OIST

Elective Course Catalog

Academic Year 2023

September 2023 to August 2024

Note: these course groupings are approximate, and for convenience of the reader only. They do not imply any separate programs of study or departmental divisions. Course content and terms offered are subject to change.

Chemistry

B33 – Organic Photonics and Electronics

Ryota Kabe

Explore the exciting interdisciplinary world of organic photonic and electronic devices, with wide application in industry and research. Lectures and accompanying experiments develop an understanding of fundamental concepts in synthesis and purification of organic optoelectronics. Perform a range of photophysical functional analyses. Discover and discuss device physics and fabrication of organic LEDs, transistors, solar cells, and lasers.

2 credits, offered in Term 1

B40 – Introduction to Polymer Science

Christine Luscombe

Learn how polymers, widely used in everything from clothing to paints, drug delivery to electronics, function. Discover which applications are appropriate for different polymers, and how polymers can be synthesized. Through classroom discussion, presentations, and journal club, explore the interrelationship between molecular structure, morphology, and properties, develop characterization techniques, and evaluate environmental impact and sustainability issues relating to polymers.

2 credits, offered in Term 1

A208 – Bioorganic Chemistry

Fujie Tanaka

Design and synthesize small organic functional molecules for understanding and controlling biological systems. Build a solid foundation of modern synthetic organic chemistry strategies, including stereoselective, enantioselective, and asymmetric methods. Through lectures and literature studies, explore a range of mechanisms of catalytic reactions controlling reaction pathways and molecular interactions essential in organic reactions and in the design and synthesis of catalysts, functional small organic molecules, and protein conjugates.

2 credits, offered in Term 2

A213 – Inorganic Electrochemistry

Julia Khusnutdinova

Discover the principles of electrochemistry with a particular focus on redox behavior of transition metal complexes including metalloproteins. Review the application of transition metal complexes as catalysts for renewable energy storage and production, including metal-catalyzed water oxidation, proton reduction and CO2 reduction processes. Perform cyclic and pulsed voltammetry, electrolysis, and spectroelectrochemistry in the laboratory. Course evaluation based on weekly lab reports and homework, class presentation and final exam.

2 credits, offered in Term 1

A214 – Nucleic Acid Chemistry and Engineering

Yohei Yokobayashi

Learn basic principles of nucleic acid chemistry and engineering through lectures and discussions. Build on this basic knowledge to explore current research in the field of nucleic acid chemistry and engineering. Emphasis will be placed on discussing current and future applications of nucleic acids in diverse fields including chemistry, biology, materials, medicine, biosensors, and engineering through current literature. Depending on the number of students and availability of resources, either development of a research proposal or a short laboratory session will be performed.

2 credits, offered in Term 2

A220 – New Enzymes by Directed Evolution

Paola Laurino

Discover and apply a range of technologies and techniques to generate, isolate, and enhance mutated bacterial proteins. Lectures and readings about protein structure, function and evolution are complemented by an extensive laboratory project in directed protein evolution that develops applicable research skills. Special topics in protein engineering include gene mutations, ancestral protein reconstruction, and rational design of new enzymes. Explore additional topics by journal club and student presentations.

2 credits, offered in Term 1

A226 – Synthetic Chemistry for Carbon Nanomaterials

Akimitsu Narita

Learn classical and modern approaches in the organic synthesis of molecular nanocarbons and related compounds, with a focus on the large polycyclic aromatic hydrocarbons known more recently as nanographenes. Explore the relationship between their structures and optical, electronic, and magnetic properties along with related analytical techniques. Discover relevant methods in polymer chemistry and surface sciences for synthesis and characterization of graphene nanoribbons and other carbon nanostructures. Discuss the latest developments in the related research areas in class presentations.

2 credits, offered in Term 3

Engineering and Applied Sciences

B13 – Theoretical and Applied Fluid Mechanics

Pinaki Chakraborty

Explore a wide spectrum of flows from nature to engineering while learning the basic concepts, equations, and methods of fluid mechanics. Consider conservation laws and constitutive equations, derive the Navier-Stokes equations, and interpret exact and approximate solutions. Discussion includes an introduction to the theory of hydrodynamic stability and turbulent flows.

2 credits, offered in Term 2

B14 – Theoretical and Applied Solid Mechanics

Gustavo Gioia

An introduction to the basic concepts, equations, and methods of the mechanics of solids, including solutions of representative problems in linear elasticity. Through lectures and reading exercises, discover the concepts of stress and strain, and discuss conservation laws and constitutive equations. Derive the Navier equations of linear elasticity, and use them and the Airy stress-function method to understand the mechanics of fracture and of plastic deformation. Solve problems to illustrate the behavior of cracks, dislocations, and force-induced singularities in applications in materials science, structural engineering, geophysics, and other disciplines.

2 credits, offered in Term 3

A105 – Nonlinear Waves: Theory and Simulations

Emile Touber

Many physical processes exhibit some form of nonlinear wave phenomena. However diverse they are (e.g. from engineering to finance), however small they are (e.g. from atomic to cosmic scales), they all emerge from hyperbolic partial differential equations (PDEs). This course explores aspects of hyperbolic PDEs leading to the formation of shocks and solitary waves, with a strong emphasis on systems of balance laws (e.g. mass, momentum, energy) owing to their prevailing nature in Nature. In addition to presenting key theoretical concepts, the course is designed to offer computational strategies to explore the rich and fascinating world of nonlinear wave phenomena.

