PHYSICS HANDBOOK

2020-21

DEPARTMENT OF PHYSICS

ASHOKA UNIVERSITY

Contents

Introduction

Physics is, simultaneously, a doorway to some of the most beautiful and profound phenomena in the universe, e.g. black holes, supernovae, Bose-Einstein condensates, superconductors; a driver of lifestyle-changing technology, e.g. engines, electricity, and transistors; and a powerful way of perceiving and analysing problems that can be applied in various domains, both within and outside standard physics. The beauty and profundity of the phenomena studied by physicists offer romance and excite passion, and the utility of its discoveries and the power of its methods arouse interest.

These methods can be very intricate and demanding: theoretical physics requires a skilful combination of physical and mathematical thinking, and experimental physics requires in addition the ability to turn tentative ideas into physical devices that can put those ideas to the test. As a result, the successful practice of physics demands rigour, flexibility, mechanical adroitness, persistence, and great imagination. The physicist's imagination is nourished not just by physics but also by other areas of human enquiry and thought, of the kind that an Ashoka undergraduate is expected to encounter.

With all of this in mind, the physics programme has been designed to: (i) allow students wishing to major in physics to discover real physics and make a wise choice, in the first year; (ii) provide a thorough training in fundamental physics, in the second year; and (iii) bring together everything learnt earlier, and give students the option to pursue more advanced courses in physics or branch out into other areas, in the third year. The idea is to accompany those wishing to become professional physicists as they take the first steps in that direction, and to introduce everyone who goes through the programme to the physicist's way of thinking.

Physics Major – Typical Trajectory

Year 1: Discovering College-level Physics

A student wishing to major in physics is expected to take the following foundation courses in semester 1: 1) Q*uantitative Reasoning and Mathematical Thinking* and 2) *Principles of Science*. These courses will introduce the student to the kind of thinking that is expected in physics, but without the full mathematical and experimental accoutrements of the compulsory courses in the major sequence.

The physics-major sequence begins in semester 2, with two courses, one in theoretical physics and the other in experimental physics. The first purpose of these courses is to provide an experience of college-level physics on the basis of which a student can decide whether or not to major in physics,

i.e. they are *gateway courses*. The second purpose of these courses is to serve as an introduction to the physicist's way of thinking about problems and solving them, something that has proved useful not just to physicists but also to those in other disciplines that make use of quantitative methods and experiments, e.g. mathematics, computer science, economics, psychology, and biology.

Year 2: The Physics Core

The eight physics courses in semesters 3 and 4, i.e. the second year, form the core of the physicist's undergraduate canon: *Mathematical Physics*, *Classical Mechanics*, *Electricity & Magnetism in Light of Relativity*, *Thermal Physics*, *Oscillations, Waves and Optics*, and *Quantum Mechanics*, and two accompanying labs. Anyone majoring in physics is expected to be thorough in these areas. Each semester has three theory courses and one lab.

Year 3: Choosing a Direction and Bringing Physics Together

In semester 5 there will be several elective courses, of which each student majoring in physics is required to take two. This semester has been freed of compulsory courses for various reasons: to provide a reprieve (to those who need it) after the intensity of the second year, to encourage exploration, and to allow those who wish to study in a different institution for a semester to do so without missing any compulsory courses.

In semester 6 there will be two required courses that bring together all the physics learnt in earlier semesters, so that the student leaves with a view of physics as an integrated subject: *The Physics of Matter* and an accompanying lab. In addition there will be one more elective course.

The three electives may be chosen from a spectrum including not just advanced physics courses but also quantitative courses from other disciplines, e.g. Mathematics, Computer Science, Biology, and Economics. One elective that will also be a Critical Thinking Seminar is *The Physics of Einstein's Miraculous Year*, which a physics major would take in semester 5. Two other electives, *Biophysics* and *Astronomy and Cosmology*, signal Ashoka's intention to encourage collaboration between physics and biology, and its interest in furthering the study of the cosmos. From the student's point of view, the electives chosen is likely to indicate a post-graduate direction – towards theoretical physics, towards experimental physics, towards applied physics, or away from physics, perhaps into an allied discipline that would benefit from training in physics.

Total number of courses in the physics-major sequence: 0 + 2 + 4 + 4 + 2 + 3 = 15 (12 mandatory
and 3 elective).

Physics Minor

To minor in physics a student must do six courses in physics. Of these the two gateway courses – *Mathematical and Computational Toolkit* and *Introduction to Physics Through Experiments* – are compulsory. At least two more courses should be taken from among the compulsory courses offered in semesters 3 and 4. The remaining two may be either other compulsory courses offered or elective courses offered by the Physics Department or cross-listed with Physics (but not courses offered by other departments that physics majors may take in semesters 5 and 6).

General Information on the Physics Courses

Mathematical level — All theory courses are calculus-based. The level of mathematical sophistication will increase progressively. The mathematical-physics courses in semesters 2 and 3 will be application-oriented rather than proof-oriented.

Labs — All lab courses will involve extensive use of instruments to make observations. These experiments will in general illustrate ideas studied in the accompanying theory courses.

