CURRICULUM HANDBOOK

Master of Science [M.Sc.]

in

THEORETICAL AND APPLIED PHYSICS

[CLASS OF 2025]

AFRICAN UNIVERSITY OF SCIENCE AND TECHNOLOGY

SUMMARY

#	COURSE NAME	CODE	CREDIT UNITS	CATEGORY
1	Foundation in Mathematics for Science and Engineering	MTH 800	3	Core
2	Mathematical Methods for Physics	PHY 800	3	Core
3	Classical Mechanics	PHY 801	3	Core
4	Electrodynamics I	PHY 802	3	Core
5	Quantum Mechanics I	PHY 803	3	Core
6	Statistical Physics	PHY 804	3	Core
7	Introduction to Computer Programming	PHY 805	3	Core
8	Solid States Physics	PHY 806	3	Core
9	Fluid Dynamics	PHY 807	3	Core
10	Modeling and Simulations	PHY 808	3	Core
11	Introduction to Laser Matter Interaction	PHY 809	3	Core
12	Quantum Field Theory	PHY 810	3	Core
13	Introduction to Computational Physics	PHY 811	3	Core
14	Quantum Mechanics II	PHY 812	3	Elective
15	Structure and Materials Characterizations	MSE 811	3	Elective
16	Electronic Properties of Materials	MSE 813	3	Elective
17	Master Dissertation	PHY 899	PASS/FAIL	Core
18	Biophysics	PHY 901	3	Elective
19	Photonics	PHY 902	3	Elective
20	Electrodynamics II/ Intro to Particle Physics	PHY 903	3	Elective
21	Solar Energy	PHY 904	3	Elective
22	Computational Fluid Dynamics	PHY 905	3	Elective
23	Laser Physics	PHY 906	3	Elective
24	General Relativity	PHY 907	3	Elective

Note:

- General grade and examination requirements, calculation of GPA and CGPA, and other academic requirements can be found in Chapter 4 of the AUST Student Handbook.
- A minimum of 39 Credit Units is required for a Master of Science degree in Theoretical and Applied Physics.
- ALL *Core Courses* are compulsory.
- There is no credit load for the *Master Dissertation*, with a grade of PASS/FAIL awarded for the course. A grade of a PASS is needed for an award of a Master of Science degree in Theoretical and Applied Physics.

COURSE NAME – PHY 800: Mathematical Methods for Physics

References

a. (Text book, title, author, and year)

- Mathematical Methods by Arfken and Weber
- Methods of Theoretical Physics I & II by Morse and Feshbach
- S. Hassani Mathematical Methods for Students of Physics and related fields

b. (other supplemental materials): Nil

Specific course information

a. Brief description of the content of the course (catalog description)

This course provides modern mathematical tools to tackle most realistic physical problems
Function, relations and sets; Basic logic; Proof techniques; Combinatorics; Trees and graphs; lattices, Boolean algebra.

b. Prerequisites or Co-requisites

Linear Algebra, Calculus

Specific goals for the course

- The student will be able to use this course to get better understanding of physical systems.
- The Student will be well-equipped with various mathematical techniques in order to bring full analytical solutions and to some approximations to some extends.

Brief list of topics to be covered

- Introduction to Complex Analysis, Group Theory, Green Functions, Tensors.
- Fourier Series and Fourier Transforms.
- Integral Equations and Partial Differential Equations.
- Euclidean space and dot product.
- Co variant and Contravariant Vectors.
- Functional Derivatives.
- Gradient, Divergence, Curl in Curvilinear, Cylindrical and Spherical Coordinates.
- Symmetries in Physics, Conservative Fields, Stokes and Gauss Theorems.
- Maxwell Equations and Conservation Laws.
- Transformations Rules. Minkowski space-time, Livi-civita Connections.
- Strain and Stress Tensors. Diffeomorphisms. Smooth, Euclidean and Pseudo-Euclidean Manifolds.

