Course Archive AY2018

Degree Completion Requirements for AY2018/2019

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 candidates 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 submitted with the thesis to denote that the "material is worthy of publication". Students in AY2016 cohort and onwards must provide evidence that a paper has been submitted, if none has been published.

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: Examination and final versions of the thesis are submitted only as PDF files. All theses are published online in the OIST Institutional Repository. Partial embargo periods are available by negotiation.

Courses Offered in AY2018/2019

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: 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

A103 Stochastic Processes with Applications

Course Coordinator: Simone Pigolotti

Description:

This course presents a broad introduction to stochastic processes. The main focus is on their application to a variety of modeling situations and on numerical simulations, rather than on the mathematical formalism. After a brief resume of the main concepts in probability theory, we introduce stochastic processes and the concept of stochastic trajectory. We then broadly classify stochastic processes (discrete/continuous time and space, Markov property, forward and backward dynamics). The rest of the course is devoted to the most common stochastic processes: Markov chains, Master Equations, Langevin/Fokker-Planck equations. For each process, we present applications in physics, biology, and neuroscience, and discuss algorithms to simulate them on a computer. The course includes “hands-on” sessions in which the students will write their own Python code (based on a template) to simulate stochastic processes, aided by the instructor. These numerical simulations are finalized as homework and constitute the main evaluation of the course.

Aim:

The course is aimed at students interested in modeling systems characterized by stochastic dynamics in different branches of science. Goals of the course are: to understand the most common stochastic processes (Markov chains, Master equations, Langevin equations); to learn important applications of stochastic processes in physics, biology and neuroscience; to acquire knowledge of simple analytical techniques to understand stochastic processes, and to be able to simulate discrete and continuous stochastic processes on a computer.

Course Content:

1) Basic concepts of probability theory. Discrete and continuous distributions, main properties. Moments and generating functions. Random number generators.

2) Definition of a stochastic process and classification of stochastic processes. Markov chains. Concept of ergodicity. Branching processes and Wright-Fisher model in population genetics.

3) Master equations, main properties and techniques of solution. Gillespie algorithm. Stochastic chemical kinetics.

4) Fokker-Planck equations and Langevin equations. Main methods of solution. Simulation of Langevin equations. Colloidal particles in physics.

5) First passage-time problems. Concept of absorbing state and main methods of solution. First passage times in integrate-and-fire neurons.

6) Element of stochastic thermodynamics. Work, heat, and entropy production of a stochastic trajectory. Fluctuation relations, Crooks and Jarzynski relations.

Course Type:

Elective

Credits:

2

Assessment:

Reports (numerical simulations): 60% hands-on sessions, 20% homework assignments, 20% participation in class

Text Books:

Lecture Notes (mostly).

“Random walks in Biology” by H. C. Berg (1993) Princeton University Press

“Stochastic Methods: A Handbook for the Natural and Social Sciences” by C. Gardiner (2009) Springer

Reference Books:

“An Introduction to Probability Theory and its Applications, Vol 1” by W. Feller (1968) Wiley

“The Fokker-Planck Equation”, by H. Risken (1984) Springer

Prior Knowledge:

• Basic calculus: students should be able to calculate integrals, know what a Fourier transform is, and solve simple differential equations.

• Basic probability theory: students should be familiar with basic probability theory, e.g. discrete and continuous distributions, random variables, conditional probabilities, mean and variance, correlations. These concepts are briefly revised at the beginning of the course.

• Scientific programming: the students are expected to be already able to write, for example, a program to integrate a differential equation numerically via the Euler scheme and plot the results. Python is the standard language for the course. The students are required to install the Jupiter notebook system and bring their own laptop for the hands-on sessions.

A104 Vector and Tensor Calculus

Course Coordinator: Eliot Fried

Description:
A geometrically oriented introduction to the calculus of vector and tensor fields on three-dimensional Euclidean point space, with applications to the kinematics of point masses, rigid bodies, and deformable bodies. Aside from conventional approaches based on working with Cartesian and curvilinear components, coordinate-free treatments of differentiation and integration will be presented. Connections with the classical differential geometry of curves and surfaces in three-dimensional Euclidean point space will also be established and discussed.

Course Content:

1. Euclidean point and vector spaces
2. Geometry and algebra of vectors and tensors
3. Cartesian and curvilinear bases
4. Vector and tensor fields
5. Differentiation and integration
6. Covariant, contraviant, and physical components
7. Basis-free descriptions
8. Kinematics of point masses
9. Kinematics of rigid bodies
10. Kinematics of deformable bodies

Course Type:
Elective
Credits:
2
Assessment:
weekly problem sets, a midterm examination, and a final examination
Text Book:
none, working from personal notes
Reference Book:
none
Prior Knowledge:
multivariate calculus and linear (or, alternatively, matrix) algebra

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

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 CO_2 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

A216 Quantum Mechanics I

A217 Quantum Mechanics 2

Course Coordinator: Denis Konstantinov

Description:

This is a two-term graduate course that covers most of the essential topics of modern nonrelativistic quantum mechanics. The course is primarily intended for graduate students with background in Physics.

Aim:

This two-term courses aims to prepare students for taking further advanced courses in Physics and Material Science offered in OIST, such as the Solid State and Condensed Matter Physics, Advanced Quantum Mechanics, Advances in Atomic Physics, Quantum Field Theory, etc.

Course Content:

Quantum Mechanics I

1. Early crisis of classical mechanics and motivations for a new approach in physics: black body radiation and “ultraviolet catastrophe”, Plank’s hypothesis. Einstein’s explanation of photoelectric effect. Bohr’s model of hydrogen atom.
2. Brief review of analytical mechanics: Newtonian mechanics and conservation laws, constrains and Lagrange reformulation of classical mechanics. Hamiltonian formalism. Poisson brackets and canonical transformations. The Hamilton-Jacoby equation.
3. Brief review of classical electrodynamics: Maxwell equations and boundary conditions, effect of continuous medium, propagation of electromagnetic waves. Ray optics and eikonal approximation. Charged particle in electric and magnetic fields.
4. Motivations for postulates of quantum mechanics: Young’s double-slit experiment. de Broglie’s hypothesis of matter waves.
5. Bra-ket formalism, Hilbert space, operators, and their matrix representation. Postulates of quantum mechanics. General uncertainty relation.
6. Canonical transformation in quantum mechanics as a main approach to describe motion of a physical system. Translation in space and operator of momentum. Coordinate and momentum representations. Coordinate-momentum uncertainty relation and the Standard Quantum Limit.
7. Time-evolution operator. Energy-time uncertainty relation. The Schrodinger equation of motion and continuity equation. The Heisenberg picture and equation of motion for operators.
8. Some exactly solvable problems in wave mechanics: particle in free space and motion of the Gaussian packet, particle in the box, linear potential, potential barriers and tunneling. Quantum harmonic oscillator: two approaches in solving the problem, coherent and squeezed states of the quantum harmonic oscillator.
9. The WKB approximation. Feynman’s path integral and classical limit of the quantum mechanics.
10. Quantum particle in static electric and magnetic fields. Gauge transformation and the Aharonov-Bohm effect. Macroscopic quantum coherence and the Josephson effect. Charged particle in the uniform magnetic field: Landau states and their degeneracy. The Quantum Hall effect.
11. Rotations in space and operator of angular momentum. Orbital and spin angular momentums. Coordinate representation of orbital angular momentum. Spherical harmonics.
12. The Schrodinger equation of motion in 2D and 3D. Particle in central potential: 2D and 3D rigid rotators, particle in a spherical box, 3D quantum harmonic oscillator, Hydrogen atom and emission spectrum.
13. Scattering and diffraction of a quantum particle: Born approximation, expansion into the partial waves.