The use of computers — All theory courses will include computational exercises, generally using the programming language Python. Labs will also require the use of computers.

Duration — Theory: two lectures a week each lasting 1.5 hours. Lab: one 3-hour lab session per week. (In addition there may be a one-hour tutorial per week for each theory course and a one-hour preparatory session per week for lab course.)

Description of Physics Courses

1. Compulsory Courses

Mathematical and Computational Toolkit

Basic mathematical and computational methods, using examples from physics, including differentiation, integration, ordinary differential equations, plotting, fitting, approximation, dimensions, symmetry, complex numbers, Fourier series, factorials and the Stirling's approximation, multi-variable calculus, the one-dimensional random walk and diffusion, the Gaussian integral, an introduction to vector calculus, an introduction to linear algebra using matrices. Pre-requisites: calculus at the high-school level. (Spring.)

Recommended course content

Differentiation and integration in physical settings; functions of one variable (1); linear, polynomial, trigonometric, exponential, and logarithmic functions; the Dirac delta function; the Heavyside step function (1).

Cartesian coordinate systems; graphs and plotting; graphs of motion (1); maxima and minima; Taylor series (1).

Approximation and estimation; using infinite series to approximate functions; approximating integrals; methods of estimation (1).

Least-squares fit of a straight line to data (1).

Dimensional awareness and analysis (1).

Awareness and exploitation of symmetry (1).

Complex numbers and the complex plane; the Euler relation (1).

1st- and 2nd-order ordinary differential equations with constant coefficients (2). Periodic functions and Fourier series (1).

The factorial function and its uses; Stirling's approximation (1).

Functions of more than one variable: partial derivatives (1); constrained maximization and Lagrange multipliers (1); conservation and the continuity equation (1).

The random walk on a one-dimensional lattice; continuous limit; diffusion current; the diffusion equation as a continuity equation (1).

The Gaussian integral (1).

Scalars and vectors; common vector identities; scalar and vector fields; gradient; divergence; curl; line integral; surface integral (4).

Matrices and determinants; inverse of a matrix; characteristic equation; Caley-Hamilton theorem; eigenvalues and eigenvectors; rotation matrices and change of coordinate systems (3).

Fermat's principle, principle of least action (1).

Recommended computational exercises: plotting graphs; determining the mean and standard deviation of a distribution; plotting a histogram; calculating the factorial of a large number; using a random-number generator to plot a random walk, and to determine the value of π; writing a programme to calculate the least-squares fit; determining derivatives and integrals; demonstrating the idea of the Fourier series by superposing sinusoids; solving 1^{st}- and 2^{nd}-order ODEs using the Euler method; performing matrix operations.

Note: All mathematical ideas will be illustrated with physical examples, especially from classical mechanics and electricity & magnetism, so as to give a jump-start to the physics courses in the next semester.

References: *Mathematical Tools for Physics*, by J Nearing, *Basic Training in Mathematics: A Fitness Program for Science Students*, by R Shankar, *Computational Physics*, by Mark Newman, and *Introduction to Computational Physics*, by Richard Fitzpatrick (http://farside.ph.utexas.edu/teaching/329/329.html).

Physics Lab 1

An introduction to physics through experiments. The idea behind this course is to help students, using simple experiments, to acquire the skills, protocols, and attitudes required to perform and design experiments and to analyze observations successfully, so that they become a part of his/her mind-set. Pre-requisites: none. (Spring.)

Recommended background training

Measurement and Instruments: length measurement; time measurement; measurement of mass; least count; Vernier calipers; screw gauge; travelling microscope; stopwatches; current; voltage; resistance; multi-meter; ammeter; voltmeter; oscilloscope; DC and AC power sources; ideal versus non-ideal instruments.

Errors: least-count errors; errors on time measurements; random errors; ways of reducing errors; systemic errors; propagation of errors; sensitivity of errors to measurements; choice of instruments keeping sensitivity in mind.

Procedure: understanding why a certain procedure is followed; improving the procedure.
Precautions: when setting up experiment; when taking observations;
Troubleshooting: what to do when experiments break down or fail.
Representation of data: patterns in data; averaging; plotting;
least-squares fitting.
Data analysis: awareness of relative importance of different measurements, in light of errors; how to detect "bad" data, and what to do with them; calculations.

Conclusions: drawing appropriate conclusions from an experiment; whether the declared aim of the experiment was reasonable; what else one can conclude; expressing the result; units; awareness of the errors involved.

Ball-park awareness: knowing whether the result obtained makes sense; order-of-magnitude estimates.

Design: design of an experiment with an aim in mind.

Instrument building: how to design and build an instrument for a particular purpose. Honesty: the importance of not fudging data, calculations, or results.

<u>Recommended experiments</u>

Measurement of length (1): paper, wire, table, etc.

Measurement of time (1): spring-mass system; simple pendulum.

Measurement of currents and voltages (2): awareness of the effect of the non-ideal nature of the instruments used; voltage-divider circuit; measurement, display, and superposition of AC voltages using an oscilloscope.