- Vector Fields and Covector Fields. Flow of Vector Field.
- Lie Bracket and Lie Derivative. Differential Forms. Exterior Derivatives.
- Invariant Volume Element. Hodge Operator.
- Groups of Transformations. Finite Groups. Group of Permutations. Rotation Group SO(3). Euler Angles. Linear Group Representation. Matrix Group. Lie Groups. Unitary and Orthogonal Groups. Lie Algebras. Vector Fields on Lie Group.

COURSE NAME – PHY 801: Classical Mechanics

References

a. (Text book, title, author, and year)

- H. Goldstein, Ch. Poole, J. Safko: Classical Mechanics, 3rd ed., Addison-Wesley, Publishing Co., San Francisco, 2002

b. (other supplemental materials): *Nil*

Specific course information

a. Brief description of the content of the course (catalog description)

Foundation of Classical Mechanics, Principles (D'Alembert, Variational, Hamiltonian), Symmetries, Theorems, Transformations, Equations of motion (Newton, Lagrange Hamiltonian), Application on Mechanical and Electrical Systems.

b. Prerequisites or Co-requisites

Basic Classical Mechanics, Mathematics for Physics.

Specific goals for the course (in terms of outcomes by the student)

- The student will be able to derive the equation of motion from various approaches including D'Alembert principle, Variational Principle, Hamiltonian formulation, Energy Conservation for non-dissipative systems.
- The Student will be able to make use of symmetries and theorems to find solutions to complex mechanical and electrical problems.
- The Student will be able to deal with all type of advanced classical mechanics including the scattering problems.

Brief list of topics to be covered

- Review of Newtonian Mechanics: Mechanics of a particle and of a system of particles.
- Review of Newtonian Mechanics: Constraints.
- Virtual displacements, Equilibrium, D'Alembert Principle, Lagrange's Equations.
- Velocity-dependent potentials. Dissipation function.
- Applications of the Lagrangian formulation of Mechanics.
- Hamilton Principle. Useful techniques of the calculus of variations.
- Hamilton Principle and Lagrange's Equations. Nonholonomic systems.

- The central force problem. Reduction to one-body problem. The equations of motion and first integrals.
- Classification of orbits.
- The viral theorem.
- Orbit's differential equations. Integrable power-law potentials. Bernard's theorem.
- The Kepler problem. Description of the motion.
- Dissipative forces. General procedure.
- Frictional forces. Examples.
- Generalized viscous forces.
- Forces proportional to nth (n > 1) power of speed.
- Application of Lagrange's equations to passive electrical circuits.
- Examples of the application of Lagrange's equations to active electrical circuits.
- Oscillations: the eigenvalue equation and principal axis transformation.
- Frequencies of free vibration. Normal coordinates.
- Application to a linear triatomic molecule.
- Forced vibrations. Dissipative forces.
- Hamilton equations of motion. Legendre transformations.
- Conservation theorems. Cyclic coordinates, Routh's procedure.
- Hamilton equations from a variational principle. The principle of least action.
- The equations of Canonical transformations. Examples of of Canonical transformations.
- The Symplectic approach to Canonical transformations. Poisson brackets and other canonical invariants.

COURSE NAME – PHY 802: Electrodynamics I

References

a. (Text book, title, author, and year)

- Electromagnetism by D. J. Griffiths
- Classical Electrodynamics by J. D. Jackson

b. (Other supplemental materials): Nil

Specific course information

a. Brief description of the content of the course (catalog description)

Brief review of Electrostatics and Magnetostatics; use of various laws and methods to tackle the mutual interaction of electric and magnetic fields. Understanding and application of fundamental laws of electricity and magnetism.

b. Prerequisites or Co-requisites

Classical Mechanics, Mathematics for Physics, Basic Classical Electrodynamics.

Specific goals for the course (in terms of outcomes by the student)

- The student will be able to play with various fascinating electrostatics and magnetostatics phenomena.
- The Student will be able to appropriately make use of various laws and theorems to tackle problems.

Brief list of topics to be covered

- Electrostatics: Electric Field; Electric potential; Laplace equation and its solutions via method of images, Green's function, series method, separation of variables; Multipole expansion and multiple moments; Electric fields in ponder-able media.
- Magnetostatics: Biot-Savart law; Lorentz force law; Electrodynamics: (Faraday's law); Maxwell's equations; Magnetic fields in ponderable media.