Whilst the course is aimed at graduate students with an engineering/physics background, biologists interested in wave phenomena in biological systems (e.g. neurons, arteries, cells) are also welcome.

2 credits, offered in Term 2

A106 – Computational Mechanics

Marco Rosti

Numerical solutions to partial differential equations have wide application in many areas of physics, mechanics, engineering, and applied mathematics. Learn different techniques for solving elliptic, parabolic, and hyperbolic equations, such as finite differences and finite volumes. Discuss possibilities and limitations of numerical techniques. Evaluate and comment on the stability and convergence of these numerical methods. Explore systems of partial differential equations and the Navier-Stokes equations. Use Python or MATLAB coding in weekly exercise sessions to numerically solve diffusion, convection, and transport problems in multiple dimensions.

2 credits, offered in Term 3

A212 – Microfluidics

Amy Shen

Investigate the interface between engineering and miniaturization, one of the most intriguing and active areas of inquiry in modern technology, through the interdisciplinary research area of microfluidics. Explore emerging microfluidics disciplines, including molecular assembly to bulk and device level scales, and applications in novel materials synthesis, bio-microtechnology and nanotechnology. Learn about fundamental aspects of fluid mechanics, scaling laws and flow transport at small length scales and consider multi-phase flow, droplet-based microfluidics along with capillary-driven, pressure-driven, and electro-kinetic based microfluidics. Observe standard microfabrication techniques, micro-mixing and pumping systems.

2 credits, offered in Term 3

Cell Biology

B15 – Immunology

Hiroki Ishikawa

Learn basic principles of immunology including the cellular and molecular mechanism of innate and adaptive immunity. Recognize the contribution of the various cell types in adaptive immunity and describe immune signaling pathways. Explore the clinical importance of the immune system in various diseases such as HIV/AIDS, autoimmunity, and allergy. Discover ways to manipulate the immune response, such as vaccination, and thereby combat infectious diseases and cancer. Research an immune system question from the literature and present findings.

2 credits, offered in Term 3

B20 – Introductory Evolutionary Developmental Biology

Hiroshi Watanabe

Survey the range of modern animal body plans, and discover how these have evolved through time. Examine the developmental processes leading to specific body plans in multicellular animals, and some of the specific molecular mechanisms at the genetic and cell signalling level. Learn about and use some of the software and hardware techniques for researching development in animals. Discuss modern approaches and recent findings in the field, with student presentations and reports on specific issues in evolutionary developmental biology.

2 credits, offered in Term 2

B21 – Biophysics of Cellular Membranes

Akihiro Kusumi

Explore concepts of biophysics including thermal conformational fluctuation and thermal diffusion, and consider how cells might take advantage of these physical processes to enable their functions. Discover how the cell membrane system functions in light of these physical processes to fulfil its critical contribution to cell signal transduction and metabolism. With extensive use of student presentations about topics of cellular signaling in the context of cellular cancer biology, immunology, and neurobiology, discuss the dynamic structures of the plasma membrane, including domain structures, tubulovesicular network, endocytosis and exocytosis, and cytoskeletal interactions. Learn methods of single-molecule imaging-tracking and manipulation for directly “seeing” the thermal, stochastic processes exhibited by receptors and downstream signaling molecules during signaling in live cells.

2 credits, offered in Term 3

B27 – Molecular Biology of the Cell

Keiko Kono

Survey the molecular biology of the cell, the universal biochemical mechanisms at the heart of all living organisms, through lectures based on the classic text by Alberts et al. Working through research-based problem sets, explore the cell and its components and constituents from the level of individual molecules to their interaction, dynamics, and control at the cellular and intercellular level. Classroom discussions explore new findings that may challenge previous conclusions.

2 credits, offered in Term 1

B35 – Genetics and Modern Genetic Technologies

Tomomi Kiyomitsu

A hands-on introduction to the key concepts of genetics and advances in modern genetic technologies. Learn about fundamental principles of genetics underpinning biologically inherited traits, from classical population genetics to modern molecular genetics. Investigate modern genetic technologies for sampling, analysing, and editing genes and experience gene manipulation in the laboratory using CRISPR/Cas9 technology in cultured cells. Discuss the various advantages, drawbacks, and ethics of particular gene-editing technologies.

Students who complete this course will understand the key concepts of genetics and the advantages of modern genetic technologies. In addition, through the exercise of genome editing using cultured human cells, students can realize the power, simplicity of use, and potential risks of genome editing technologies.

2 credits, offered in Term 1

A303 – Developmental Biology

Ichiro Masai

Learn fundamental principles and key concepts in the developmental processes of animal organisms. One model system is Drosophila, looking at embryonic development of body plan patterning and subsequent organogenesis. Another model is vertebrate neural development in zebrafish, looking at vertebrate body plan, cell fate decisions, neuronal specification, axon guidance and targeting, and synaptogenesis. Extend these bases by practical exercises using genetic tools for live imaging of fluorescence-labeled cells using Drosophila and zebrafish embryos. Debate specific topics in developmental biology and apply these findings by writing a mock grant application. Occasional guest lectures on special topics.

2 credits, offered in Term 2

A304 – Evolutionary Developmental Biology

Noriyuki Satoh

Learn about the most recent theory and techniques in evolutionary and developmental biology with an emphasis on the underlying molecular genomics. Trace the history of animal body plans, and consider the genetic toolkits responsible for this evolution. Examine recent advances in decoding the genomes of various animals, plants, and microbes. Through class presentations, critically analyze research in developmental biology and present findings on topics such as comparative genomics, the evolution of transcription factors and signal transduction molecules and their relation to the evolution and diversification of the various complex body plans present through history.

2 credits, offered in Term 3

A307 – Molecular Oncology and Cell Signaling

Tadashi Yamamoto

Explore recent progress in cancer research and the mechanism of tumor development (carcinogenesis) from molecular and cellular functions of oncogenes and anti-oncogenes. Through readings, recent research papers, and hands-on exercises, gain insights into the relevance of genome sciences and systems biology to cancer research. Study the contributions and relevance of signal transduction, cell cycle progression, cell adhesion, and gene regulation to tumor development and discuss animal models of cancer and modes of treatment and drug development. Visiting speakers provide insight into various advanced topics.

2 credits, offered in Term 2

A308 – Epigenetics

Hidetoshi Saze

Epigenetic regulation of gene activity is essential for development and response to environmental changes in living organisms. Discover fundamental principles and key concepts of epigenetics, including the specific molecular mechanisms and structural changes. Examine these changes in the context of modifying factors such as transposable elements, RNA interference, and dosage compensation. Discuss recent advances in epigenetic reprogramming, stem cell applications, and the influence of epigenetic changes on disease. Critically review and discuss original research publications about epigenetic phenomena.

2 credits, offered in Term 3

A320 – The Cell Cycle and Human Diseases

Franz Meitinger

Cell division is the key to life. We all started out as a single cell, which divided billion of times to form an organism with complex tissue structures and the ability to think, create and learn. Defects in cell division are often fatal at an early stage of human development. Mutations in the germline can lead to genetic disorders that impair physical and mental abilities such as microcephaly or DNA repair-deficiency disorders, which increase the predisposition for diseases that occur later in life. On the other hand, mutations in dividing somatic cells can lead to genome instability, which is a hallmark of cancer. Many of the above-mentioned diseases are related to defects in the cell cycle, which coordinates genome and cell organelle duplication with cell division. Main topics of this course include genetic disorders that are related to mechanisms of cell division and are discussed using primary literature. Central elements of the cell division machinery and disease-causing defects are investigated in the laboratory using fluorescent imaging of living cells in combination with clinically relevant drugs and protein-specific chemical inhibitors.

2 credits, offered in Term 2

Ecology and Evolution

B23 – Molecular Evolution

Tom Bourguignon

Recent advances in technology and software for analysis of genetic sequences have rapidly expanded our understanding of the process of evolution at the molecular level. Learn about the basic concepts of molecular evolution, and how they contribute to evolution on larger scales. Use modern tools for gene sequencing to determine changes in genes and their resulting protein changes, and discuss the impact of these on the biology of organisms. Learn how to use a number of widely-used bioinformatics tools for gene annotation, orthology, constructing phylogenetic trees, and genomics and proteomics. Apply these tools to answer important questions in biology such as the evolution of species. Explore the use of modern genetic sampling and sequencing tools and techniques in the analysis of environmental and ancient DNA.

2 credits, offered in Term 3

B41 – Fundamentals of Ecology

David Armitage

Investigate the fundamental question of ecology: the processes that determine the distribution and abundance of organisms. Through reading, discussion, and lecture, explore the principles governing population dynamics over time and space, theories of community assembly and species coexistence, and processes of material cycling through ecosystems. Differentiate and critique major theories of population and community ecology, develop and analyze simple population dynamic models, critically evaluate primary literature and cogently summarize a scientific controversy through writing. Beyond the core subject matter, identify more general principles of the causal feedbacks, scale dependencies, and contingencies of complex social systems.

2 credits, offered in Term 1

A319 – Microbial Evolution and Cell Biology

Filip Husnik

Discover the vast genetic, cellular, and biochemical diversity of life that rests within single-celled organisms: the prokaryotes (bacteria and archaea) and microbial eukaryotes (protists). Through literature and laboratory exercises, explore the immense diversity of single-celled organisms (both prokaryotes and eukaryotes), focusing on their evolution, ecology, genetics, biochemistry, and cell biology, with a focus on the evolutionary history and major cellular innovations that occurred in single-celled organisms during the evolution of life. Apply these insights to critically analyze research papers, design a research project, and write a grant application. In the laboratory, practice a range of techniques for studying cultured and field-sampled protists and prokaryotes, including microscopy and genomic approaches.

2 credits, offered in Term 1

Mathematics and Computational

B29 – Linear Algebra

Liron Speyer

A basic math introduction to linear algebra, directed at physics or engineering students, but also beneficial to neuroscientists and others who require linear and matrix algebra in their research. Course assignments offer practice in linear maps between vector spaces, how these can be realised as matrices, and how this can be applied to solving systems of linear equations. Topics include matrix operations, solving systems of linear equations, eigenvalues, eigenvectors, diagonalisation and Gram-Schmidt orthonormalisation.

Not intended for mathematicians.

2 credits, offered in Term 1

This is an alternating years course.

B31 – Statistical Tests

Tomoki Fukai

Develop the basic methodology of hypothesis testing with the goal of using statistical analysis in experimental and simulation studies. Through lectures and exercises using Python, explore the fundamentals of probability theories and statistical methods including sample means, sample variances, p-values, t-test, u-test, Welch test, confidence intervals, covariance, ANOVA, multivariate analyses, correlations, information theory, mutual information, and experimental design.

1 credit, offered in Term 2

B32 – Statistical Modeling

Tomoki Fukai

Learn the mathematical methods to analyze high-dimensional data for statistical inference. Use large data sets to construct a statistical model that not only describes the dataset but also allows for prediction of future data. Progress from simple regression models through more sophisticated techniques for dimensional reduction, categorization, and decision making. Use Bayesian approaches and clustering techniques as an introduction to machine learning. Weekly exercises and homework consolidate this learning.

This course provides an introduction to machine learning. Students are required to have some knowledge and skills in mathematics. However, the course is not intended for pure theorists.

This course can be taken immediately after the course B31 Statistical Testing, or as a stand-alone course.

1 credit, offered in Term 2

B36 – Introduction to Real Analysis

Xiaodan Zhou

An investigation into the mathematical foundations of calculus. Through lectures and exercises, visit fundamental concepts of mathematical analysis including logic, basic set theory, functions, number systems, order completeness of the real numbers and its consequences, sequences and series, topology of R^n, continuous functions, uniform convergence, compactness, theory of differentiation and integration. Expand mathematical proof and writing skills through ample practice with Latex to communicate mathematics effectively and demonstrate rigorous math thinking in preparation for more advanced courses.

2 credits, offered in Term 1

This is an alternating years course.

B46 – Introduction to Machine Learning

Makoto Yamada

Learn how to use machine learning methods for real data. Beginning with the basics of machine learning including linear algebra, probability, linear regression, and logistic regression, and progressing to deep learning methods. In addition to the lectures, hands-on classes develop competencies in practical use of these techniques. Finally, implement these in student-driven machine learning projects (possibly using data provided from OIST units).

2 credits, offered in Term 1

B48 – Introduction to Complexity Science

Ulf Dieckmann

Complex systems are ubiquitous and play key roles in physical nature, biological life, and social dynamics. We will address the following questions: What is systems thinking, and how can it help us recognize commonalities across disciplines and domains of application? How can complex systems be understood and modeled, including their structure, dynamics, agency, and function? What are the key tools in a complexity scientist's toolbox? Addressing these questions, we will use a cross-disciplinary approach suitable for students with backgrounds in physics, chemistry, biology, neuroscience, social sciences, mathematics, and computer science.

2 credits, offered in Term 2

A101- Adaptive Systems

Kenji Doya

Explore common mathematical frameworks for adaptation at different scales and link them with biological reality. The course is in a "flipped learning" style; each week, students read a book chapter and experiment with sample codes before the class.

In the first class of the week, they present what they have learned and raise questions.

In the second class of the week, they 1) present a paper in the reference list, 2) solve exercise problem(s), 3) make a new exercise problem and solve it, or 4) propose revisions in the chapter.

Toward the end of the course, students work on individual or group projects by picking any of the methods introduced in the course and applying that to a problem of interest to them.

2 credits, offered in Term 3

A102 – Mathematical Methods of Natural Sciences

Jonathan Miller

An exploration and practicum in advanced mathematical techniques for application in the natural sciences. The emphasis is on calculating physical quantities using analytical and numerical, exact and approximate methods. Instruction stresses calculational approaches rather than rigorous proofs with substantial practice in analytic calculation skills acquired via problem sets. Examples and applications are drawn from a variety of fields.

2 credits, offered in Term 2

A104 – Vector and Tensor Calculus

Eliot Fried

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. Through problem sets, students explore not only conventional approaches based on working with Cartesian and curvilinear components but coordinate-free treatments of differentiation and integration. Connections with the classical differential geometry of curves and surfaces in three-dimensional Euclidean point space will also be established and discussed.

2 credits, offered in Term 1

A107 – Lie Algebras

Liron Speyer

Learn the fundamental objects in algebra, especially representation theory, with hands-on experience in computing representations and constructing sophisticated proofs for some powerful (and quite beautiful!) results. Practice focuses on the basic structures of simple Lie algebras over the complex numbers, as well as the theory of highest weight representation including Verma modules and enveloping algebras, concluding with Weyl's character formula for finite-dimensional simple modules. Additional topics include root systems, Cartan subalgebras, Cartan/triangular decomposition, Dynkin diagrams, and the Killing form.

2 credits, offered in Term 1

This is an alternating years course.

A108 – Partial Differential Equations

Qing Liu

Through lectures and assignments, explore a variety of PDEs with emphasis on the theoretical aspects and related techniques to find exact solutions and understand their analytic properties. Learn both basic concepts and modern techniques for the formulation and solution of various PDE problems. Main topics include the method of characteristics for first order PDE, formulation and solutions to the wave equation, heat equation and Laplace equation, and classical tools to study properties of these PDEs.

2 credits, offered in Term 3

A110 – Measure Theory and Integration

Xiaodan Zhou

Explore foundational concepts of modern measure theory that underpin advanced mathematical topics such as functional analysis, partial differential equations, and Fourier analysis. Through lectures and exercises, investigate fundamental concepts of Lebesgue measure and integration theory and apply the definitions and properties of Lebesgue measure and measurable sets. Discussion includes measurable functions, Lebesgue integrals, limit theorems of integrals, the Fubini theorem, and LP space. Using Latex for mathematical writing, hone mathematical proof and writing skills to communicate mathematics effectively and develop rigorous math thinking to prepare for more advanced courses.

2 credits, offered in Term 1

This is an alternating years course.

A115- Partial Differential Equations II

Ugur Abdulla

Learn modern theory of partial differential equations (PDEs) with emphasis on linear and nonlinear PDEs arising in various applications such as mathematical physics, fluid mechanics, mathematical biology and economics. Explore topics including Sobolev spaces and their properties, second order elliptic, parabolic, and hyperbolic PDEs, concept of weak differentiability, weak solutions, Lax-Milgram theorem, energy estimates, regularity theory, Harnack inequalities, and topics on nonlinear PDEs.

2 credits, offered in Term 2

Marine Sciences

B34 – Coral Reef Ecology and Biology

Timothy Ravasi

Discover the largest and most complex biological structures on earth in this introduction to tropical coral reefs and the organisms and processes responsible for their formation. From an overview of reefs and their tropical marine environment, expand into the evolution, systematics, physiology, ecology, and symbiosis of reef building corals. Learn about the structure and ecological dynamics of coral reef fish communities, and the major characteristics of other key animals and plants on reefs. Recognize key processes on shallow and deep reefs, and variability among reefs, including those of the Okinawan area. Examine cutting-edge questions in coral reef biology and conservation. Critically analyze natural and human disturbances to reefs with an emphasis on current models of management and conservation. Design a marine refuge area based on ecological and conservation principles. Develop practical skills in sample and survey methods via snorkeling activities.

2 credits, offered in Term 3

B42 – The Diversity of Fish

Vincent Laudet

Learn about the rich diversity of fish and the incredible array of traits, behaviors, and survival mechanisms they display. Through lectures, projects, and discussions, use the diversity of fish to examine how they interact with, and are shaped by, their diverse environments. Integrate results from the scientific disciplines of ecology, physiology, and biophysics and explore the value and limits of biological models. Conduct a bibliographical research project that uses viewpoints from several scientific disciplines to solve a biological question about a species of fish, and present your findings.

2 credits, offered in Term 1

A224 – The Earth System

Satoshi Mitarai

Learn how climate and climate change are driven by interactions between the ocean and the atmosphere, the two key components of the Earth system. Discuss global energy balance, atmospheric circulation, surface winds and ocean circulation, deep-sea thermohaline circulation, Holocene climate, the El Niño Southern Oscillation, projections of future atmospheric CO2 and other greenhouse-gas concentrations, and the effects of climate change on marine environments. Create, analyze, and present predictions using the latest atmosphere-ocean coupled general circulation models (CMIP) to assess potential effects of climate change on ocean-atmosphere systems. Explore past global changes and those anticipated in the future due to anthropogenic carbon releases, based upon IPCC future climate change scenarios and past climate records. Develop tools to describe the influence of climate change on ocean environments quantitatively, and to consider potential outcomes for marine ecosystems on which students' own research is focused.

2 credits, offered in Term 3

Neuroscience

B24 – Neural Dynamics of Movement

Marylka Yoe Uusisaari

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.

2 credits, offered in Term 1

B37 – Introduction to Embodied Cognitive Science

Tom Froese

Explore key theoretical trends that underpin embodied cognitive science and develop a framework with which to distinguish and define an embodied perspective. Describe the scope and interdisciplinary nature of cognitive science and identify the main theoretical trends emerging in embodied cognitive science. Learn and discuss the key differences between an embodied perspective compared to the traditional stance. Use the interdisciplinary tools of an embodied cognitive approach to consider open problems and challenges and offer potential solutions. Demonstrate this understanding through weekly written exercises and a final paper. Prior experience in cognitive science (any discipline) is highly advantageous but not essential.

2 credits, offered in Term 1

B38 – Human Subjects Research: A Primer

Gail Tripp

Learn about the particular requirements of research with human subjects with reference to conceptualization, research design, sampling and data collection methods, ethics, and statistical treatment of data. Gain experience on how to formulate clear and testable hypotheses; describe different sampling methods, their strengths and limitations; identify any ethical issues or concerns for a given research study; evaluate the strength of different research designs, together with their appropriateness for addressing different research questions; judge the quality of research methods and measures based on indices of reliability and validity. Prepare an information letter(s) and consent form(s) for a human subjects research study. Prepare a grant application/research proposal (background, hypotheses, methods, statistical analyses, significance) for a human subjects research study. Present a research report on a topic of interest. The emphasis is on behavioral sciences research, but the content can generalize across many study fields.

2 credits, offered in Term 1

A310 – Computational Neuroscience

Erik De Schutter

Explore topics in computational neuroscience, beginning with single neuron properties and then introducing integrate-and-fire neuron simulations. Revise the biophysical properties of neurons and the Hodgkin-Huxley equations and extend these findings to cable theory and passive dendrite simulations. Study excitability and the contributions of various ion channels, phase space analysis, reaction-diffusion modelling and calcium dynamics. Model single neurons, neuronal populations, and networks using NEURON software. Investigate models of synaptic plasticity and learning. Discuss seminal papers associated with each topic and produce reports on modeling exercises.

2 credits, offered in Term 2

A306 - Neuroethology

Yoko Yazaki-Sugiyama

Explore the neuronal mechanisms that underlie and control complex animal behavior. Learn about sensory processing mechanisms responsible for behaviors such as echolocation and sensory navigation. Learn about motor control mechanisms such as central motor pattern generators, stereotyped behavior, and spatial navigation. Discuss the evolutionary strategy and the biological ideas of animal behavior and underlying neuronal mechanisms, including sexually dimorphic behavior, behavioral plasticity, learning and memory, and the critical period. Critically analyze original research papers and literature to provide an understanding of modern experimental techniques in neuroethology.

2 credits, offered in Term 2

A312 – Sensory Systems

Izumi Fukunaga

The course will cover general concepts and specific sensory modalities. Classes alternate between lecture-style teaching and a journal club. Each lecture will be based on a textbook chapter (including Kandel et al.'s Principles of Neural Sciences) 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.

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.

2 credits, offered in Term 3

A313 – Cognitive Neurorobotics

Jun Tani

Explore the principles of embodied cognition by a synthetic neurorobotics modeling approach in combination with hands-on neurorobotics experiments and related term projects. Combine related interdisciplinary findings in artificial intelligence and robotics, phenomenology, cognitive neuroscience, psychology, and deep and dynamic neural network models. Perform neurorobotics simulations and control experiments with extensive coding in C++ or Python. Critically analyze and report on recent papers in neurorobotics and artificial intelligence.

2 credits, offered in Term 1

A314 – Neurobiology of Learning and Memory I

Jeff Wickens

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.

2 credits, offered in Term 3

A315 – Quantifying Naturalistic Animal Behavior

Sam Reiter

Naturalistic animal behavior is complex. Learn the practical skills of how to record and track this complex behavior using modern tools, and the pros and cons of different approaches. Discuss recent work on modeling individual and collective animal behavior while maintaining quantitative rigor, as well as the relationship between behavior and the brain. Investigate connections between behavior and neural activity in the model animal systems of nematode, fruitfly, squid, and mouse. Read and assess papers weekly. Design and complete a short project in studies of complex behavior, with support from relevant literature. Present the results of the project to the class.

2 credits, offered in Term 3

A316 – Neuronal Molecular Signaling

Marco Terenzio

Review receptor signaling and its associated signaling cascades and transcriptional responses as well as peripheral local translation of signaling molecules. Discuss the mechanisms of active transport utilized by the neurons to convey organelles and signaling complexes from the plasma membrane to the nucleus, with a focus on the dynein machinery and retrograde axonal transport. Learn about links between defects in axonal trafficking and neurodegenerative diseases and between local translation of the response to axonal injury and the induction of a regenerative program, in both peripheral and central nervous systems. In the laboratory, learn and use the most recent techniques for neuronal cell culture and the live imaging and quantifying of intracellular transport. Journal clubs develop critical analysis of recent research papers in the field of molecular neuronal signaling and anterograde/retrograde messenger transport.

2 credits, offered in Term 3

A318 – Neurobiology of Learning and Memory II

Kazumasa Tanaka

Learn fundamental neural mechanisms of learning and memory, with a focus on memory. Through lectures and journal club presentations, discover connections between synaptic plasticity and memory, and the important role of the hippocampus in different types of memory. Compare and contrast synaptic and systems consolidation mechanisms of memory, and their effects and consequences. Apply this knowledge in preparing a mock grant proposal for a significant question in memory research.

2 credits, offered in Term 3

Physics

B10 – Analytical Mechanics

Mahesh Bandi

Explore the concepts and techniques of classical analytical mechanics so essential to a deep understanding of physics, particularly in the areas of fluid dynamics and quantum mechanics. Develop from the basic principles of symmetry and least action to the Galilean, Lagrangian, and Newtonian equations of motion and laws of conservation. Use the Lagrange formalism to describe particle motion in multiple modes, before exploring the equations of Euler and Hamilton, and canonical transformations. Use the calculus of variation to develop Maupertuis's principle and the Hamilton-Jacobi equations, and build a starting point for the consideration of waves in other courses. Ongoing homework exercises and small exams provide continuing assessment.

2 credits, offered in Term 1

B11 – Classical Electrodynamics

Tsumoru Shintake

Learn the theory and application of classical electrodynamics and special relativity, covering the essential equations and their applications, and build a firm grounding for later studies of quantum physics. Through lectures and exercises, an understanding of static electromagnetic fields is extended through Maxwell’s equations to a discussion of dynamic vector fields and electromagnetic waves. 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. Demonstrate understanding and application of these concepts in mid-term and final exams.

2 credits, offered in Term 2

B12 – Statistical Physics

Nic Shannon

Explore why matter can exist in more than one phase, and how it can transform from one phase into another. Develop the ideas of entropy, free energy and thermal equilibrium starting from the question “what is temperature?”. From the context of thermodynamics, and as natural consequences of a statistical description of matter, develop a simple physical picture of phase transitions with an emphasis on the unifying concept of broken symmetry. Demonstrate understanding of the subject through weekly problem sets, and deliver a final presentation on a modern example of the application of statistical physics ideas, chosen by the student. Accessible to students from a wide range of education backgrounds.

2 credits, offered in Term 1

B30 – Surface Sciences

Yabing Qi

Discover the fundamental properties of physics and chemistry occurring at surfaces and interfaces, central to many recent developments in science and technology, such as physical chemistry, electronic devices, catalysis, semiconductor processing, new materials development, biomaterials, biotechnology and biomedicine, nanotechnology, and others. Through lectures, projects, and assignments, learn the basic concepts of the field, and operation principles of major analytical techniques and instruments, such as scanning tunneling microscopy (STM), atomic force microscopy (AFM), X-ray photoelectron spectroscopy (XPS), and ultraviolet photoemission spectroscopy (UPS). Discuss the applications of these concepts and instruments in various research fields.

2 credits, offered in Term 2

A103 – Stochastic Processes with Applications

Simone Pigolotti

A broad introduction to stochastic processes, focusing on their application to describe natural phenomena and on numerical simulations rather than on mathematical formalism. Define and classify stochastic processes (discrete/continuous time and space, Markov property, and forward and backward dynamics). Explore common stochastic processes (Markov chains, Master equations, Langevin equations) and their key applications in physics, biology, and neuroscience. Use techniques to analyze stochastic processes and simulate discrete and continuous stochastic processes using Python.

2 credits, offered in Term 3

A203 – Advanced Optics

Síle Nic Chormaic

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.

2 credits, offered in Term 2

This is an alternating years course.

A205 – Quantum Field Theory

Shinobu Hikami

Learn quantum field theory from lectures and by working through classic and recent papers to follow developments in the field. Progress from a reconsideration of basic concepts in quantum effects acting on electrons and other particles, through to Feynam rules and diagrams, and Weyl and Dirac spinors. Develop these concepts into gauge theories, field quantization, symmetry breaking, and renormalization. Finally consider quantum chromodynamics, gravity and nuclear forces, and possibilities to unified field theory including strings. Confirm these findings through homework exercise sets and a final examination. Due to recent developments, an emphasis is placed on random matrices and the resulting statistical field theory.

2 credits, offered in Term 3

A209 – Ultrafast Spectroscopy

Keshav Dani

Discover and use the techniques of ultrafast spectroscopy with an overview of modern methods and applications. Through exercises and presentations, explore 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.). Use these tools and techniques to perform measurements in the laboratory. Confirm these concepts through regular exercise sets and a final presentation.

2 credits, offered in Term 3

A210 – Advanced Quantum Mechanics

Thomas Busch

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; labwork: quantum eraser, interaction free measurement.

2 credits, offered in Term 2

This is an alternating years course.

A211 – Advances in Atomic Physics for Quantum Technologies

Síle Nic Chormaic

Advanced level course in atomic physics. Progress in laser control of atoms has led to the creation of Bose-Einstein condensates, ultrafast time and frequency standards and the ability to develop quantum technologies. In this course we will cover the essentials of atomic physics including resonance phenomena, atoms in electric and magnetic fields, and light-matter interactions. This leads to topics relevant in current research such as laser cooling and trapping.

2 credits, offered in Term 2

This is an alternating years course.

A218 – Condensed Matter Physics

Yejun Feng

Condensed matter physics has evolved from solid state physics into a subject which focuses on collective behavior, symmetry, and topological states. This course provides an introduction to the field, arranged along three major concepts of lattice, electrons, and spins. We survey both central theoretical concepts and their experimental demonstrations, such as Landau levels and quantum Hall effects, superconductivity, and magnetic excitations. Several of these topics are developed from fundamental concepts to an advanced perspective.

2 credits, offered in Term 2

A219 – General Relativity

Yasha Neiman

We begin by introducing tensors in non-relativistic physics. We then give an overview of Special Relativity, and discuss the special nature of gravity as an "inertial force". With this motivation, we develop the differential geometry necessary to describe curved spacetime and the geodesic motion of free-falling particles. We then proceed to Einstein's field equations, which we analyze in the Newtonian limit and in the linearized limit (gravitational waves). Finally, we study two iconic solutions to the field equations: the Schwarzschild black hole and Friedman-Robertson-Walker cosmology. We will use Sean Carroll's textbook as the main reference, but we will not follow it strictly.

2 credits, offered in Term 1

This is an alternating years course.

A221 – Relativistic Mechanics and Classical Field Theory

Yasha Neiman

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.

2 credits, offered in Term 1

This is an alternating years course.

A223 – Quantum Materials Science

Yoshinori Okada

Discover a range of interesting quantum materials and their unique functionalities. Learn about the concept of materials design and its realization in bulk single crystal growth and epitaxial thin film growth. Learn the principles of single particle spectroscopy, particularly focusing on photoemission and tunneling spectroscopy. Experience quantum materials growth and characterization in the laboratory. Discuss and make presentations on recent literature. Discover potential R&D applications with a range of guest speakers from industry.

2 credits, offered in Term 3

A225 – Statistical Mechanics, Critical Phenomena and Renormalization Group

Reiko Toriumi

An introduction to the methods of statistical mechanics that evolves into critical phenomena and the renormalization group.

The analogy between statistical field theory and quantum field theory is addressed throughout the course.

The key concept emphasized in this course is universality; we are concerned with systems with a large number of degrees of freedom which may interact with each other in a complicated and possibly highly non-linear manner, according to laws which we may not understand. However, we may be able to make progress in understanding the behavior of such problems by identifying a few relevant variables at particular scales. The renormalization group addresses such a mechanism.

Some selected topics are covered, such as conformal field theory, vector models/matrix models, and SLE.

2 credits, offered in Term 1

A227 – Quantum Engineering – Simulation and Design

Jason Twamley

Develop skills in the computational modelling of quantum machines and integrated quantum devices used for fundamental quantum mechanics studies, quantum sensing, quantum communication and quantum computing. Use “engineering” style skills to design and model – theoretically and computationally – various composite quantum devices: integrated photonic with atomic, condensed matter and motional atomic systems including cavity quantum electrodynamics, cavity optomechanics, Nitrogen vacancy defects in diamond, and levitated quantum systems. Learn and use computational techniques to simulate the properties of integrated quantum devices using Python, with a final computational project. Discuss the latest literature in journal club style.

2 credits, offered in Term 3

A228 – Quantum Many-body Physics

Philipp Höhn

Explore the interface of condensed matter physics, quantum information theory and high-energy physics, a highly active area of current research, through the lens of quantum many-body physics. Study correlation structures and their role in determining the physical properties of these systems. Understand the special role of ground states and their entanglement properties, such as entanglement area laws and how correlations decay over distance. Learn how to sidestep the complexity of many-body systems and efficiently describe their properties using approximation tools, such as tensor networks and several renormalization methods that have become standard workhorses in the modern literature. Review standard phase transitions and find out how symmetries lead to a novel notion of symmetry protected phases and topological phase transitions. Time permitting, discover how to compute entanglement entropies in the presence of gauge symmetries and in quantum field theory. Practice these findings in exercises and journal club presentations and explain them in a final oral exam.

2 credits, offered in Term 1

A229 – Statistical Fluctuations and Elements of Physical Kinetics

Denis Konstantinov

Explore and explain key ideas of physical kinetics, for systems both at equilibrium and then driven out of equilibrium by a variety of factors. Derive the very important relation (FDT) between fluctuations and dissipation in a dynamic system coupled to a noisy environment. Describe (within certain approximations) the dynamics of classical systems driven out of equilibrium. Apply models and equations to quantify the transport properties of some idealized solid-state and condensed-matter systems. Extend some of these ideas to quantum systems, in particular those interacting with an environment, and explore the dynamics of dissipative ("open") quantum systems. Develop an intuitive understating of the physical picture rather than pursuing a rigorous mathematical description of the phenomena with numerous examples and model problems from solid state and condensed matter physics, atomic physics, and quantum optics, and reinforce these with regular problem sets.

2 credits, offered in Term 3

A230 – Quantum Optics for Qubits

Hiroki Takahashi

Work from basic notions of quantum optics to prepare a theoretical foundation that facilitates understanding of the working principles of modern quantum devices, such as linear optical quantum computers, ion traps, and superconducting circuits. Describe physical systems used in quantum technology applications by simple quantum physics of spins (two level systems) and harmonic oscillators. Solve dynamics of quantum systems using master/Schrödinger equations. Explain working principles of important quantum devices and protocols such as cavity QED, quantum input-output relation, two-qubit entangling gates, ion traps, Josephson junctions, and some circuit QED. Critically analyze and make presentations on important literature in the field, and demonstrate understanding of quantum optics through regular problem sets.

2 credits, offered in Term 3

A273 – Ultracold Quantum Gases

Thomas Busch

The course will start out by introducing the fundamental ideas for cooling and trapping ultracold atoms and review the quantum mechanical framework that underlies the description of interacting matter waves in the ultracold regime. This will introduce the idea of degenerate Bose and Fermi gases, and in particular the concept of Bose-Einstein condensation.

After this the main properties of Bose-Einstein condensates will be discussed, including coherence and superfluidity, and for Fermi gases the physics of the BCS transition will be introduced. Conceptually important developments such as optical lattices, Feshbach resonances, artificial gauge fields and others will be explained in detail as well. New developments in the area of strongly correlated gases will be introduced and applications of cold atoms in quantum information or quantum metrology provide the final part of the course.

The course will mostly focus on the theoretical description of ultracold quantum gases, but regularly discuss experimental developments which go with these.

2 credits, offered in Term 2

This is an alternating years course.