Random errors (2): multiple measurements; histogram; mean; standard deviation; standard error on the mean.

Bridges (2): Wheatstone bridge; off-balance bridge; a simple AC bridge. Optics (2): verifying the lens-maker's formula; two-slit interference.

Electronics (2): rectifier; transistor amplifier.

Project possibilities: Real-time measurements of motion: object falling under gravity; oscillating system. Interfacing a measuring device with a computer. Experiments with

Arduino kits. Building a temperature-controlled bath.

Mathematical Physics

The mathematical foundation for the core physics courses: linear algebra, ordinary and partial differential equations, complex analysis, and Fourier transforms. Pre-requisites: Mathematical and Computational Toolkit (or equivalent). (Monsoon)

Recommended course content (hyperlink)

Linear algebra (6): vectors; dual vectors; operators; Hermitian and unitary operators; eigenvalues and eigenvectors; basis vectors; representation of vectors and operators in a basis; orthogonality and completeness; diagonalization; change of basis; degeneracy.

Ordinary differential equations (6): homogeneous ODEs with constant coefficients; series method; 2^{nd}-order ODE as a system of equations; matrix methods; non-homogeneous ODEs; the method of variation of parameters; ODEs with variable coefficients; the Legendre and Bessel equations; the Frobenius method; non-homogeneous ODEs; properties of Legendre Polynomials and Bessel Functions; coupled ODEs; continuous limit.

Partial differential equations (4): classical wave equation; diffusion equation; separation of variables in various coordinate systems.

Complex analysis (8): analytic functions; derivatives; Cauchy-Riemann conditions; singularities; series expansions; contour integration; Cauchy-Goursat theorem; Cauchy integral formula; residue theorem; real integrals using contour integration.

Fourier Transforms (2): FT as limit of Fourier series; FT of derivatives; the inverse FT as a contour integral; convolution theorem; Parseval's relation; application of FT to solving differential equations.

Recommended computational exercises: solving 1st- and 2nd-order ODEs using Runge-Kutta and Verlet methods; diagonalizing matrices; determining the discrete Fourier transform of a function; plotting Legendre and Bessel functions using the series expansions.

References: *Mathematical Tools for Physics*, by J Nearing, *Basic Training in Mathematics: A Fitness Program for Science Students*, by R Shankar, *Physical Mathematics*, by Kevin Cahill, *Introduction to Electrodynamics*, by D J Griffiths, and *Complex Variables and Applications*, by J W Brown and R V Chruchill.

Classical Mechanics

Newtonian mechanics and an introduction to Lagrangian and Hamiltonian mechanics. Newtonian mechanics is, both historically and otherwise, the starting point of all of physics. The Lagrangian and Hamiltonian formulations of classical mechanics allow a more profound vision of the subject while also introducing the language in which much of higher-level theoretical physics is expressed. Pre-requisites: Mathematical and Computational Toolkit (or equivalent). (Monsoon)

<u>Recommended course content:</u>

Frames of reference and Galilean relativity (1): inertial frames; “common sense” transformations; the role of time in Galilean relativity; the impossibility of a frame-independent velocity in Galilean relativity.

Newton’s laws (4): making sense of each law; finding an expression for the force from physical considerations; application of the second law to various situations; using the third law.

Momentum (2): the dynamics of systems of particles; centre of mass; centre-of-mass coordinate system; conservation; impulse; momentum and mass flow.

Work and energy (2): integrating the equation of motion in one and several dimensions; the work-energy theorem; applications; potential energy; potential energy and stability; conservative and non-conservative forces;

Collisions (2): elastic and inelastic collisions; collisions in lab frame and centre-of-mass frame; limit on lab-france scattering angle.

Rotation and angular momentum (3): torque; angular form of Newton’s second law; fixed-axis rotation; moment of inertia; perpendicular- and parallel-axes theorems; motion involving rotation and translation; orbital motion; spin.

Central-force motion (4): central forces; equations of motion in in a generalized central potential; conservation of angular momentum; orbits; perturbed orbits as superposition of azimuthal motion and radial oscillations; closed orbits and nature of potential; precession of orbits in other potentials; full solution to Kepler problem; the idea of perturbation and precession of orbits in the presence of other planets, and in a Newtonian approach to general relativity; determination of stellar parameters using planetary orbits; extrasolar planets.

The principle of least action (4): Lagrangian mechanics; space-time symmetries and conservation of energy, momentum, and angular momentum.

Non-inertial frames of reference (2): uniformly accelerating systems; the force of gravity and the principle of equivalence; rotating coordinate systems; the Foucault pendulum.

Hamiltonian mechanics and phase space (2).

Recommended computational exercises: determining orbits on the computer; computational study of a driven damped pendulum as an example of a chaotic system.

References: *An Introduction to Mechanics*, by D Kleppner and R J Kolenkow, *Classical Mechanics: the Theoretical Minimum*, by L Susskind and G Hrabovsky; *Introduction to Classical Mechanics*, by D Morin, *The Feynman Lectures in Physics vol 1*, by R Feynman.

Electricity & Magnetism in Light of Relativity

The beautiful theory of electricity and magnetism is, with classical mechanics, the heart of classical physics. What is often not appreciated at the undergraduate level is that electricity and magnetism are related in a way that reveals the structure of space-time. In this course relativity will be used from the beginning to relate electric and magnetic fields, so that their unity, as components of the electromagnetic field are revealed and used in the study of Maxwell's Equations. Pre-requisites: Mathematical and Computational Toolkit (or equivalent). (Monsoon.)

<u>Recommended course content</u>

Frames of reference and Einsteinian relativity (4): Lorentz transformations; four-vectors; transformation of partial derivatives.

Charge (2): Lorentz invariance of charge; charge conservation; equation of continuity; transformation of the equation of continuity between inertial frames.

Electrostatic fields (4): surface-integral and divergence: Gauss's law; line integral and curl; electrostatic potential; the potential in various situations; Laplace's equation; properties of solutions to Laplace's equation; Poisson's equation.

Conductors (2): conductors and insulators; the electric field near a conductor; the electric field and potential inside a closed conductor; what is an electrical ground; lightning conductors; capacitance; generalized capacitance of several conductors; energy stored in a capacitor; the idea of boundary-value problems.

Electric currents and magnetic fields (4): circuits; the field of a moving charge; steady currents and the continuity; magnetic fields; Biot-Savart and Ampere's laws; the vector potential.

Electromagnetic induction (4): motional EMF; Faraday's law; motional EMF and Faraday's law in light of relativity; self inductance; mutual inductance; energy stored in a the magnetic field; the symmetry of mutual inductance.

Maxwell's equations (4): the displacement current; form-invariance in inertial frames; discovering Maxwell's equations from minimal assumptions using relativity; the idea of the electromagnetic field tensor.

Electromagnetic waves in vacuum (2): the wave equation for the electric and magnetic fields; where electro-magnetic waves come from; energy transport and the Poynting vector; radial dependence of electric and magnetic fields in freely-propagating electromagnetic waves; Doppler shift from transformation of electro-magnetic field.

Recommended computational exercise: using the relaxation method to solve Laplace's equation.

References: *Electricity & Magnetism*, by E M Purcell, *Principles of Electrodynamics*, by M Schwartz, *Introduction to Electrodynamics*, by D J Griffiths, and *The Feynman Lectures in Physics vol 2*, by R Feynman.

Physics Lab 2

Experiments in classical mechanics and electricity & magnetism. Pre-requisites: Physics Lab 1. (Monsoon.)

Recommended experiments

Air track (2): conservation of momentum; conservation of energy; one-dimensional elastic and inelastic collisions.

Kater's pendulum (2): determination of the acceleration due to gravity. Moment of inertia (2): determination of the moment of inertia of a flywheel.
Carey-Foster's bridge (2): determination of a small resistance using Carey-Foster's bridge.

Measurement of charge (2): using a ballistic galvanometer to measure charge; determination of the discharge curve of a capacitor using a ballistic galvanometer.

Measurement of capacitance and inductance (2): using RC and RL circuits with AC sources to measure capacitance and inductance.

Homework: design and realization of an experiment given an aim.

Thermal Physics

An Integrated Approach to Thermodynamics, Kinetic Theory, and Statistical Mechanics. There are three approaches to study systems with large numbers of atoms and molecules, which exhibit properties like temperature and entropy: kinetic theory, classical thermodynamics, and statistical mechanics. In this course, these three approaches will be taught in an integrated fashion.

Pre-requisites: Mathematical Physics (or equivalent).

Recommended course content

Thermal equilibrium (2): temperature; microscopic model of an ideal gas; equipartition of energy; heat and work; the first law; heat capacity.

Transport phenomena (2): Newton's law of cooling; microscopic models of heat conductivity, viscosity, and diffusion.

The second law (4): microstates and macrostates in a two-state system; the large-number limit; counting states in an ideal gas; entropy; entropy of mixing; reversible and irreversible processes; free expansion; Joule-Thomson process. implication of interactions; thermal equilibrium and temperature in light of entropy; mechanical equilibrium and pressure in light of entropy; first law in light of entropy; entropy and heat flow; measuring entropy; entropy in classical thermodynamics; paramagnetism; diffusive equilibrium and chemical potential.

Engines and refrigerators (2): the Carnot engine; real heat engines and refrigerators; liquefaction of gases.

Towards absolute zero temperature (1): the third law.

Free energy as available work (2): electrolysis, fuel cells, and batteries.

Thermodynamics identities (1).

Gibbs free energy and the chemical potential (2): phase transformation in pure substances; the Clausius-Clayperon equation; the van der Waal's model; phase transformations of mixtures; dilute solutions; chemical equilibrium.

Boltzmann statistics (3): the canonical ensemble and Boltzmann factor; the partition function; the equipartition theorem in light of Boltzmann statistics; the Maxwellian speed distribution; free energy and the partition function; the partition function for composite systems; the ideal gas revisited.

Quantum statistics (3): the grand canonical ensemble and the Gibbs factor; bosons and fermions; Fermi-Dirac and Bose-Einstein distributions; photon gas and electron gas.

Random walks and Brownian motion (4): random walk on a one-dimensional lattice; diffusion and drift currents; the Einstein relation; the Langevin equation; the diffusion equation and

Fokker-Planck equations.

References: *An Introduction to Thermal Physics*, by D Schroeder, *Concepts in Thermal*

Physics, by S J Blundell and K M Blundell, *Statistical and Thermal Physics: with Computer Applications*, H Gould and J Tobochnik, *Entropy, Order Parameters and Complexity*, by J P Sethna, and *Elements of Non-equilibrium Statistical Mechanics*, by V Balakrishnan.

Recommended computational exercises: introduction to the one- and two-dimensional Ising models; studying random walks; introduction to Monte Carlo simulations.

Oscillations, Waves, and Optics

Oscillatory phenomena appear in all areas of physics, both classical and quantum (to the point where a famous textbook begins by saying that the domain of physics is all phenomena that be reduced to coupled oscillators). The methods used to study oscillatory motion are powerful and wide-ranging in their utility. Pre-requisites: Mathematical Physics (or equivalent).

<u>Recommended course content</u>

The harmonic oscillator (4): examples; equation of motion; the damped harmonic oscillator; Green's function of the damped harmonic oscillator; forced oscillator; computational solution of the equation of a pendulum for large-amplitude oscillations, as an example of chaos.

Coupled oscillators (4): two coupled mechanical and LC oscillators; N coupled mechanical and LC oscillators and their continuous limit; diagonalization of the potential energy matrix in coupled systems.

Oscillations of a string (4): the wave equation; sound waves in air; transverse waves in elastic media; torsional waves.

Characterization of waves (2): wave-fronts and rays; phase and group velocities; pulses and wave packets; dispersion relations.

Waves in dispersive systems (2): waves water, in plasmas, in waveguides, in quantum mechanics, and in gravitational systems.

Optics (8): light as an electromagnetic wave; interference and diffraction; two-slit and N-slit interferometer; coherence; Fraunhofer diffraction by a circular aperture; Fresnel diffraction by a wire and a straight edge.

Optical devices (2): prism; lenses; mirrors; telescopes; microscopes; diffraction gratings.

Recommended computational exercise: solving the wave equation.

References: *Waves*, by F S Crawford, *Waves and Oscillations*, by R Fitzpatrick, *Optics*, by E Hecht, and

Principles of Optics, by E Wolf and M Born

Quantum Mechanics

There are several approaches to teaching quantum mechanics at the undergraduate level. In this course a modern approach using vector spaces and spin-½ particles will be followed. This approach takes one straight to the heart of the quantum conundrum and reveals the subject it all its extraordinariness, without in any way being inaccessible to those who some training in linear algebra and partial differential equations.

Pre-requisites: Mathematical Physics (or equivalent).

Recommended course content

Review of linear algebra in the context of QM (2).

Stern-Gerlach experiments (2): the quantum state and its description by a vector; physical variables and operators.

Basis (4): basis vectors as eigenstates of Hermitian operator; change of basis; states and operators in different bases; rotation, identity, and projection operators; expectation values of physical variables; compatible and incompatible observables.

Angular momentum (4): non-commutativity of rotations; commuting operators; eigenvalues and eigenstates of the angular momentum operators; raising and lowering operators; the spin-½ eigenvalue problem; a Stern-Gerlach experiment with spin-1 particles.

Time evolution (4): the Hamiltonian; the Schrodinger equation; time dependence of expectation values; precession of spin-½ particle in a magnetic field; magnetic resonance; the ammonia molecule and the ammonia maser; energy-time uncertainty relation.

A system of two spin-½ particles (2): the hyper fine splitting of the ground state of Hydrogen; the addition of angular momenta for two spin-½ particles; the Einstein-Podolsky-Rosen paradox; Bell inequalities.

Wave mechanics in one dimension (4): position eigenstates and the position operator; translation and the momentum operator in the position basis; momentum space; the Gaussian wave packet; general properties of the solutions to Schrodinger equation in position space; the particle in a box; scattering in one dimension.

The one-dimensional harmonic oscillator (4): torsional oscillations of the ethylene molecule; creation and destruction operators; position-space wave functions; the zero-point energy; the classical limit; time dependence; solving the Schrodinger equation in position space; inversion symmetry and the parity operator.

Recommended computational exercise: solving the Schrodinger equation in one dimension for a simple potential.

References: *A Modern Approach to Quantum Mechanics*, by J Townsend, *Quantum*

Mechanics, by L Susskind, and *Principles of Quantum Mechanics*, by R Shankar.

Physics Lab 3

Experiments in oscillations, waves, optics, heat, and quantum mechanics.

Pre-requisites: Physics Lab 1.

Recommended experiments

LCR circuit (2): forced damped oscillator;

resonance. Mechanical resonant circuit (2).

Coupled mechanical and electrical oscillators (2).

Oscillations of a string: Fourier analysis of the wave pattern (2).

Measurement of heat conductivity of a good conductor (2).

One experiment to demonstrate random walks (2).

Two experiments to demonstrate quantum mechanics (2).

Homework: design and realization of an experiment given an aim.

The Physics of Matter

The various areas of fundamental physics that are studied separately in semesters 3 and 4 must of course be used to study systems to understand which one must call upon more than one of these areas. The purpose of this course is to show how fundamental physics can be used to study a number of interesting phenomena.

Recommended course content

Electric and magnetic properties of matter

(4). Elastic properties of solids (2).

Crystals and band structure (2).

Semiconductors, insulators, and

conductors (2). Electronic devices (2).

Superconductivity (2).

Glasses and amorphous materials (2).

Liquids (2).

Colloids (2).

Polymers (2).

Bose-Einstein condensation (2).

The Chandrasekhar mass limit: white-dwarf and neutron stars (2).

Physics Lab 4

Experiments on the properties of matter. Pre-requisites: Physics Lab 1 and all earlier physics theory courses.

Recommended experiments

Experiments using various electronic devices.

A selection of experiments illustrating various properties of matter – to be decided.

2. Proposed Elective Courses

Cosmology

The aim of cosmology is to apply laws of physics to the universe as a whole. Observations tell us that the universe is neither eternal nor static, and therefore it raises questions as to when and how did the universe start? What did it look like in the past? How will it evolve in the future? Aim of this course is to use all the physics that you have learned as an undergraduate to try and answer these questions.

Soft Matter Physics

The course will provide a birds-eye view of soft matter physics, concentrating on physical ideas and building up the mathematical description as I go along. Examples will include: Polymers: DNA, proteins, plastics, fabrics; Gels: jelly, rubber; Suspensions/Dispersions (one phase in another): river water, blood; Surfactant solutions: detergents, shampoos; Emulsions and foams: paint, shaving cream; Liquid crystals: displays; Greases, pastes, powders, granular media; Colloids (suspensions of small particles in a medium): Milk; Membranes: Cell membranes and Magnetorheological fluids.

Advanced Mathematical Physics

This course is designed for those who wish to pursue theoretical physics at the postgraduate level. The techniques developed here will be used in the two other electives that will be offered for the same group: Advanced Quantum Mechanics and Statistical Mechanics, and Advanced Classical Mechanics and Electrodynamics.

References: *Mathematics for Physics* by M Stone and P Goldbart, *Mathematical*

Methods for Physicists by G B Arfken, *Physical Mathematics*, by Kevin Cahill*, Complex Variables and Applications*, by J W Brown and R V Churchill, and *Mathematics for Physicists* by P Dennery and A Krzywicki.

Advanced Quantum Mechanics and Statistical Mechanics

A second course each in quantum mechanics and statistical mechanics is advisable for those wishing to pursue theoretical physics. In this course half a semester will be spent on each of these two subjects.

Advanced Classical Mechanics and Electrodynamics

A second course each in classical mechanics and electrodynamics is advisable for those wishing to pursue theoretical physics. In this course half a semester will be spent on each of these two subjects.

Physics ASP

The fourth year ASP provides the opportunity for students to study physics at a level more advanced than the usual undergraduate level. Alternatively, students wishing to broaden their education further can use it to take a minor/concentration in any other subject or simply take whatever courses in any department they wish to.

Advanced Major

The advanced major is for students intending to pursue higher studies and research in physics. It would enable them to take some advanced physics courses as well as get an idea of research through the capstone project/thesis.

Requirements :

7th Semester : Required to take 16 credits of which the capstone project comprises 8 credits. The students can opt for 1 or 2 courses comprising 4 credits/course.

8th Semester : Required to take 16 credits of which the capstone project comprises 8 credits. The students can opt for 1 or 2 courses comprising 4 credits/course.

Over the whole year (2 semesters), courses apart from Thesis may be taken from outside the department also (needn't necessarily be Physics courses).

Capstone Project and Thesis :

Interested students should talk to prospective advisors about possible projects in their 6th semester. After mutual agreement - the advisor agrees to guide the student and the student agrees to work on one of the projects suggested by the advisor - students should start with necessary background reading / preliminary work over the summer before the start of the fourth year.

At the end of the 7th semester the project would be assessed with a presentation and report - this will be evaluated by the physics faculty. Students without satisfactory progress at this stage may not continue for the thesis subsequently.

At the end of the 8th semester the thesis has to be submitted and defended before a panel which may also include some external members. *It is mandatory to successfully complete the capstone project and thesis to be eligible for the advanced major.*

Other options (Minor/Concentration)

Students not opting for the advanced major can take courses as per their interest in the fourth year. It is recommended that physics majors take two physics electives over the year. Those minoring in physics (or taking it as a concentration) may take physics courses accordingly to meet the necessary requirements.

TF/TA-ship Policy

- The department doesn't currently offer TAship but there are possibilities of voluntarily working as TAs for the physics courses (for the 4th year students).
- The Teaching Fellows are recruited after a departmental screening process.
- MLS students are assigned to be TAs as a part of their academic requirements.

Independent Study Module (ISM)

- Students may opt for an ISM if interested.
- A successfully completed ISM would contribute 4 credits to the student's GPA.
- Students who wish to take up an ISM can contact the Professor whose guidance they prefer seeking and can discuss the course load and hours to spend.
- Further instructions will be provided by the Professor.

Faculty

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Somendra Mohan Bhattacharjee received his Ph.D. in Physics from Carnegie Mellon University, Pittsburgh, USA, B. Sc in Physics (Honours) from Presidency College, Calcutta, and M. Sc. in Physics from the University of Calcutta. After doing post-doctoral research at the University of Massachusettes, Amherst, USA, and Bell Labs, Murray Hill, he joined the Institute of Physics, Bhubaneswar as a faculty member and continued till April 2019.

His research interest is in theoretical condensed matter physics and biology-inspired physics mostly related to phase transitions. The force-induced unzipping transition of DNA is one of his most important contributions. He is a fellow of the Indian National Science Academy and Indian Academy of Sciences, and a J C Bose National Fellow. He was a Regular Associate of ICTP, Trieste, Italy.

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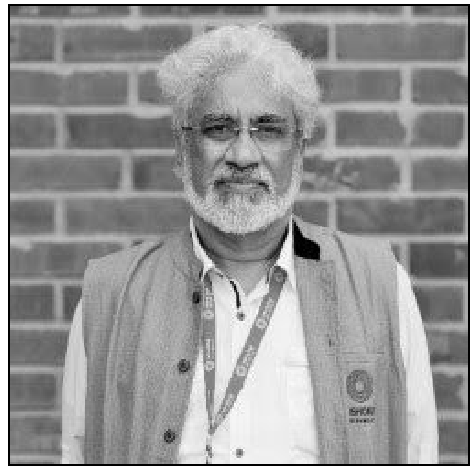

Professor Sabyasachi Bhattacharya is a physicist and works on dynamical aspects of disordered condensed matter systems. He is a Distinguished Professor at the Tata Institute of Fundamental Research (TIFR) of which he was the former Director. Professor Bhattacharya received his B.Sc. at the Presidency College, Kolkata, M.Sc. at the University of Delhi, and his Ph.D. at Northwestern University, all in Physics. He conducted post-doctoral research at the National Magnet Laboratory at MIT, University of Rhode Island. He was at the University of Chicago as a James Franck Distinguished Fellow before joining the Exxon Corporate Research Laboratory. He subsequently worked at the NEC Research Institute at Princeton where he was the Chair of the NEC Board of Fellows. Professor Bhattacharya currently serves, among other organizations, on the Editorial Board of the Reports on Progress in Physics, the Technology Advisory Council of British Petroleum, the IIT-Council of the Ministry of Human Resource Development and the Council of IIT-Bombay and the Mentor Group of Presidency University, Kolkata. He is a frequent visitor to the New York University, the University of Chicago, the Cavendish Laboratory and the Trinity College at the University of Cambridge. He is a Fellow of the American Physical Society. Apart from Physics, he is interested in higher education policy in India related specially to science and technology research.

Professor Bhattacharya was a Non-Resident Senior Fellow at CASI from September 2012 through August 2013.

Gautam Menon

Professor of Physics and Biology,

Ashoka University.

Ph.D. Indian Institute of Science, Bangalore

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Gautam I Menon is a Professor of Physics and Biology at Ashoka University. Prior to joining Ashoka, he was a Professor with the Theoretical Physics and Computational Biology groups at the Institute of Mathematical Sciences, Chennai, where he was the founding Dean of the Computational Biology group. He is currently an adjunct Professor in the Department of Biological Sciences at the Tata Institute of Fundamental Research, Mumbai, India.

He completed a BSc. (Hons) in Physics at St. Stephens College, Delhi, an MSc from IIT Kanpur, and a Ph.D. from the Indian Institute of Science, Bangalore. Following post-doctoral work at the Tata Institute of Fundamental Research in Mumbai and the Simon Fraser University in Vancouver, Canada, he joined the Institute of Mathematical Sciences. His research work, spread over approximately 80 papers, covers a range of areas in both physics and biophysics. He has written several articles on the interface of science and society as well as on science policy.

He was awarded a DST Fast Track Fellowship for Young Scientists in 2002 and the Swarnajayanti Fellowship of the DST in 2005. He was named a DAE-SRC Outstanding Research Investigator in 2010. He was named an Outstanding Referee by the American Physical Society in 2012, as well as recognized as an Outstanding Reviewer of the UK-based "Reports on Progress in Physics" in 2016. He was a Visiting Professor at the Mechanobiology Institute and the Department of Biological Sciences at the National University of Singapore between 2011-2013. He has served on scientific review committees of several international agencies, including the Human Frontier Science Program and the Wellcome Trust-DBT India Alliance. His research has been funded by several national and international agencies, including the European Union, the Indo-French CEFIPRA as well as the DBT, DST and DAE in India. He has lectured in universities and scientific conferences around the world and in India, including in the USA, Canada, France, Germany, Switzerland, Singapore, the Netherlands and the UK. He was elected a Fellow of the National Academy of Sciences, India in 2019.

He works on a number of biophysical problems including nuclear architecture, axonal transport, collective cell migration and cell adhesion, all in the general field of mechanobiology. The modeling of infectious disease and its implications for public policy is a long-standing interest of his, while the use of machine learning methods in clinical contexts is a more recent one.

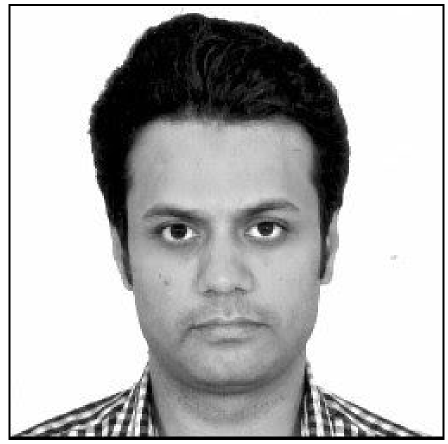
Amin Nizami

Assistant Professor of Physics,

Ashoka University

Ph.D. University of Cambridge

(Current Course coordinator of Physics)



Mail : amin.nizami@ashoka.edu.in

Amin received his PhD in Theoretical Physics from the University of Cambridge (at the Department of Applied Mathematics and Theoretical Physics). His main research interests include various aspects of quantum field theory, holography, quantum information and statistical mechanics. His main area of specialisation is in conformal field theory.

Amin received his BSc in Physics (with Mathematics and Statistics) from AMU, Aligarh, India and Masters (Part III of Mathematical Tripos) in Theoretical Physics from the University of Cambridge. Prior to joining Ashoka he was a postdoctoral fellow at the International Centre for Theoretical Sciences and a research associate at the Centre for High Energy Physics, Indian Institute of Science, Bangalore.

Pramoda Kumar

Ph.D. Coordinator of Physics,

Assistant Professor of Physics,

Ashoka University

Ph.D. Centre for Liquid Crystal Research (renamed as Centre for Nano and Soft Matter Sciences), Bangalore

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Research Experience:

- The Jacob Blaustein Institutes for Desert Research - Ben Gurion University of the Negev, Israel (Blaustein Postdoctoral Fellow Nov. 2015 - Feb. 2019)
- Centre for Nano and Soft Matter Sciences, Bangalore (Visiting Scientist, May 2015 – Sept. 2015)
- Harvard-School of Engineering and Applied Sciences, Cambridge (Postdoctoral fellow, Sept. 2013 - Feb, 2015).
- Weizmann Institute of Science, Israel (Feinberg Graduate School Postdoctoral Fellow, Dec. 2012– Aug. 2013)
- Max-Plank Institute for Dynamics and Self-Organization, Goettingen (Postdoctoral Fellow, Sept. 2010 - Oct.2012)

Research Interest:

Experimental soft-condensed matter physics, pattern formation in dissipative systems, interface instability, charge transport phenomena in ion-selective membranes, bio-physics and non-Newtonian hydrodynamics

Frequently Asked Questions

1. What are going to be the mandatory courses to pursue a minor in Physics?

Answer: The gateway courses (Mathematical and Computational Toolkit and Laboratory 1) are the mandatory courses to pursue a physics minor. Apart from these two, the student is expected to take 4 courses of their choice. Of these 4 courses at least two should be taken from among the other core courses. The remaining two can be core or elective courses and one of them can also be an ISM. So, in total a student has to do 6 courses to complete a minor in Physics.

2. What are the mandatory courses for a concentration in Physics?

Answer: The gateway courses (Mathematical and Computational Toolkit and Laboratory 1) are the mandatory courses to pursue a physics concentration. Apart from these two, the student is expected to take 2 courses of their choice from among the core courses. So, in total a student has to do 4 courses to complete a concentration in Physics.

3. What are the mandatory courses for the Ashoka Scholar Programme (ASP) students?

Answer: A project (Capstone project) and the Capstone thesis are mandatory for an Advanced Major in Physics.

4. Will the mandatory courses be offered every semester?

Answer: The mandatory gateway courses are offered in the spring semesters. Other core courses are spread throughout the 6 semesters. All courses are not offered in every semester.

5. What are the prerequisites to major in Physics?

Answer: The student is expected to have a science/mathematics background in their high school (at +2 level). Calculus is a recommended course to be taken in their first semester.

6. I am interested in doing a TAship/writing a thesis although I'm not in my fourth year as

yet.

Answer: The current TAship policy doesn't allow students (except 4th years) to become TAs.

7. Who should I contact in case I have further questions?

Answer: You can reach out to the Academic Representative of the Department.

8. Is thesis mandatory for ASP students?

Answer: Thesis is mandatory for an Advanced Major in Physics. See also Q. 9.

9. Do the ASP 4th year count as an Advanced Major?

Answer: Yes. But only if the capstone project + thesis option is chosen. Otherwise the fourth year may be used to get a double major / minor in other subjects.

10. Will the labs be independent of the theory courses - in terms of number of credits?

Answer: Yes. They are independent of the theory courses in terms of the number of credits - 4 credits for each theory course or lab.