COURSE NAME – PHY 803: Quantum Mechanics I

References

a. (Text book, title, author, and year)

- Introduction to Quantum Mechanics, 2nd ed. by D. J. Griffiths

b. (Other supplemental materials)

- L. Susskind, A. Friedman, Quantum Mechanics the theoretical minimum.
- R. Shanker, Principle of Quantum Mechanics.

Specific course information

a. Brief description of the content of the course (catalog description)

This course intends to provide an overview of the basic theory of modern quantum mechanics. Basic applications and common approximation methods of quantum mechanics are explored as well, with special emphasis on essential physical principles supported by mathematical developments.

b. Prerequisites or Co-requisites

Classical Mechanics, Mathematics for Physics, Linear Algebra, Complex Numbers, Partial Differential Equations, as well as some Electrodynamics concepts

Specific goals for the course (in terms of outcomes by the student)

- The students will be able to demonstrate knowledge of the main aspects of the historical development of quantum mechanics, to discuss and interpret the various experiments that revealed the wave properties of matter, and to learn how the limitations of classical mechanics have been resolved.
- Students will be able to understand the central concepts and principles such as, the Schrödinger equation, the wave function, the uncertainty principle, stationary and non-stationary states.
- Student will be able to solve the Schrödinger equation for simple systems and describe the properties of a particle in simple potentials.
- Students will be able to understand the significance of operators and eigenvalue problems, and the role of angular momentum to describe for instance the hydrogen atom.

Brief list of topics to be covered

- Review of Mathematical background and Classical Mechanics.
- Failures of Classical physics and adhoc 'quantum' solution; Blackbody radiation: Planck's model, The Hydrogen atom: Bohr's model, Compton Effect, Photoelectric effect, Wave-particle duality, de Broglie's hypothesis.
- Systems and Experiments; Quantum States.
- Axioms of Quantum Mechanics: The Wave function, Probabilistic interpretation of the Wave function, Normalization, Uncertainty principle (elementary).
- The Time-Independent Schrödinger Equation, Stationary States; Five potentials (bound &/or scattering states): i) Infinite square well, ii) Simple Harmonic Oscillator, iii) Zero Potential (Free Particle), iv) Dirac Delta Potential and v) Finite Square Well.
- Formalism beyond (1) above: Uncertainty principle (rigorous), Dirac's bra and ket notation.
- Quantum mechanics in 3D, Schrödinger Equation in 3D (case of Hydrogen atom) Angular momentum, Spin: Stern-Gerlach Experiment, addition of Angular Momenta.

COURSE NAME – PHY 804: Statistical Physics

References

a. (Text book, title, author, and year)

- Statistical Mechanics by R.K. Pathria, Introduction to modern statistical mechanics by D. Chandler.
- Statistical physics of particles by M. Kardar.
- An introduction to chaos in non-equilibrium statistical mechanics by J. R. Doffman.

b. (Other supplemental materials): Nil.

Specific course information

a. Prerequisites or Co-requisites

Classical Mechanics, Mathematics for Physics.

Brief list of topics to be covered

- Thermodynamics: Macroscopic systems, state variables, laws of thermodynamics, phase equilibria, engines and fridges.
- Equilibrium Classical Statistical Mechanics: ensembles, entropy of mixing, ideal gas.
- Hamiltonian mechanics, Liouville's equation, Poincare recurrence, Boltzmann equation and H-theorem.
- Equilibrium Quantum Statistical mechanics: quantum statistics, density matrix, bosonic and fermionic systems.
- Bose-Einstein condensation.

COURSE NAME – PHY 805: Introduction to Computer Programming

References

a. (Text book, title, author, and year)

- D. Beazley, B. K. Jones, Python Cookbook 3rd edition

b. (other supplemental materials)

- H. Fangohr, Introduction to Python for Computational Science and Engineering.
- E. Ayars, Computational Physics with Python.

Specific course information

a. Brief description of the content of the course (catalog description)

Introductory course for computer programming. Algorithms of few commonly studied physical systems and its implementations in one of the main scientific programming language such as Fortran or Python.

b. Prerequisites or Co-requisites

Foundation of Mathematics.