14. Spin-1/2 particle. Stern-Gerlach experiment. Matrix representation of spin-1/2 states and Pauli matrices. Spin-1/2 particle in the uniform magnetic field.
15. Spinor. Addition of angular momentums. Spin-orbit interaction.

Quantum Mechanics 2

1. N-particle systems. Indistinguishable particles and Pauli exclusion principle. System of spin-1/2 particles and exchange interaction. Introduction to second quatization methods.
2. Symmetries in quantum mechanics. Invariance under unitary transformations and conservation laws. Space inversion symmetry and parity. Lattice symmetry: Bloch waves and energy bands. Time reversal symmetry.
3. Approximation methods in quantum mechanics: variational methods, time-independent perturbation theory. Time-independent perturbation theory in case of degenerate states. Selection rules for orbital angular momentum.
4. Hydrogen atom revisited: fine structure and hyperfine splitting.
5. Hydrogen atom in static electric and magnetic fields: quadratic and linear Stark effects, Zeeman splitting and Paschen-Back effect.
6. Time-dependent perturbation theory. Dyson series for the time-evolution operator. Transitions under time-dependent perturbations: adiabatic and sudden perturbations.
7. Harmonic perturbation and interaction of quantum particle with electromagnetic field. The Fermi's golden rule. Stimulated emission and absorption of electro-magnetic waves by a quantum particle.
8. Exactly solvable time-dependent problem: two-level system approximation and the Rabi oscillations.
9. Introduction to the quantum electrodynamics: quantization of electro-magnetic field. Photons and vacuum fluctuations of electro-magnetic field.
10. Hydrogen atom revisited (again): the Lamb shift.
11. Interaction of quantum particle with electromagnetic field revisited: beyond semi-classical description. Spontaneous emission. The Einstein coefficients.
12. Some topics of modern quantum mechanics: cavity QED and Janes-Cummings Hamiltonian. Implications for qubits.
13. Introduction to quantum mechanical statistics. Density matrix formalism. Pure and mixed ensembles of particles. Description of a system of noninteracting particles.
14. Dynamics of an open quantum system and dephasing. Density matrix approach and the master equation. Von Neumann's postulate of quantum measurements.

Course Type: Elective

Credits: 2 per course

Assessment:

Homework: 30%, Midterm Exam: 30%, Final Exam: 40%.

Text Book:

Modern Quantum Mechanics, by J. J. Sakurai (1994) Addison-Wesley

Principles of Quantum Mechanics, 2nd edition, by Shankar (1994) Springer

Lectures on Quantum Mechanics, by Gordon Baym (1969) Westview Press

Reference Book:

Quantum Mechanics: Vol I & II, by Cohen-Tannoudji, Diu, Laloe (1977). Wiley-Interscience

Quantum Mechanics, Vol. 3, and Quantum Electrodynamics, Vol. 4, 2nd edition, by Landau and Lifshitz (1982) Elsevier

Statistical Mechanics, by R.K. Parthria and P. D. Beale (2011) Elsevier

Prior Knowledge:

Students who take the course are expected to be familiar with general topics in Classical Mechanics, Electrodynamics and Calculus. Entry to the second part requires a pass in the first part.

A218 Condensed Matter Physics

Course Coordinator:

Yejun Feng

Description:

Condensed matter physics is both old fashioned (originated from solid state physics in 1950's or even metal physics in 1920's) and also new style (with emphasis on collective behaviour, symmetry, and topological conditions). Over the past century, this sub-field of physics has grown into a monstrous size with various ramifications such that any offered perspective would always be partial and biased. Here this class will be served at the introduction level, and at a few places, I will try to demonstrate how to evolve from fundamental concepts to perspectives of advanced topics. Nevertheless, the first half of this course is built on the single particle picture and is of mean field nature. The second half starts to introduce a few examples of electron correlation. More specialized fields, such as spintronics and topological states and excitations, will not be covered here.

Aim:

This is a class designed for beginner students who would pursue a Ph.D. in fields related to physics, materials science, device engineering, and chemistry. The course covers major concepts and topics in condensed matter, with an emphasis on the shifting new perspective and paradigms in this evolving field. During the weekly three-hour lecture, I will try to split the time with half on theory and half on experimental demonstration of those theoretical concepts.

Course Content:

1. Introduction: the change of perspective and paradigms.
2. Crystals and Symmetry.
3. Phonons.
4. Inelastic probes.
5. Order and disorder
6. Phase transitions and Landau's theory
7. Band structure
8. Fermi surface probes.

9. Hatree-Fock.
10. Electronic excitations in metals.
11. Electrical transport.
12. Superconductivity: BCS.
13. Superconductivity: Quasi-particle gap.
14. Superconductivity: GL.
15. Josephson tunnelling.
16. Josephson devices.
17. Parity sensitive probes.
18. Odd parity superconductivity.
19. Magnetic interactions
20. Itinerant magnetism
21. Spin glass and spin ice
22. Spin excitations and spin liquids.
23. Quantum phase transitions.
24. Non-conventional quantum phase transition.

Notes on Assessement:

There will be four to six assignments. For each assignment, each student is expected to pick one original research paper out of 3-5 suggested choices, and write an essay on it. Each essay should represent individual's own work and should not be the collective effort of a study group. The writing format could be either a critique of the research paper (~1000 words) either placed in its contemporary context or from a historical retrospect, or detailed mathematical derivations of certain formula. For the final presentation, each student is expected to give a half-hour presentation to extensively discuss one of his/her homework assignment papers in a perspective of both depth and breadth, much beyond his/her homework scope.

Course Type:

Elective

Credits:

2

Assessment:

Essays (4-6) 70%, final presentation, 30%.

Text Book:

Ashcroft & Mermin, Solid State Physics (1967).

Chaikin & Lubensky, Principles of condensed matter physics (1995).

Reference Book:

D. Pines, Elementary excitations in solids (1963).

L. P. Levy, Magnetism and superconductivity (1997).

J. R. Schrieffer, Theory of superconductivity (1964).

S.K. Ma, Modern theory of critical phenomena (1976).

M Tinkham, Introduction to superconductivity (1996).

Prior Knowledge:

Students are required to have basic understanding of quantum mechanics (e.g., A216 QM I and A217 QM II), and basic concepts of statistics.

A220 New Enzymes by Directed Evolution

Course Coordinator:

Paola Laurino

Description:

During this course the student will experience a research project. We are planning to run enzyme evolution experiments generating a random library of enzyme mutants and selecting for improved activity in vivo (bacterial strains). Student will create variants of Kan Kynase enzymes. The enzymes will be selected for higher antibiotics resistance to assess improved variants. After a few rounds of evolutions, advantageous mutations will be enriched in the variants pool and identified by sequencing. The enriched mutations will be highlighted in the protein structure and then analysed.

Aim:

This course aims to experience different technologies that are used during protein engineering experiments. These technologies will be explained in detail in theory and in practice with the idea that the student can apply them independently during the course project and in future research.

Course Content:

1. Week 1 Recombinant DNA technology: PCR, cloning, site-specific mutagenesis, random mutagenesis (2hrs)

Lab 1.1 Medium preparation, transformation for overexpression of plasmid (4hrs)

Lab 1.2 Plasmid extraction, quantification (4hrs)

2. Week 2 Introduction on enzymes activity: case study Kan Kinase (1hr)

Lab 2.2 PCR gene, DNA gel, DNA purification (6hrs)

Lab 2.3 library generation by error prone PCR, DNA isolation (6hrs)

3. Week 3 Neutral mutations, deleterious mutations, epistatic mutations (1hr)

Lab 3.1 Digestion insert and vector, purification, set up ligation (8hrs)

Lab 3.2 Medium preparation, EtOH purification and transformation in expressing bacterial strains (BL21DE3). (5hrs)

4. Week 4 Sager sequencing introduction (1hr)

Lab 4.1 Colony PCR, DNA isolation, (5hrs)

Lab 4.2 Sager sequencing preparation, Sager sequencing (8hrs)

5. Week 5 Design of a improved enzyme by directed evolution experiments: kan kinase as case study (1hrs)

Lab 5.1 I Round of selection: Preparation of Kan Plate (different conc), Transformation (6hrs)

Lab 5.2 colony PCR of the surviving colonies and plasmid isolation (5hrs)

6. Week 6 Protein visualisation programs introduction -pymol (2hrs)

Lab 6.1 II Round of selection: Preparation of Kan Plate (different conc), Transformation (6hrs)

Lab 6.2 Colony PCR of the surviving colonies and plasmid isolation (5hrs)

7. Lab 7.1 Sager sequencing of a pool of surviving variants (8hrs)

Lab7.2 Extra time to repeat or catch up with experiments (6hrs)

8. Presentation of a research article where they perform Directed Evolution (2-4hrs depending of number of students)

Course Type:

Elective

Credits:

2

Assessment:

Homework: 25%, Laboratory report 50%, Presentation, 25%.

Text Book:

Structure and Mechanism in protein Science. A guide to Enzyme Catalysis and Protein Folding. Alan Fersht, World Scientific.

Prior Knowledge:

basic biochemistry, molecular biology or organic chemistry

A221 Relativistic Mechanics and Classical Field Theory

Course Coordinator:

Yasha Neiman

Description:

We begin with a gentle and thorough introduction to Special Relativity, and take some time to have fun with shapes in Minkowski space. We proceed to an advanced treatment of relativistic particles, electromagnetic fields and weak gravitational fields (to the extent that doesn’t require General Relativity). Antiparticles are introduced early on, and we put an emphasis on actions and phase space structures. We introduce the geometric concept of spinors, and the notion of spin for particles and fields. We discuss the Dirac equation and the resulting picture of the electron. We introduce conformal infinity. Time allowing, we discuss a bit of conformal field theory and some physics in de Sitter space.

Aim:

An introduction to Special Relativity, with a variety of applications.

Course Content:

1. Tensors in 3d: moment of inertia, Maxwell's equations, stresses etc.
2. Special Relativity in 3d language.
3. Special Relativity in 4d language: Minkowski spacetime.
4. Some fun geometry in Minkowski spacetime: spheres, polyhedra etc.
5. Relativistic particles and antiparticles in electromagnetic and weak gravitational fields.
6. Phase space structure in relativistic mechanics.
7. Maxwell's equations; plane waves and the electromagnetic field of point charges.
8. Linearized Einstein equations; plane waves and the distant gravitational field of point masses.
9. Relativistic thermodynamics and hydrodynamics.
10. Spinors in 3d and 4d.
11. The little group and spin for massive and massless particles.
12. The Dirac equation and the relativistic electron.
13. The conformal boundary of Minkowski spacetime.
14. (*) Conformal symmetry and the embedding-space formalism.
15. (*) An introduction to de Sitter space through the embedding-space formalism.

Course Type:

Elective

Credits:

2

Assessment:

Midterm exam 25% (only if helps the final grade); Final exam 75%. Mandatory homework submission.

Text Book:

Landau & Lifshitz vol. 2 ("Classical Theory of Fields").

"Fields", Warren Siegel [https://arxiv.org/abs/hep-th/9912205].

Reference Book:

"Special Relativity", Thomas M. Helliwell.

"Spinors and Spacetime, Vol. 1: Two-spinor Calculus and Relativistic Fields", Roger Penrose & Wolfgang Rindler.

Prior Knowledge:

Maxwell's equations in differential form. Solving Maxwell's equations to obtain electromagnetic waves. Quantum mechanics.

A222 Theoretical Condensed Matter Physics

Course Coordinator:

Fabian Pauly

Description:

In this course, we introduce fundamental theoretical concepts for the description of many-body systems in solids. A particular emphasis will be put on the quantum mechanical formulation, first principles electronic structure methods as well as optical and transport properties.

Aim:

Modern introduction to theoretical concepts and techniques of condensed matter physics

Course Content:

1. Introduction
2. Concept of a solid
3. Lattice vibrations and phonons
4. Electrons in crystals
5. Electron-phonon interaction
6. Ab-initio electronic structure methods
7. Electronic transitions and optical properties
8. Transport phenomena
9. Superconductivity
10. Magnetism
11. Low-dimensional systems and nanostructures
12. Topological quantum materials

Course Type:

Elective

Credits:

2

Text Book:

Fundamentals of Condensed Matter Physics, by M. L. Cohen, S. G. Louie, (2016) Cambridge University Press

A Quantum Approach to Condensed Matter Physics, by P. L. Taylor, O. Heinonen (2002) Cambridge University Press

Condensed Matter Physics, by M. P. Marder (2015) Wiley

Reference Book:

Solid State Physics, by Neil W. Ashcroft, N. David Mermin, (1976) Cengage Learning

Introduction to Many-Body Physics, by P. Coleman (2016) Cambridge University Press

Electronic Structure: Basic Theory and Practical Methods, by R. M. Martin, (2008) Cambridge University Press

Prior Knowledge:

Basic knowledge of quantum mechanics (see courses A216 and ideally A217)

Ideally taught after Condensed Matter A218

A223 Quantum Materials Science

Course Coordinator:

Yoshinori Okada

Description:

After overviewing various interesting quantum materials and their unique functionalities, this course will introduce the concept of materials design and its realization in bulk single crystal growth and epitaxial thin film growth. Then, the principles of single particle spectroscopy will be introduced, particularly focusing on photoemission and tunneling spectroscopy. This course is ideal for students interested in both crystal growth and spectroscopy in quantum materials science.

During this course, several lectures by external scientists and engineers from R&D companies will be arranged. Also, "4. Group discussion and presentations based on recent literatures" and "6. Experiencing quantum materials growth and their characterization" will be arranged acording to circumstances and students' preference.

Aim:

This course hopes to provide the student with sufficient knowledge to enjoy quantum materials growth and analysis at the frontiers of quantum materials science.

Course Content:

1. Overview of recent interests in quantum materials
2. Materials design concepts and various growth methods
   2-1. bulk single crystal growth
   2-2. epitaxial thin film growth
3. Single particle spectroscopies
   3-1. electronic states in momentum space
   3-2. electronic states in real space
   3-3. heterogeneous electronic states
4. Group discussion and presentations based on recent literatures
5. Lecture by external speakers
   (Lectures will be invited from R&D companies)
6. Experiencing quantum materials growth and their characterization
   (This will be flexibly arranged depending on attendee's preference)

Course Type:

Elective

Credits:

2

Assessment:

Presentation 50%, Report 50%

Text Book:

None

Prior Knowledge:

Undergraduate level of condensed matter physics

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

A312 Sensory Systems

Course Coordinator: Izumi Fukunaga

Description:

The course will cover general concepts and specific modalities as detailed in the table below. Classes alternate between a lecture-style teaching and a journal club. Each lecture will be based on a textbook chapter (Kandel et al's Principles of Neural Sciences, in combination with other, specialised books described in the "Textbooks" section) to cover basic and broad topics, but will also serve as an opportunity to introduce concepts required to understand the research article associated with the lecture.

Aim:

The course is structured for students who would like to know about sensory systems in the brain at an advanced level. The overall aim is expose students to research-level materials, but starting from basic concepts. Topics will include specialisations as well as common principles found in the mechanisms of sensory perception, and will cover the somatosensory, visual, auditory, olfactory systems from transduction to higher cognitive functions. In parallel, the course aims to develop students' ability to read and discuss primary research articles, to give students an exposure to some of the latest techniques and developments.

Course Content:

1 (wk1) Overview lecture/intro Motivation; Modality, basic organisation: transduction, pathways, maps, integration, perception

2 (wk1) Sensory coding lecture/intro Relationship between a physical stimulus and sensation; intensity, threshold, adaptation, effect of background, discriminability

3 (wk2) Somatosensory system I lecture/intro

4(wk2) Somatosensory system I Journal club "Robust temporal coding in the trigeminal system" by Jones, Depireuz, Simons & Keller 2004

5(wk3) Somatosensory system II lecture/intro

6(wk3) Somatosensory system II Journal club "Active spatial perception in the vibrissa scanning sensorimotor system" by Mehta, Whitmer, Figueroa, Williams & Kleinfeld 2007

7(wk4) Hearing I lecture/intro

8(wk4) Hearing I Journal club "Ca2+ current-driven nonlinear amplification by the mammalian cochlea in vitro" by Chan & Hudspeth 2005

9(wk5) Hearing II lecture/intro

10(wk5) Hearing II Journal club "In vivo coincidence detection in mammalian sound localization generates phase delays" by Franken, Roberts, Wei, Golding & Joris 2015

11(wk6) Vision I lecture/intro

12(wk6) Vision I Journal club "Wiring specificity in the direction-selectivity circuit of the retina" by Briggman, Helmstaedter & Denk, 2011

13(wk7) Vision II lecture/intro

14(wk7) Vision II Journal club "Functional specificity of local synaptic connections in neocortical networks" by Ko, Hofer, Pichler, Buchanan Sjostrom & Mrsic-Flogel, 2011

15(wk8) Vision III lecture/intro

16(wk8) Vision III Journal club "Explicit information for category-orthogonal object properties increases along the ventral stream" by Hong, Yamins, Majaj & DiCarlo 2016

17(wk9) Chemical Senses I lecture/intro olfaction

18(wk9) Chemical Senses I Journal club "Random convergence of olfactory inputs in the Drosophila mushroom body" by Caron, Ruta, Abbott & Axel, 2013

19(wk10) Chemical Senses II lecture/intro gustation

20(wk10) Chemical Senses II Journal club "A chemosensory gene family encoding candidate gustatory and olfactory receptors in Drosophila", by Scott, Brady, Cravchik, Morozov, Rzhetsky, Zucker and Axel, 2001.

Assessment: Careful reading of the research article set for each journal club; Each student is asked to write a 1-page summary of the paper in their own words (Homework: 70%). The summary should include the context/rationale for the experiments, methods, results and the significance of the work. The summary will be assessed on clarity, balance, and whether or not student has understood the work. Class participation, 30%.

Course Type:

Elective

Credits:

2

Assessment:

Homework: 70%; Class participation, 30%.

Text Book:

1. Principles of Neural Science (MIT Press) by Kandel, Schwartz, Jessell, Siegelbaum, Hudspeth

2. Auditory Neuroscience (MIT Press) by Schnupp, Nelken and King

3. Principles of Neural Design (MIT Press) by Peter Sterling and Simon Laughlin

Reference Book:

1. Vision by David Marr

Prior Knowledge:

The course is aimed at students with a background in neuroscience (either at the BSc/MSc level or having successfully completed some of the basic neuroscience course offered at OIST). It assumes knowledge in cellular neurophysiology and neuroanatomy. Most relevant courses at OIST will include: B05 (Neurobiology; requirement), A405 (Emerging technologies in life sciences; desirable), B09 (Learning and behaviour; desirable), A310 (Computational neuroscience; highly desirable). B05 is the most important (in terms of subject matters listed on the course’s website), so a pass in this course will be a pre-requisite.

A313 Cognitive Neurorobotics

Course Coordinator:

Jun Tani

Description:

The primary objective of this course is to understand the principles of embodied cognition by taking a synthetic neurorobotics modeling approach. For this purpose, the course offers an introduction of related interdisciplinary knowledge in artificial intelligence and robotics, phenomenology, cognitive neuroscience, psychology, and deep and dynamic neural network models. Special focus is given to hands-on neurorobotics experiments and related term projects.

Aim:

This course aims to provide an overview of the synthetic approach to understand embodied cognition by using deep dynamic neural network models and robotics platforms.

Course Content:

1. Introduction: cognitive neurorobotics study

2. Cognitism: compositionality and symbol grounding problem

3. Phenomenology: consciousness, free will and embodied minds

4. Cognitive neuroscience I: hierarchy in brains for perception and action

5. Cognitive neuroscience II: Integrating perception and action via top-down and bottom-up interaction

6. Affordance and developmental psychology

7. Nonlinear dynamical systems I: Discrete time system

8. Nonlinear dynamical systems II: Continuous time system

9. Neural network model I: 3-layered perceptron, recurrent neural network

10. Neural network model II: deep learning, variational Bayes

11. Neurorobotics I: affordance & motor schema

12. Neurorobotics II: higher-order cognition, meta-cognition, and consciousness

13. Neurorobotics III: hands-on experiments in lab

14. Paper reading for neurorobotics and embodied cognition I

15. Paper reading for neurorobotics and embodied cognition II

Course Type:

Elective

Credits:

2

Assessment:

Mid-term exam: 40%, final term project report: 60%.

Text Book:

Exploring robotic minds: actions, symbols, and consciousness as self-organizing dynamic phenomena. Jun Tani (2016) Oxford University Press.

Prior Knowledge:

Basic mathematical knowledge for the calculus of vectors and matrices and the concept of differential equations are assumed. Programming experience in Python, C or C++ is also required.

A314 Neurobiology of Learning and Memory

Course Coordinator:

Jeff Wickens

Description:

The aim of this course is to engage students in thinking about and discussing fundamental issues in research on neural mechanisms of learning and memory. Topics include the neural mechanisms of learning, memory, emotion, and addictive behavior. Students will be expected to read original reports including classical papers as well as recent advances. The course includes an experimental requirement in which students must design and conduct an experiment related to learning and memory mechanisms of the brain.

Aim:

The aim of this course is to engage students in thinking about and discussing fundamental issues in research on neural mechanisms of learning and memory.

Course Content:

1. Historical perspectives on learning and memory. Classification of learning and memory functions. Theories of memory and learning.
2. Experimental models of memory. Developmental plasticity. Anatomical plasticity. Conditioned reflexes. Imprinting. Extinction. Forgetting.
3. Synaptic plasticity: Homosynaptic and heterosynaptic plasticity, long-term potentiation, long-term depression. Spike-timing dependent plasticity.
4. Cellular mechanisms of synaptic plasticity. Intracellular messages, retrograde messages, receptor phosphorylation, protein synthesis, gene expression, synaptic tagging. Amino acid receptors. AMPA, NMDA, mGluR, nitric oxide.
5. Invertebrate models. Aplysia, honey bees, drosophila. Sensitization of reflexes.
6. Neural circuits for reinforcement learning. Substrates of reward and punishment.
7. Neuromodulation and memory. Dopamine, acetylcholine, serotonin, other neuromodulators. Volume transmission.
8. Cellular mechanisms of reinforcement. Neurochemical basis. Habits, action-outcome learning, behavioral flexibility.
9. Memory and aging. Amnesia. Memory enhancers.
10. Neurochemistry of emotion. Drugs and mood. Addictive behavior.

Course Type:

Elective

Credits:

2

Assessment:

Students will be required to: (i) prepare and present a lecture on the neural basis of a higher integrative function (40%); (ii) design and conduct an experiment on learning and memory (40%); (iii) participate in class discussions (20%).

Text Book:

Selected original papers. Selected chapters from the online course, https://nba.uth.tmc.edu/neuroscience/s1/iend.html

Prior Knowledge:

Students should have previously taken at least two basic courses in neuroscience: Neurobiology, and at least one other basic neuroscience course; or have completed the equivalent by documented self-directed study or skill-pill participation.

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)

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.

B05 Neurobiology

Course Coordinator: 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 is a combination of student-led presentations on each of the key topics, and also student presentations of several classic papers, and a series of laboratory explorations of the topics covered in class.

Aim:

This course provides an overview of cellular neurophysiology and looks closely at the fundamental aspects of action potentials and synaptic signalling, in preparation for other advanced courses in neuroscience.

Course Content:

Theory Classes

Membrane potential (I)

Methods for recording electrical signals

Cell membrane compositions

Intracellular and extracellular ionic compositions

Membrane potential, polarization, depolarization, hyperpolarization

Membrane capacitance

Electrical properties of cell membrane

Nernst equation

Calculation: Equilibrium potentials of Na+ and K+, based on extracellular and intracellular ionic compositions.

Membrane potential (II)

Selective permeability of Na and K ions

Resting membrane potential described by Goldman-Hodgkin-Katz equation

Hodgkin-Huxley membrane model circuit

Active transport

Na-K ATPase

Action potential (I)

Voltage-clamp recording; principle and practice

Cable properties of axonal membrane

Molecular structure of voltage-gated Na channels

Relationship between single Na channel currents vs whole cell Na currents

Channel activation, channel deactivation vs channel inactivation

Na current-voltage relationship

Voltage dependence of Na channel conductance

Mechanism of channel inactivation: the ball-and-chain model

Action potential (II)

Voltage-gated K channels: molecular structure

Single K channel vs whole cell K currents

K current-voltage relationship

Voltage dependence of K channel conductance

Mechanism of action potential generation and repolarization

Refractory period

Calculation: Amount of Na influx in response to a single action potential, and its impact on intracellular Na concentration (assuming cell size).

Synaptic transmission (I)

Structural organization of synapses

Equilibrium potential for Ca ion.

Voltage-gated Ca channels: molecular structure and subtype classification

Ca current-voltage relationship and conductance

Non-linear relationship between Ca and transmitter release.

Synaptic transmission (II)

Roles of Ca channels and K channels in transmitter release

Quantal nature of transmitter release; from binomial to Poisson theorem

Synaptic transmission (III)

Exocytosis, endocytosis, vesicle recycling

Molecular mechanisms of transmitter release

Ca domain in the nerve terminal: how to estimate its size?

Synaptic vesicle recycling and reuse

Vesicular transmitter refilling mechanism

Synaptic transmission (IV)

Ligand-gated ion channels: molecular structure

Nicotinic acetylcholine receptor, AMPA receptor, NMDA receptor,

Glycine receptor, GABA(A) receptor

EPSP/EPSC, IPSP/IPSC; Equilibrium potentials: calculation

Regulatory mechanisms for intracellular Cl concentration

Sensory transduction mechanisms

G protein-coupled receptors

Second messengers and targets

Muscle spindle, stretch-activated channels

Auditory transduction, from sound to action potentials

Visual transduction, from light to action potentials

Olfactory transduction, from odor to action potentials

Synaptic integration & modulation

Patellar-tendon reflex

Reciprocal inhibition

Postsynaptic inhibition, presynaptic inhibition

Feedback and feedforward inhibition

Lateral inhibition

Retrograde inhibition

Autoreceptor

Short-term facilitation and depression

Long-term potentiation (LTP) and depression (LTD)

Long-lasting LTP (LLTP)

Role of NMDAR in LTP

Role of glia in LTP

Laboratory Sessions (Takahashi Unit)

Membrane Potential

Action Potential

Synaptic Transmission

Synaptic integration & modulation

Course Type:

Elective

Credits:

2

Assessment:

Student presentations on classic papers, class discussion, and a final report summarising what the student learned in the course.

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

Ion Channels of Excitable Membranes, 3 edn, Bertil Hille (2001) Sinauer

Principles of Neural Science, 5 edn, Kandel, Schwartz, Messel, Siegelbaum and Hudspeth (2012) McGraw-Hill

Reference Book:

Fundamental Neuroscience 3 edn, Larry Squire, (2008) Elsevier (Academic Press)

The Synaptic Organization of the Brain, 5 edn, Gordon M. Shepherd (2003) OUP

Encyclopaedia of Neuroscience (5 volumes) (2009) Springer

From Neuron to Brain (Nicholls et al eds), Sinauer

Prior Knowledge:

No assumed experience in neuroscience. Some knowledge of basic cell biology will be helpful but is not required.

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

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

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

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

B21 Biophysics of Cellular Membranes

Course Coordinator:

Akihiro Kusumi

Description:

Description: Students will learn several basic concepts of biophysics including thermal conformational fluctuation and thermal diffusion, and how cells might take advantage of these physical processes to enable their functions. As a biological paradigm, the cellular membrane system (and their functions), with a special attention paid to signal transduction in the plasma membrane, will be extensively covered. This is because the membranes are critically important for a variety of cellular processes, in the fields of cancer biology, immunology, neuroscience etc., and also because the membrane system provides us with an interesting and useful biological paradigm to learn how the life processes are made possible by thermal-physical processes. As a way of directly “seeing” the thermal, stochastic processes exhibited by receptors and downstream signaling molecules undergoing signaling in live cells, the methods of single-molecule imaging-tracking and manipulation will be discussed quite extensively. Through this course, students will better understand the interdisciplinary field of biology, chemistry, physics, and mathematical science.

Aim:

Aims: This lecture series introduces the basic concepts and current research in cellular biophysics of biological membrane systems.Aims: This lecture series introduces the basic concepts and current research in cellular biophysics of biological membrane systems.

Course Content:

1. Introduction to Biophysics

2. Biological Membrane Structure and Molecular Dynamics

3. Signaling in the Plasma Membrane I

4. Single-molecule Imaging and Manipulation of Plasma Membrane Molecules

5. Interaction between the Plasma Membrane and the Cytoskeleton

6. Force Involved in Organizing Membrane Molecules

7. Domain Structures of the Plasma Membrane

8. Signaling in the Plasma Membrane Enabled by Its Meso-Scale Domain Organization

9. 3D-Organization of the Plasma Membrane: Endocytosis and Exocytosis

10. Membrane Deformation

11. Interaction between the Cytoplasmic Membranes and the Cytoskeleton

12. Tubulovesicular Network in Cells

13. Signaling in the Plasma Membrane II

14. Biological Meso-scale Mechanisms

Course Type:

Elective

Credits:

2

Assessment:

Report 50%; Final exam 50%

Text Book:

Mary Luckey, Membrane Structural Biology 2nd Ed. Cambridge University Press

Prior Knowledge:

Biology, chemistry, or physics at undergraduate levels

B22 Computational Methods

Course Coordinator:

Kenji Doya

Description:

The course starts with basic programming using Python, with some notes on other computing frameworks. Students then get acquainted with data manipulation and visualization using “numpy” and “matplotlib.” After learning how to define one’s own function, students learn iterative methods for solving algebraic equations and dynamic simulation of differential equations. The course also covers basic concepts in stochastic sampling, distributed computing, and software management. Toward the end of the course, each student will pick a problem of one’s interest and apply any of the methods covered in the course to get hands-on knowledge about how they work or do not work.

Aim:

This course aims to provide students from non-computational backgrounds with the basic knowledge and practical skills for computational methods required today in almost all fields of science. Python is used as the standard programming language, but the concepts covered can be helpful also in using other computing tools for data analysis and simulation.

Course Content:

1. Introduction to Python
2. Vectors, matrices and other data types
3. Visualization
4. Functions and classes
5. Iterative computation
6. Ordinary differential equation
7. Partial differential equation
8. Optimization
9. Sampling methods
10. Distributed computing
11. Software management
12. Project presentation

For each week, there will be homework to get hands-on understanding of the methods presented.

Course Type:

Elective

Credits:

2

Assessment:

Homework: 75% (2 hours per week), Project 25%.

Text Book:

Valentin Haenel, Emmanuelle Gouillart, Gaël Varoquaux: Python Scientific Lecture Notes. (http://scipy-lectures.github.com/)

Reference Book:

Python Documentation. (https://docs.python.org/)

Prior Knowledge:

Prerequisite courses and assumed knowledge: Basic computer skill with Windows, MacOS, or Linux is assumed. Each student will bring in a laptop provided by the Graduate School. Knowledge of basic mathematics, such as the calculus of vectors and matrices and the concept of differential equations, is assumed, but pointers for self-study are given if necessary.

B23 Molecular Evolution

Course Coordinator:

Tom Bourguignon

Description:

Life sciences have been greatly influenced by the progress of DNA sequencing technologies. The field of Evolutionary Biology is no exception, and increasingly relies upon fast generation of DNA sequences, that are analysed using fast evolving bioinformatics tools. The aim of this course is to introduce the basic concepts of molecular evolution to students of all scientific backgrounds. We will explore some important questions in Biology, and through concrete examples, determine how molecular evolution theory help answering them. The students will also learn how to use a number of widely used bioinformatics tools.

Aim:

Understanding the theoretical concepts of molecular evolution and their application to solve biological questions.

Course Content:

1. DNA, RNA and protein
2. Replication and mutation
3. Building a genome
4. Gene
5. Selection
6. Drift and population genetics
7. Evolution of species

8. Using DNA to build phylogenies
9. Putting dates on trees
10. High throughput sequencing: the rise of genomics and transcriptomics
11. Working with genome-scale data: Annotation, gene orthology, RNAseq…
12. Genomics of symbiosis
13. Amplicon metagenomics and environmental DNA
14. Ancient DNA and protein

Course Type:

Elective

Credits:

2

Assessment:

1/4 participation, 1/4 presentation, 1/2 homework and essay.

Text Book:

An Introduction to Molecular Evolution and Phylogenetics, by Lindell Bromham (2015) Oxford University Press

Prior Knowledge:

Assumes general knowledge in biology; ideally follow-on course from B16 Ecology and Evolution

B24 Neural Dynamics of Movement

Course Coordinator:

Marylka Yoe Uusisaari

Description:

The course will start from the mechanisms of animal movement, including the evolutionary, ecological and energetic aspects; we will explore the anatomical and mechanical features of the body machinery (such as muscles, bones and tendons) before investigating the structure and dynamic function of the neuronal circuits driving and controlling movements. We will thus examine neuronal function at various levels, allowing the students to familiarize themselves with many fundamental concepts of neuroscience; the theoretical lectures will be complemented by practical exercises where the students will study movement in themselves and their peers in the motion capture laboratory environment as well as with more classical approaches.

Aim:

This course aims to provide an introductory-level overview of the structures and mechanisms underlying brain function in the context of generating and modulating physical movement of the body.

Course Content:

BLOCK 1 (4 weeks): The physical reality of movement

- Environments, evolution and fitness
- Movement styles - running, flying, swimming
- Mechanics of movement - forces, angles, timing
- Body mechanics - muscles, bones, tendons

BLOCK 2 (5 weeks): Movement generation

- Reflexes and drive in neuromuscular control
- Principles of neuronal circuit function
- Pattern generation in spinal systems
- Ascending brainstem pathways - reflex modulation
- Descending brainstem pathways - drive and modulation of locomotion

BLOCK 3 (4 weeks): Moving with purpose

- Motor cortex - commanding descending pathways
- Somatosensory cortex - monitoring movement
- Adjusting movements - sensory feedback, cerebellar systems
- Motor learning
- Linking motor behavior to cognitive function

Course Type:

Elective

Credits:

2

Assessment:

Participation and Discussion 40%; In-term exams 30%; Project work 30%

Text Book:

TBA

Reference Book:

Principles of Neural Science, by Kandel, Schwartz, Jessell, Siegelbaum, Hudspeth (2012) MIT Press

Handbook of Brain Microcircuits, by Shepherd & Grillner (2010) Oxford University Press

Prior Knowledge:

This is a basic level course, that will be adjusted accordingly to the interests of enrolled students. No prior knowledge assumed.

B25 Statistical Mechanics

Course Coordinator:

Reiko Toriumi

Description:

Statistical physics deals with large collections of particles, typically about 1023. Anything big enough to see with our eyes (daily experience) has enough particles in it to qualify as a subject of statistical physics. Within physics, statistical physics is widely used in condensed matter physics, cosmology, and furthermore it shares a lot of techniques with Quantum Field Theory, which successfully describes at least three fundamental forces in nature: the Strong, Weak, and Electromagnetic forces. Many physical systems, as they constitute many degrees of freedom, exhibit phase transitions which statistical mechanics lets us explore. At the critical point where phase transitions happen, seemingly different systems exhibit the same universal behavior. This is really an observer's dream. Statistical mechanics bridges the microscopic world with the macroscopic world, i.e., makes the connection between one particle and 1023particles. It is a way to let the different scales talk to each other. Our course will strive to demonstrate the unity of these perspectives.

Aim:

The course is designed as an introduction to the methods of Statistical Mechanics. Statistical physics is a thrilling intersection of physical and mathematical ideas which can describe experiences ranging from our daily life to very non-daily ones, possibly including quantum gravity.

Course Content:

We plan to cover the following material from the textbook
- Chap 1: The Statistical Basis of Thermodynamics
- Chap 2: Elements of Ensemble Theory
- Chap 3: The Canonical Ensemble
- Chap 4: The Grand Canonical Ensemble
- Chap 5: Formulation of Quantum Statistics
- Chap 6: The Theory of Simple Gases
- Chap 7: Ideal Bose Systems
- Chap 8: Ideal Fermi Systems
- Chap 9: Statistical Mechanics of Interacting Systems: Cluster Expansions Method
- Chap 12: Phase Transitions: Criticality, Universality and Scaling
- Chap 14: Phase Transitions: Renormalization Group Approach

The instructor reserves the right to make minor changes in the syllabus, as needed.

Note: homework asignments are due every Wednesday, before the class. There will be no late homework submission accepted, unless it is discussed with the instructor beforehand.

Lecture meets with Toriumi: Wed:10-12 Fri: 10-11
Discussion meets with Toriumi: Mon: 10-11

The exams will be closed book, but you can bring a single sheet of paper on which you can write what you want to refer to during the exam on both sides. Note that I will decide how many midterms we will do shortly after we start the course. Depending on the number of midterms, there will be adjustments on the distribution for the weights of each element (i.e., homework and exams).

Expectations: Students are expected to attend every lecture and discussion. Students are responsible for the materials that are covered in lectures. Note that in lectures, we will cover additional materials that are not discussed in the textbooks. Discussion sessions are designed for you to practice solving problems.
One of the important things in your scienti c career is good communication. You will have

collaborators, peers, students and public for you to communicate your scientific results with. Without you communicating well about your results, your results may well be equal to nothing. Students are therefore expected to practice good communication with the instructor. Your homework, and your exams for example, are ways to communicate with the instructor. Keep in mind that it is not just about showing that you solved the problems, but it is about showing and demonstrating that your work is legitimate. You are expected to work toward this goal.

Course Type:

Elective

Credits:

2

Assessment:

Weekly assignments (30%); 2 x midterm exams (2 x 20%); final exam (30%)

Text Book:

Statistical Mechanics, by Pathria and Beale (2011) Elsevier

Reference Book:

An introduction to Thermal Physics, by Schroeder (2000) Addison Wesley

David Tong, online lectures on Statistical Mechanics

Prior Knowledge:

Students should have knowledge of Classical Mechanics and Quantum Mechanics to advanced undergraduate level.

PD1 Professional Development I for 2018 Students

Course Coordinator:

Ulf Skoglund

Description:

This course aims to develop knowledge and skills important for leadership in scientific research and education. The three main components of the course are (1) weekly seminars covering basic principles of research conduct and ethics, scientific communication, and aspects of science in society, (2) a cross-disciplinary group project, and (3) practical experience to develop presentation and teaching skills.

Seminars

Seminars are held every Friday afternoon throughout the year. Seminars last 1 hour. It is imperative that you not only attend the seminars but that you also engage by participating in discussion and asking questions. You may be assigned specific responsibilities to facilitate discussion. In order to participate in discussion well, you’ll need to prepare. This means more than simply reading the required articles. You'll need to reflect on them as well. You will be informed how to obtain the required articles one week ahead of the seminar they will be used in.

Group Project

The group project component aims to develop skills required for effective teamwork, including leadership, project management, cooperation and creative interaction, cross-disciplinary communication, and coordination of group activity. Group project work is timetabled on Friday afternoons for two hours every second week, alternating with presentation and teaching skills training. Timing of project activity is flexible and different times may be decided by the group. The project component will require involvement in a student led group project. Projects will not be directly supervised by a faculty member, but there will be opportunities for consultation where certain expertise is required. The nature of possible projects will be explained in class but they may include development of new research tools and applications, inventions to solve problems, field studies, or creation of resources for research and learning. There will be a self-assessment requirement by group members to recognize the contributions of different members, and an overall grade based on a final presentation. A prize will be awarded for the best project.

Presentation and Teaching Skills

The presentation skill component comprises a set of opportunities for students to gain experience in giving presentations to various groups and teaching at different levels. It is timetabled on Friday afternoons for two hours every second week, alternating with group project activity, but may be arranged flexibly. Students develop skills by a range of different assignments including: acting as teaching assistants; assisting with visiting student programs; contributing to outreach activities; presenting and participating in journal clubs; and giving a presentation based on research rotations. There will be a self-assessment requirement including a report documenting activities and evaluation of the research presentation.

Aim:

The aim of this course is to provide information essential to beginning one's career as a professional scientist, and to develop skills fundamental to modern scientific practice.

Course Content:

Term 1 Module: Research conduct and ethics

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

Term 2 Module: Scientific communication

- scientific writing
- poster presentations
- scientific talks
- communicating science to the non-specialist
- teaching science
- grant applications

Term 3 Module: Life in science and science in society

- science and the law
- intellectual property and patents
- working in science
- reputation/visibility/personal profile
- funding of science
- research and social responsibility
- leadership in research and education
- This course continues in the 2nd year. Students in second year are expected to attend seminars presented by guest speakers. Students in second year may also participate in additional specific training if there is a need, such as further developing presentation and writing skills.

Course Type:

Mandatory

Credits:

1

Assessment:

Attendance and participation

Other Courses Offered

Special Topics

Basic Cell Biology

Coordinator: Professor Keiko Kono

Efficient Scientific Computing with Julia

Taught by Valentin Churavy, PhD student at MIT
Under the approval of Prof Ulf Skoglund, Dean of the Graduate School

Scientific computing is a cornerstone of research, many scientific projects now involve coding in some form — may it be modeling, simulations or data analysis — and doing so in a performant and reproducible manner is a requirement to contribute effectively. This course uses Julia to teach the fundamentals of best practices for reproducible code, performance analysis, and contributing to open-source. It furthermore focuses on aspects of HPC computing necessary to analysis and study large problems — in particular GPU computing.

Participants should posses some programming experience in either Julia, Python, MATLAB or C/C++. As part of the course students will design a small project, that can lead to an open-source contribution, an implementation of scientific program, or the performance improvement thereof. While the course uses Julia, the knowledge should be transferable to other languages.

Computational Biology: Artificial Intelligence for Bioinformatics

Professor Hiroaki Kitano (OIST adjunct professor)
with other presenters

7/22 (Mon) 09:00-13:00: Kitano & Asai (Intro /Hands-on I Physiological Modeling)

7/23 (Tue) 09:00-13:00: Kitano (Signal Transaction/Cell Cycle)

7/24 (Wed) 09:00-13:00: Funahashi (Hands-on Ⅱ CellDesigner Modeling)

7/25 (Thu) 09:00-13:00: Kitano (AI for Life Science/Wrap-up)

Non-equilibrium Nanophysics

Dr Juan David Vasquez Jaramillo (Pauly Unit)

Statistical mechanics, a beautiful approach to equilibrium, is well known in physics for its broad range of applicability to describe the state of systems with a macroscopic number of particles. When the context changes, and the length scale is reduced as far as the Nanoscale, defining thermodynamics becomes cumbersome and new approaches must be introduced.

In the present course, we will develop the theory of quantum mechanical non-equilibrium processes from the Brownian harmonic oscilator, deriving Keldysh field theory, and putting it into context in models describing tunneling probes such as scanning tunneling microscopy (STM) or inelastic electron tunneling spectroscopy (IETS). Computer exercises will be developed to illustrate these examples and the students will be expected to be able to reproduce a scientific paper in their field of interest in relation to advanced statistical mechanics, non-equilibrium nanophysics or molecular electronics, as well they will be able to write a review on their topic of interest of maximum 25 pages and a minimum of 75 references.

20 hours (4 hours per week for 5 weeks) in Term 3

States and Properties of Matter

Professor Mahesh Bandi

Offered as a series of four special topics courses presented over two terms (two courses per term). It treats the standard (gases, liquids and solids) and few exotic (polymers and colloids) classical states of matter, and explains how these states and their bulk properties emerge from the few interatomic and intermolecular forces at play. The emphasis is on developing strong physical intuition for microscopic mechanics using the simplest models that illuminate the concept. In doing so, we explain both the strengths and shortcomings of these simple models, and in particular, analyse the limiting conditions where they fail. Therefore, rather than theoretical rigour, the focus of the treatment is on performing quick order-of-magnitude calculations. As a result, although the mathematics is unsophisticated, Calculus is a pre-requisite. Wherever possible, scientific facts will be connected with the seminal experiments that established them.

Term 2, Classes Wednesday 2-4 and Thursday 3-5, Room B714a (modules 3 & 4 in term 3 at time and location TBD)

Quantum Models for Black Holes: Sachdev-Ye-Kitaev and generalizations

Professor Frank Ferrari (Université Libre de Bruxelles), Visitor in Toriumi Unit

Holography predicts that black holes can be described quantum mechanically by large N matrix models at strong coupling. We shall describe very recent ideas that have allowed to build exactly solvable models of this kind, providing an explicit quantum mechanical description of string-size black holes. These ideas are at the confluence of several different fields: condensed matter theory (disordered systems); quantum chaos; string theory and holography; matrix and tensor models (graph theory), etc. Many properties associated with black holes are found in the quantum mechanical description and will be discussed in the course, in particular the loss of unitarity at large N (and unitarity restoration at finite N), the quasi-normal behaviour, an emergent reparameterization invariance and maximal chaos.

Lectures 12 hours between 22 March to 10 April, and attendance at parts of workshop "Workshop on recent developments in AdS/CFT" on 2 & 3 April 2019

Skill Pills AY2018-2019

Skill Pill: Arduino August 28, 29

Skill Pill: Git August 13, 14, 15, 1PM to 3PM

Skill Pill: Julia July 11, 12, 16, from 10AM to 12PM

Skill Pill: Computational Reproducibility June 27, from 10AM to 12PM

Skill Pill: MATLAB May 13, 15, 20, 22, 1PM to 3PM

Skill Pill: Terminal May 27, 28, June 2 3PM to 5PM

Skill Pill: Intro to Molecular Dynamics May 20, 23, 27

Skill Pill: macOS Tips and Tricks March 21, 10AM to 12PM

Skill Pill: Endnote April 19, 1PM to 3PM

Skill Pill: Intro to Programming March 19, 20, 26, 27

Skill Pill: Classical and ab initio Molecular Simulations February 18, 25 and March 4, 2PM-4PM

Skill Pill: Non-Equilibrium Green Functions February 25, 27 and March 6, 6, 10AM-12PM

Skill Pill: Blender February 19, 21, 26 and 28 , 10AM - 12PM

Skill Pill: Beautiful Python January 22 and 24, 10AM - 12PM

Skill Pill: Field Studies of Animals February 1, 10AM - 12PM

Skill Pill: Linear Dynamical Systems February 4 and 6, 3:30PM - 5:30PM

Skill Pill: Vector Calculus Identities January 10, 11, 17 and 18 (non-regular schedule)

Skill Pill: Quantitative Genetics January 10 and 11, 1PM-3PM

Skill Pill: Intro to Molecular Biology Methods December 5, 6 and 12, from 1PM to 3PM

Skill Pill+: Evolutionary Genomics December 15 (Saturday) and 16 (Sunday AM)

Skill Pill: Asymptote November 27, 28 and December 4, 1PM - 3PM

Skill Pill: Amira November 22, 27 and 29, 10AM - 12PM

Skill Pill: LaTeX November 6, 7, 13 and 14, from 1 to 3 PM

Skill Pill: Thermodynamics of Open Quantum Systems October 10 and 12, 10AM to 12PM

Skill Pill: Inkscape September 25 and 27, 1PM to 3PM