Okinawa Institute of Science and Technology

Elective Course Catalog

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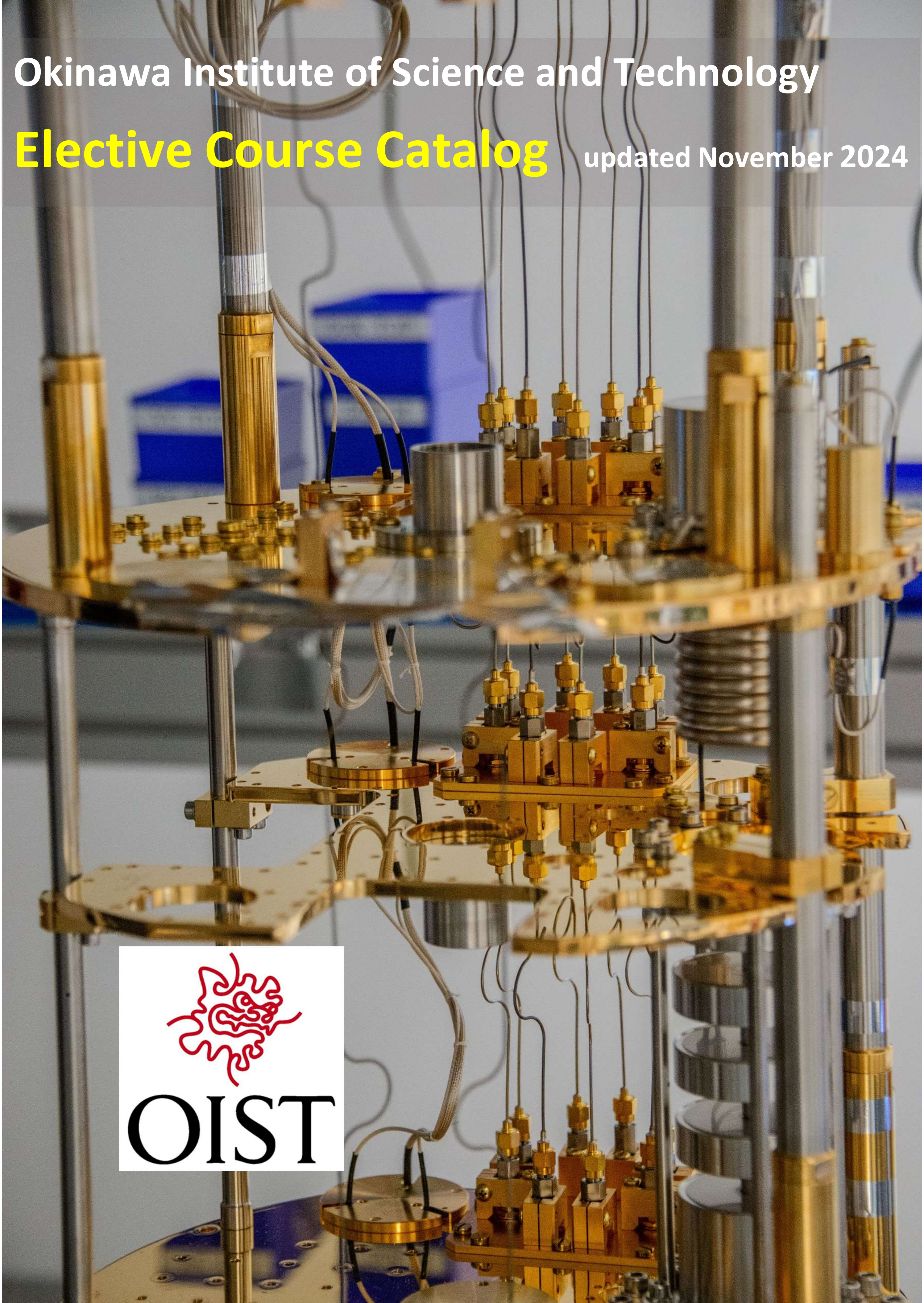

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Note: these course groupings are approximate, and for convenience of the reader only. They do not imply any separate programs of study or departmental divisions. Course content and terms offered are subject to change.

Some faculty alternate between teaching two courses; these years are indicated where applicable.

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 3

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 2

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

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

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

Cell Biology

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

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

A409 – Electron Microscopy

Matthias Wolf

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.

2 credits, offered in Term 3

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, 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

A321 – Macroevolution

Lauren Sallan

Macroevolution, or evolution above the population level and on long timescales, addresses fundamental questions regarding the origins of species, past and present. These include (but are not limited to): How are highly dissimilar species related? Why are animals on distant continents so similar? How and when did major groups, like arthropods or fishes, originate? What drives evolutionary arms races between predators and prey? Why are there so many more species of beetle than crocodile? Why are there more species in the tropics than the Arctic? Why do some animals survive mass extinction? How can invasive species spread so rapidly? Exploring these topics provides class participants with an opportunity to learn important concepts underlying our understanding of modern biodiversity and the fossil record. Using different methods and lines of evidence, including evolutionary trees (phylogeny), developmental and morphological observations, biodiversity and ecological databases, past climate and global events, biomechanics, mathematical modeling, and even data from modern genomics, they begin to answer essential questions about the evolution of life. This course will consist of lectures introducing concepts and methods followed by discussion sessions based on student questions and readings outside class.

2 credits, offered in Term 2

This course alternates with A324 Paleontology and the Diversity of Life.

A324 – Paleontology and the Diversity of Life

Lauren Sallan

In this course we will survey the biodiversity of life on Earth and the characteristics of important groups organisms, largely from the viewpoint of the fossil record. We will explore the evolution of life through deep time, i.e. all 4.6 billion years of the planet's existence, with an emphasis on the rise of complex life in the last 540 million years. Students will be introduced to the tree of life and major groups in the ocean and on land, and the influences of ecology, biogeography, mass extinction and other factors on the evolution of modern forms. We will also discuss the use of fossils to solve diverse questions in multiple fields, including ecology, evolutionary biology, environmental science, and geology, and the application of cutting-edge methods to the fossil record.

2 credits, offered in Term 2

This course alternates with A321 Macroevolution.

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

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 course alternates with A107 Lie Algebra.

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

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 course alternates with A110 Measure Theory and integration.

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

B49 – Dynamical Systems

Mahesh Bandi

An introduction to chaos theory and related topics in nonlinear dynamics, including the detection and quantification of chaos in experimental data, fractals, and complex systems. Most of the important elementary concepts in nonlinear dynamics are discussed, with emphasis on the physical concepts and useful results rather than mathematical proofs and derivations: there are several other resources for the latter. Courses in Chaos & Nonlinear Dynamics tend to be either purely qualitative or highly mathematical; this course attempts to fill the middle ground by giving the essential equations, but in their simplest possible form.

2 credits, offered in Term 2

This course alternates with A233 stability analysis of Nonlinear Systems.

B53 – Introduction to Applied Cryptography

Carlos Cid

An introductory course in modern, applied cryptography that explores the uses and limitations of cryptography. Students will learn about the main cryptographic algorithms and mechanisms for providing confidentiality, integrity and authentication, and their corresponding formal notions of security. During this study, students will learn how these mechanisms may be used in real-world applications such as establishing secure communication channels (e.g. the TLS protocol), but also encounter several examples of how security may fail when the same mechanisms are not properly employed. The course will also consider some of the more recent and novel applications of cryptography, such as privacy preserving mechanisms and secure computation, as well as cryptographic security in the emerging quantum world.

1 credit, offered in Term 2

B50 – Introduction to Scientific Computing

Kenji Doya

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 methods for solving algebraic equations, simulation of differential equations. and stochastic optimization. The course also covers topics of software and data 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 experience of how they work (or fail).

2 credits, offered in Term 1

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

This course alternates with A112 Introduction to the Calculus of Variations.

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 course alternates with B29 Linear Algebra.

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 course alternates with B36 Real analysis.

A111– Nonlinear Time Series Analysis and Manifold Learning

Gerald Pao

Over the last 50 years or so nonlinear dynamics and chaos has revolutionized our understanding of the complexity of the natural world. However, the vast majority of this understanding, has come from the study of toy models that captured the flavor of real problems but were not models of real systems. As such dynamical systems theory has become more an area of mathematics than natural experimental science. Much of this is because experiments were difficult to perform and we lived in a data limited world. Now with the advent of big data and increases in computing performance in the 3rd decade of the 21st century we are no longer data-limited and can take full advantage of the theory of dynamical systems for the analysis of observed data. This data science course is focused on the analysis of dynamical systems, mostly from nonlinear time series, to find hidden properties and causal relationships in complex systems. The course teaches the students what can practically be done using the intellectual framework of chaos theory and dynamical systems using a data driven approach to maximally extract information from time series and their mathematical properties hidden in the geometry of their embeddings.

2 credits, offered in Term 3

This course is offered every second year, and partners with A121 Nonlinear Time Series Analysis and Manifold Learning Laboratory.

A112 – Introduction to the Calculus of Variations

Eliot Fried

The calculus of variations originated from classical investigations into fundamental problems of maximizing enclosed areas, minimizing travel times, determining geodesics, and optimizing trajectories in mechanics. Variational problems involve the optimization of functionals, which are real-valued objects which take functions as inputs. This course will offer a comprehensive exploration of the conceptual basis and methods of the calculus of variations, including functionals, necessary conditions for optimality, necessary and sufficient conditions for optimality, essential and natural boundary conditions, variable end-point conditions, the treatment of global and local constraints, and direct methods. Applications will span geometry, physics, and engineering, revealing the pivotal role of variational methods in describing natural phenomena and in optimizing processes and systems. Through practical problem-solving exercises, students will become proficient in formulating extracting information from and variational principles. The course will provide a foundation for further exploration in various fields, including advanced physics, engineering applications, or interdisciplinary studies where variational methods find widespread application.

2 credits, offered in Term 2

This course alternates with A104 Vector and Tensor Calculus.

A113 – Brain Computation

Kenj Doya

Functional analysis is a fundamental branch of mathematics that extends the concepts of linear algebra and analysis to infinite-dimensional spaces.

Learning how supervised, unsupervised, and reinforcement learning, as well as evolutionary computations can help us understand how the brain functions both as modeling frameworks and data analysis methods. This course is based on an online text book "Brain Computation: A Hands-on Guidebook," which is based on Jupyter notebook with Python codes.

2 credits, offered in Term 3

A114 – Functional Analysis

Xiaodan Zhou, Qing Liu, Ugur Abdulla

Functional analysis is a fundamental branch of mathematics that extends the concepts of linear algebra and analysis to infinite-dimensional spaces. Its purpose is to develop tools and techniques to solve complex problems that arise in various areas of mathematics, physics, engineering, and beyond. This course will cover the fundamental concepts, theorems, and techniques of functional analysis. Topics will include normed spaces, Banach spaces, Hilbert spaces, linear operators and functionals, the Hahn-Banach theorem, duality, compact and self-adjoint operators, and the spectral theorem. The course will emphasize rigorous mathematical reasoning and the development of problem-solving skills.

2 credits, offered in Term 1, AY2025

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

A121 – Nonlinear Time Series Analysis and Manifold Learning Laboratory

Gerald Pao

The goal of this course is to select a group project and take it to completion among the students of the class. The course will encompass a complete end to end project from Data selection and posing scientific questions to submission of a complete manuscript to a peer reviewed journal as well as to a preprint server. The purpose of the project is to teach the students how to apply the techniques that they learned in the previous term in a real-life analysis problem. The scope of the class is broader as it also aims to impart instruction on how to choose a scientific problem and the data that will allow answering such questions. In addition, students will learn best practices for scientific narratives in addition to data driven problem solving.

2 credits, offered in Term 1

This course follows A111 Nonlinear Time Series Analysis and Manifold Learning, every second year.

Neuroscience

B24 – Neuromotor Systems

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 2

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

B52 – Introductory Neuroscience

Yukiko Goda

The course covers the fundamentals of neuroscience with specific emphasis on the properties of key parts/features of neural circuits: neurons (and glia), ion channels, membrane excitability, synaptic transmission, and synaptic plasticity. Why highlight these topics? To illustrate, synaptic plasticity is crucial for a variety of cognitive functions of the brain. To understand synaptic plasticity, one must appreciate the intricacies of synaptic transmission. Synaptic transmission, in turn, requires a knowledge of membrane excitability, to which ion channels play a key role. Therefore, by building an understanding of these key components, it is hoped to facilitate each student to further deepen his/her view about the basis of communication in the nervous system and to apply the knowledge gained to their own PhD projects. The course topics will be introduced logically from bottom up (cf. course content section). The course will also involve discussion of research papers highlighting key concepts covered in lectures, where students are expected to present and lead the discussion.

2 credits, offered in Term 1

A113 – Brain Computation

Kenji Doya

Explore common mathematical frameworks for brain computation at different scales and link them with biological reality. This course is based on an online textbook "Brain Computation: A Hands-on Guidebook," which is based on Jupyter notebook with Python codes. The course is in a ‘flipped learning’ style; each week, students read a book chapter and experiment with sample codes before the class. During the class, students take turns to present contents of the chapter while running and customizing the codes, present reference papers, and solve exercises. 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

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 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

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 2

A323 – Cognitive Neural Dynamics

Tomoki Fukai

This course explains how the dynamics of neural networks, especially recurrent neural networks, contribute to cognitive computation in the brain circuitry, such as memory, decision making, inference, and language processing. The environment external to the brain keeps changing dynamically; therefore, the brain's principles of information processing are likely to be dynamic. We focus on the theoretical treatments of neural network dynamics of binary, analog, and spiking neurons. Both classic and advanced models are studied. Computational implications of biological and artificial learning rules are also explored. The course targets students who are interested in computational neuroscience, artificial neural networks and Ai, learning theory, statistical physics, and nonlinear dynamical systems.

1 credit, offered in Term 2

Physics

B08 – Physics for Life Sciences

Bernd Kuhn

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. This basic course aims to introduce physical principles that are necessary in modern life sciences, such as biophysical modeling and electromagnetic and optical measurements.

2 credits, offered in Term 2

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

B51 – An Introduction to Quantum Mechanics, Quantum Optics and Quantum Science

Bill Munro

An introduction to key concepts in quantum mechanics, quantum optics and quantum science, which provides a foundation for the more advanced courses in quantum science and technology offered at OIST. Topics include: Wave particle duality, quantum interference, quantum states and their evolution, quantum cryptography, communication, computation and metrology. Content and specific topics are adjusted to the needs of each group of students. While sufficient mathematics knowledge is required to do well in the course, the focus is less on a rigorous mathematical approach than on covering a broad range of concepts and applications of quantum systems and technologies.

2 credits, offered in Term 1

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 course alternates with A211 Advances in Atomic Physics for Quantum Technologies.

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

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 course alternates with A203 Advanced Optics.

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 course alternates with A221 Relativistic Mechanics and Classical Field Theory.

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 course alternates with A219 General Relativity.

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 2

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

A231 – Quantum Information and Communication Theory

David Elkouss

A thorough initiation into the fundamental aspects of quantum communications. The course is divided into four blocks. It begins with an introduction to data compression and communication over noisy channels in classical information theory. The second part discusses quantum entropies, distance measures between quantum states and quantum data compression. The third part of the course introduces quantum channels, and derives the fundamental properties for communications over quantum channels. The course ends with an in-depth introduction to quantum key distribution including its security proof.

2 credits, offered in Term 2

This course alternates with A232 Introduction to Quantum Cryptography.

A232 – Introduction to Quantum Cryptography

David Elkouss

In this course we will study the most important cryptographic primitives such as key distribution, secure multi-party computation, oblivious information transfer, etc. and discuss the different security guarantees that quantum implementations offer. Mathematically inclined students will gain a rigorous understanding of quantum communications and quantum computation.

2 credits, offered in Term 2

This course alternates with A231 Quantum Information and Communication Theory.

A233 – Stability Analysis of Nonlinear Systems

Mahesh Bandi

Though well instructed in the central themes of physics – quantum mechanics, thermodynamics, solid state, etc. – I have come to realize that students only incidentally meet examples of instabilities, and of these the most atypical, phase changes, are usually the most emphasized. A serious discussion of non-linear response is almost entirely neglected. Yet the world is a very nonlinear place, and research in nearly all branches of science and engineering now contends with instabilities as well as non-linear responses. This course is primarily concerned with the response of systems in equilibrium to perturbing forces, and the general theory underlying their behavior. When a system is in equilibrium it can remain motionless indefinitely, until it is disturbed. Then it may sink back to its original state, or vibrate about the position of rest, or fall over. Also, if the conditions governing the system are slowly changed, the system will adjust itself to the alteration in a smooth fashion, except at critical points, where a tiny change of conditions may lead to a major alteration, as when a drip of water suddenly detaches itself from a tap. Important modern concepts to which serious attention is given include linear response functions, bifurcation and chaos in the response of driven nonlinear systems, elementary catastrophe theory, and phase changes, especially at critical points and lambda-transitions. Target students are Graduate Students in Science and Engineering.

2 credits, offered in Term 2

This course alternates with B49 Dynamical Systems.

More information is available at

https://www.oist.jp/course