Specific goals for the course (in terms of outcomes by the student)

- The student will be able to write algorithms for standard physical problems governed for instance by Ordinary Differential Equations (ODE), Time-Dependent Schrödinger Equation (TDSE), Matrix Equations, etc.
- The Student will be able to implement programs associated to (1) in Fortran or in Python.
- Students will be able to use basic visualization tools gnuplot, Xmgrace, Matlab, MatplotLib to represent their data.

Brief list of topics to be covered

- The computer: Operating systems, file system.
- Introduction to the Command line and Shell scripts.
- Algorithmic programming -- basic concepts and representations, control flow, functions and modules.
- Data Types and Data Structures.
- Introduction to programming with Fortran and/or with Python.
- Input and Output.
- Python shells; Python command line, IPython notebook, editors.

- Numerical Methods using Python (scipy) or NAC Library for Fortran.
- Visualising Data using Matlab, MatPlotLib, XMgrace, Gnuplot.
- High-performance computing (HPC)/ Parallel programming using mpi4py and/or NAC Library.

COURSE NAME – PHY 806: Solid State Physics

References

a. *(Text book, title, author, and year)*

- Solid-state physics: Principles and Modern applications by Quinn and Yi, "Introduction to Solid State Physics," by C. Kittel "Solid-state physics" by Ashcroft and Mermin, "Introduction to solid state physics" by Hook and Hall.

b. (Other supplemental materials): Nil.

Specific course information

a. Brief description of the content of the course (catalog description)

Drude model, Crystal structure, Reciprocal lattice, Crystal Binding, phonons, Electronic states, Bloch Theorem, Bloch states, Band structure, Tight Binding method, Semiconductors, Magnetism, Introduction to superconductivity.

b. Prerequisites or Co-requisites

Classical Mechanics, Quantum mechanics I and II, Mathematics for Physics.

Specific goals for the course (in terms of outcomes by the student)

- The student will be able to approximate DC and AC conductivity of metal using Drude model.
- The Student will be able to deal with electronic states from Bloch's theorem.
- The student will be able to plot and analyze band structures, to deal with magnetism and superconducting state.

Brief list of topics to be covered

- Review of the Drude model.
- DC and AC conductivity of a metal from Drude model.
- Review of the free electron model.
- Electronic density in 1-,2- and 3-dimension for a free electron system.
- Crystal structure.
- Primitive vectors and lattice vector.
- Unit cell and Primitive Unit cell.
- Reciprocal lattice.

- Electronic state: Bloch theorem.
- Bands structure.
- Tight Binding.
- Crystal Binding.
- Phonons.
- Magnetism in metal.
- Introduction to superconductivity.

COURSE NAME – PHY 807: Fluid Dynamics

References

a. *(Text book, title, author, and year)*

- George E.: Analytical Fluid Dynamics, 2000 CRC Press LLC. (ISBN: 0-8493-9114-9).
- Makinde O. D., Sibanda P.: A Mathematical Introduction to Incompressible Flow, 2000 Univ. of Zimbabwe Press (ISBN:0-908307-78-0).
- Drazin P. G., Riley N.: The Navier-Stokes Equations: A Classification of Flows and Exact Solutions. 2007 Cambridge Univ. Press (ISBN: 978-0-521-68162-9).

b. (Other supplemental materials): Nil.

Specific course information

a. Brief description of the content of the course (catalog description)

Fluid properties, compressible and incompressible fluids, Newtonian and non-Newtonian fluids, rotational and irrotational fluids, streamlines, velocity potential, Vorticity, Continuity equation, Navier Stokes equation, Energy equation, contaminant transport equation, parallel flow problems, steady and unsteady flows, boundary layer flow, hydrodynamic stability theory, etc. Applications in science, engineering and technology.

b. Prerequisites or Co-requisites

Basic Classical Mechanics, Mathematics for Physics.

Specific goals for the course (in terms of outcomes by the student)

- The students will be able to understand and apply the basic theoretical concepts of fluid flow to model and solve problems in science, engineering and technology.
- The students will be able to derive the appropriate equations governing the conservation of mass, momentum, energy and chemical species transport with respect to fluid flow, heat and mass transfer, and hydrodynamics stability.
- The students will be able to develop and implement appropriate numerical algorithms to tackle model problems with respect to fluid dynamics.

Brief list of topics to be covered

- Fluids properties, Compressible and Incompressible fluids, Newtonian and non-Newtonian fluids, Laminar and Turbulent flow, Fluids statics, Hydrostatic forces, Pascal's law

- Fluids kinematics, Lagrangian and Eulerian Coordinates, Material derivative, Streamlines, Pathlines, Streaklines, Vortcity, Velocity potential.
- Continuity equation, Momentum equations (Navier-Stokes Equations), Vorticity transport equation, Stream functions, Parallel flows, Poiseuille flows, Couette flows, Stokes flow, Flow in porous media, Darcy flow, Brinkman-Darcy flow, Brinkman-Darcy-Forchheimer flow, Open channel flow, etc.
- Conservation of energy, Zeroth and First laws of thermodynamics, Fourier heat conduction law, Energy equation, applications to heat transfer problems, Free convection flow, Forced convection flow, Mixed convection flow.
- The Dimensional Analysis, Fundamental dimensions, How to carry out a dimensional analysis? Common nondimensonal parameters, Non dimensional equations.
- Boundary layer theory, Blasius boundary layer flow, Sakiadis boundary layer flow, Von Karman momentum integral, thermal boundary layer, Concentration boundary layer.
- Ficks law, Chemical concentration transport equation, application to reactive flow problems.
- Magnetohydrodynamics, Lorenz force, Maxwell equations of electromagnetism, Application to conducting fluid flow problems.
- Hydrodynamic stability theory, Stability theory, Stability of steady parallel flows, Rayleigh`s criterion, the Orr-Sommerfeld equation.
- Numerical simulation using software like MAPLE, MATLAB, to solve nonlinear model problems for fluid flows with heat and mass transfer in science, engineering and industries.

COURSE NAME – PHY 808: Modeling and Simulations

References

a. (Text book, title, author, and year)

- Electronic Structure Calculations for Solids and Molecules: Theory and Computational Methods, Jorge Kohanoff.
- Molecular Modelling, Principles and Applications, Andrew Leach.

b. (Other supplemental materials): Nil

Specific course information

a. Brief description of the content of the course (catalog description)

It is possible to predict properties of materials "from scratch" or "ab initio" by applying the laws of quantum physics to the atoms that make up the material. The methods for doing this have been developed by solid state physicists, and are now sufficiently mature to tackle physics, chemistry, and materials engineering problems. This course provides an introduction to modeling and simulation, covering continuum methods, atomistic and molecular simulation (e.g. molecular dynamics) as well as quantum mechanics. We'll use techniques and software for simulation, data analysis and visualization. Students will get hands-on training in both the fundamentals and applications of these methods to key physics problems. Few examples will help to characterize complex structures and materials, and complement experimental observations. The lectures will provide an exposure to areas of application, based on the scientific exploitation of the power of computation.

b. Prerequisites or Co-requisites

Classical Mechanics, Quantum Mechanics I & II, Mathematics for Physics, Solid State Physics, Statistical Physics.

Specific goals for the course (in terms of outcomes by the student)

- Appreciate the range of modeling methods available to tackle physics, chemistry, and materials engineering problems.
- Know the fundamentals of theories underpinning such methods.
- Identify the key results obtained from calculations, and interpret these with regard to the physics/chemistry of the problem.
- Realize the strengths and limitations of various modeling methods.
- Understand the scope of particular methods, appreciate the errors involved and how to estimate and control such errors.

- Appreciate the trade-off between accuracy and computational resources.

Brief list of topics to be covered

- Introduction to molecular modeling & simulation, areas of application, successes and limitations.
- Fundamental approaches typically used in molecular modeling & simulation: molecular mechanics and quantum mechanics.
- Introduction to Density Functional Theory. The basic approximations: Born Oppenheimer adiabatic approximation and the effective potential concept.
- Hohenberg-Kohn theorem and variational principle, Kohn-Sham auxiliary equations.
- Solving the Kohn-Sham equations through iterative diagonalization drivers: Davidson diagonalization; Conjugate Gradient.
- Variational principle and the Hellmann-Feynman and stress theorems.
- Band structure and Density of states determination and interpretation.
- General description of a plane-wave pseudopotential code.
- Self-consistent cycle vs global minimization and Car-Parrinello method.
- Exchange-correlation functionals: Energy in LDA and GGA and how to take its derivative with respect to density.
- Type and transferability of Pseudopotentials: Empirical pseudopotentials, Norm Conserving Pseudopotentials, Ultra Soft Pseudopotentials.
- Advanced xc functionals. Hybrids, implementation and challenges.
- Crystal symmetry and how it can be used to reduce the computational work load.
- Brillouin zone sampling: periodic vs non periodic systems; metallic vs non-metallic; magnetic vs non-magnetic.
- Density Functional Perturbation Theory (DFPT) and lattice dynamical calculations.
- Treatment of van der Waals interactions, available vdW-DF functionals.
- Calculating of total (ground state) energy and forces.
- Quantum modeling of solids: Basic properties (lattice parameters, bond distances etc.
- Advanced properties of materials: What else we can do? (Magnetic, Mechanical, Vibrational, Electronic, and Optical properties of materials).
- Surface modeling (Miller indices, surface stabilities determination, surface reactivity and heterogeneous catalysis).
- Materials modeling and simulation codes and software (advantages/disadvantages), e.g. electronic structure codes (VASP, QUANTUM ESPRESSO, SIESTA, CASTEP; Molecular dynamics programs (GROMACS, LAMPS, DL-POLY, CHARMM).
- Crystal structure generation, visualization and presentation (software and their use.
- Data extraction and analysis (software and their use).

COURSE NAME – PHY 809: Introduction to Laser Matter Interaction

References

a. *(Text book, title, author, and year)*

- T. Brabec et al., Rev. Mod. Phys. 72, 545 (2000).
- F. Krausz et al., Rev. Mod. Phys. 81, 163 (2009).
- P. M. Paul et al. Science 292, 1689 (2001).
- R. Kienberger et al. Science 297, 1144 (2002).
- P. H. Bucksbaum et al. Science 317, 766 (2007).
- C. J. Joachain et al., Atoms in intense Laser Fields, Cambridge Univ. Press, New York (2012).
- M. Protopapas, C. H. Keitel and P. Knight, Rep. Prog. Phys. 60, 389 (1997).
- T. Brabec et al., Rev. Mod. Phys. 72, 545 (2000).
- M. Gavrila, Atoms in strong Laser Fields, Academic Press, (1992).

b. (Other supplemental materials): Nil

Specific course information

a. Brief description of the content of the course (catalog description)

This course intends to offer basic knowledge of lasers and the minimum background required for a possible research in the field of Light/Laser Matter Interaction, Quantum Dynamics of Complex Systems and related ones.

b. Prerequisites or Co-requisites

Classical and Quantum Mechanics, Electrodynamics, Mathematics for Physics.

Specific goals for the course (in terms of outcomes by the student)

- The student will be able to model simple physical simple physical coupled to lasers that lead in general to the Time Dependent Schrödinger Equation (TDSE).
- The Student will be able to find exact analytical solutions and when not possible to deal with realistic approximations leading to acceptable solutions.
- The Student will be able to write a code to fully solved numerically the TDSE.
- The student will get used to the computation observables likely to understand the physics of the system.

Brief list of topics to be covered

- Basic Concepts of light: the light in brief, the light and the matter, basics of laser, properties of laser pulses.
- The Volkov Theory.
- Atoms in strong Laser Fields: Time Dependent Schrödinger Equation (TDSE), Atomic Units, Length and Velocity Gauges, Theoretical Approach of Solving TDSE (excitation, dissociation and ionization), Perturbation Methods, Strong Field Approximation. Harmonic Generation.
- The Floquet Theory.
- Free electron in a Laser Field: classical description, quantum description.
- The Fast Fourier Transform Split Operator Method.

COURSE NAME – PHY 810: Quantum Field Theory

References

a. (Text book, title, author, and year)

- Lecture notes on Quantum Field Theory of David Tong.
- M. Peskin, D. Schroeder An Introduction to QFT.
- L. Ryder, Quantum Field Theory.
- S. Weinberg, The Quantum Theory of Fields.

b. (Other supplemental materials): Nil

Specific course information

a. Brief description of the content of the course (catalog description)

The course is designed to give an introduction to the wide area of Quantum Field Theory. The accent of the course will be on the conceptual grasp. Many problems and exercises illustrating the applications will be given.

b. Prerequisites or Co-requisites

Linear Algebra, Mathematical Analysis, Mathematical Methods of Physics, Classical Mechanics, Quantum Mechanics.

Brief list of topics to be covered

Introduction

- Units and Scales.
- Special Relativity.
- Lorentz group and Lorentz invariance.

Classical Field Theory

- Lagrangian Formulation. Euler-Lagrange equations of motion for fields.
- Locality.
- Scalar fields: Klein-Gordon equation.
- Vector Fields: Covariant form of the Maxwell Equations.
- Spinors: Dirac equation.

Lorentz invariance of the fields

- Noether’s Theorem.
- Translation invariance and Energy Momentum Tensor.
- Lorentz Transformation and Angular Momentum.
- Electric current. Gauge Symmetries.

Free Fields

- Canonical Quantization and the Harmonic Oscillator.
- The Free Scalar Field.
- Particles in Momentum Space.
- Complex Scalar Field.
- Schrodinger and Heisenberg Picture.
- Causality.
- Propagators: Green’s Function and Feynman Propagator.

Interacting Fields

- Interaction Picture.
- Dyson Formula.
- Scattering Theory.
- Scalar Yukawa theory: Meson decay.
- Wick’s Theorem.
- Nucleon Scattering in Yukawa Scalar Theory.
- Feynman Diagrams and Feynman Rules.
- Mandelstem variables.
- Examples of Scattering amplitudes.
- Phy^4 Theory.
- Yukawa Potential.
- Connected Diagrams and Amputated Diagrams.
- Connected Diagrams and Vacuum Bubbles.
- Measurements: Cross-sections and Decay Rates.
- Fermi Golden Rule.

The Dirac Equation

- Dirac Equation.
- Spinor representations.
- Dirac Gamma Matrices.
- Plane Wave Solutions.
- Quantization of Dirac Field.

- Anomalous Magnetic Momentum of the Electron.

COURSE NAME – MSE 811: Structure and Materials Characterizations

References

a. (Text book, title, author, and year)

- R. Brundle, C. Evans, S. Wilson: Encyclopedia of Materials Characterization, Butterworth-Heinemann, 1992.
- David Brandon, Wayne D. Kaplan Microstructural Characterization of Materials Wiley, 2008.

b. (Other supplemental materials)

- B.D. Cullity and S.R. Stock, Elements of X-ray Diffraction — Third Edition, Prentice Hall, Inc., Upper Saddle River, NJ, (2001).

Specific course information

a. Brief description of the content of the course (catalog description)

This course introduces basic principles of materials characterization and the common characterization techniques available at AUST. It covers topics including:

- Diffraction methods: basic principles, interaction of radiation and particle beams with matter, XRD, scattering techniques; Spectroscopic methods.
- Imaging: optical including confocal microscopy, scanning, transmission electron, scanning tunneling and field ion microscopy.
- Microanalysis and Tomography: energy dispersive, wavelength dispersive, Auger Processes, Electron, Ion and Atom Probe Tomography, SIMS, photoelectron spectroscopy.
- Thermal analysis: DTA, DSC. Lab visits and demonstrations will be scheduled to discuss some case studies.

b. Prerequisites or Co-requisites

Basic Knowledge on general physics and chemistry and basic optics.

Specific goals for the course (in terms of outcomes by the student)

- Provide a thorough introduction to the principles and practice of diffraction.
- Provide latest Fabrication Technologies and their relation with material structuring and properties.

- Provide the most advanced imaging instruments for investigating the modern material at the highest topographic resolution.
- Provide basic descriptions of a range of common characterization methods for the determination of the structure and composition of solids.
- Provide the latest advancement in spectroscopy for getting structural and elemental analysis of Material.
- Provide practical experience in laboratory methods and reporting.

Brief list of topics to be covered

- Introduction and review of Micro and Nano structures.
- Waves and Geometrical optics.
- Importance of Material: Importance of Material characterization, Classification of techniques for characterization.
- Vacuum systems: Vacuum range, Vacuum Pumps; Rotary, Sorption, Turbomolecular, Diffusion, Ion, Cryo. Vacuum measurement gauge: Pirani, Penning, Ionization etc. Use of Vacuum systems in Material Characterization techniques
- Optical microscopy techniques: Metallurgical Microscopes, Aberration in Optical microscopy & its remedies, Polarized light in microscopy, Differential Interference Contrast Illumination, Hot Stage Microscopy, color metallography, and image analysis techniques.
- Electron microscopy: Electron beam. Principle, Construction and Working of TEM, SEM, STEM, with their merits, limitations and applications. Techniques of replica preparation.
- Atomic Microscopy: Field Ion Microscope, Working of AFM and STM with their merits, limitations and applications.
- Spectroscopic Techniques for chemical analysis: UV-Visual(UV-VIS), IR, FTIR, EDS & WDS, X-ray Fluoroscopy (XRF), Atomic absorption spectrometer(AAS), Atomic Emission spectroscopy (AES). Secondary Ion mass spectrometry (SIMS), Rutherford backscattering spectroscopy (RBS).
- Diffraction method: Brags Law, X-ray diffraction methods, determination of crystal structure, lattice parameter, crystallite size, merits and demerits.
- Surface characterization: XPS (ESCA), UPS, Auger Electron Spectroscopy, Electron Probe Micro Analysis (EPMA), LEED, Raman Spectroscopy.
- Thermal Analysis techniques: Principle, Working and application of DTA, TGA, TMA and DSC.

COURSE NAME – PHY 811: Introduction to Computational Physics

References

a. (Text book, title, author, and year)

- "A survey of computational physics" by R. H. Landau, M. J. Paez, and C. C. Bordeianu.

b. (Other supplemental materials)

- H. Fangohr, Introduction to Python for Computational Science and Engineering.
- KWANT Quantum transport package https://kwant-project.org.

Specific course information

a. Brief description of the content of the course (catalog description)

Students will be able to tackle physical problems using computer and different software as a numerical tool.

b. Prerequisites or Co-requisites

Classical Mechanics, Mathematics for Physics, Linear Algebra.

Specific goals for the course (in terms of outcomes by the student)

- Students will be able to use a programming language to solve physical problems including but not limited to Monte-Carlo Simulations, Molecular Dynamics, Ordinary Differential Equations, Partial Differential Equations of various physical systems and use of the Landauer-Buttiker formalism.
- The student will be able to use PYTHON package called KWANT based on the tight-binding formalism to compute basic quantum transport properties.

Brief list of topics to be covered

- Introduction to UNIX, FORTRAN and/or PYTHON, compiling codes, scientific plotting/visualization, Controlling.
- Random walk, Monte-Carlo simulations (non-thermal) e.g., for radioactive decay.
- Integration: quadrature and multidimensional integration with Monte-Carlo

- Differentiation.
- Solving ordinary differential equations, Partial Differential Equations.
- Fourier analysis.
- Fault tolerance
- Monte-Carlo and Thermodynamics simulations: Ising model, atoms with the Lennard-Jones potential.
- Molecular dynamics.
- Chaos.
- Landauer-Buttiker formalism; Conductance from transmission; Resistance of a ballistic conductor, two and four terminal transports; Quantum Hall effects
- Quantum transport with tight-binding using KWANTand / or Introduction to electronic structure (with Quantum Espresso).

COURSE NAME – PHY 812: Quantum Mechanics II

References

a. *(Text book, title, author, and year)*

- