, Wee1 and Cdc25.
Lohka MJ, Hayes MK, Maller JL (1988): Purification of maturation-promoting factor, an intracellular regulator of early mitotic events. Proc Natl Acad Sci USA 85:3009–3013
Gautier J, Minshull J, Lohka M, Glotzer M, Hunt T, Maller JL (1990) Cyclin is a component of maturationpromoting factor from Xenopus. Cell 60:487–494
Gautier J, Norbury C, Lohka M, Nurse P, Maller J (1988) Purified maturation-promoting factor contains the product of a Xenopus homolog of the fission yeast cell cycle control gene cdc2+. Cell 54:433–439 Kumagai A, Dunphy WG. (1991): The cdc25 protein controls tyrosine dephosphorylation of the cdc2 protein in a cell-free system. Cell. 64:903-914.
or Kumagai A, Dunphy WG. (1992): Regulation of the cdc25 protein during the cell cycle in Xenopus extracts. Cell. 70:139-151. Tang Z, Coleman TR, Dunphy WG. (1993): Two distinct mechanisms for negative regulation of the Wee1 protein kinase. EMBO J. 12:3427-3436.
The idea of checkpoints and the 'restriction point'.
Zetterberg, A. & Larsson, O. (1985). Kinetic analysis of regulatory events in G1 leading to proliferation or quiescence of Swiss 3T3 cells. Proc. Natl. Acad. Sci. U.S.A. 82:5365-5369. and a modern version: Spencer SL, Cappell SD, Tsai FC, Overton KW, Wang CL, Meyer T. (2013): The proliferation-quiescence decision is controlled by a bifurcation in CDK2 activity at mitotic exit. Cell. 155:369-383. Weinert TA, Hartwell LH. (1988): The RAD9 gene controls the cell cycle response to DNA damage in Saccharomyces cerevisiae. Science 241:317-22.

Dasso, M. & Newport, J. W. (1990). Completion of DNA replication is monitored by a feedback system that controls the initiation of mitosis in vitro: studies in Xenopus. Cell 61: 811-823. The discoveries of G1 cyclins and of Cdk inhibitors (Rum1, p21, p27 and the cancer connection). Cross FR. (1988): DAF1, a mutant gene affecting size control, pheromone arrest, and cell cycle kinetics of Saccharomyces cerevisiae. Mol Cell Biol. 8:4675-4684.
Wittenberg C, Sugimoto K, Reed SI. (1990): G1-specific cyclins of S. cerevisiae: cell cycle periodicity, regulation by mating pheromone, and association with the p34CDC28 protein kinase. Cell 62: 225-237.
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Modelling cell cycle transitions. On the importance of dialogue between experiment and theory. Novak, B., and Tyson, J.J. (1993). Numerical analysis of a comprehensive model of M-phase control in Xenopus oocyte extracts and intact embryos. J Cell Sci 106, 1153-1168. Mochida S, Rata S, Hino H, Nagai T, Novák B. (2016): Two Bistable Switches Govern M Phase Entry. Curr Biol. 26: 3361-3367.
Textbook or required reading: Students will be provided with a list of primary papers as necessary. Chapter 17 of Alberts et al Molecular biology of the cell gives an overview of the cell cycle. David Morgan’s book The Cell Cycle (OUP, 2006) gives details.

Skill Pills AY2016-2017

Skill Pill: Linux   August 22, 24 and 29, 10AM to 12PM

Skill Pill: Python July 31, August 3, 7, 10, 10AM to 12PM

Skill Pill: General Relativity Tuesdays from July 11 to August 29 (2PM)

Skill Pill: Julia July 4, 6, 11 and 13 (5-7PM)

Skill Pill: Intro to Bioinformatics June 17, 24 (Saturdays, 10AM-6PM) + June 16 (3-5PM)

Skill Pill: SolidWorks May 18, 19, 25, 26 (10-12PM) + May 17 (11AM-12PM)

Skill Pill: Calculus May 17, 18, 24, 25 (5-7PM)

Skill Pill: DMRG May 29th and June 1st (1:30PM - 3PM)

Skill Pill: Terminal April 5, 6 and 10 (5-7PM)

Skill Pill: Differential Operators March 23, 27 and 30 (5-7PM)

Skill Pill: Intro to Programming March 18 and 25 (Saturdays, 10AM-6PM)

Skill Pill: Quantum Information 2 February 16, 22, 23 (5-7PM)

Skill Pill: Intro to Neurobiology February 4 and 11 (Saturdays)

Skill Pill: LaTeX January 30, February 2, 6, 9 (5-7PM)

December 10, 17 (Saturdays)

Skill Pill: Fourier Transforms December 1, 7 and 8 from 5 to 7PM

Skill Pill: Next-gen Sequencing November 17, 19 and 23

Skill Pill: gnuplot November 14 and 21 from 5 to 7PM

Skill Pill: R October 22 and 29 (Saturdays), 10AM to 6PM

Skill Pill: Quantum Information October 17 and 24 (Mondays), 5 to 7PM

Skill Pill: Mathematica September 13, 14, 20 and 21 (Tuesdays and Wednesdays) from 5 to 7PM

Skill Pill: Materials Modeling and Simulation September 10 (Saturday) from 10AM to 6PM

Skill Pill: Keynote September 6 and 7 (Tuesday, Wednesday) from 5 to 7PM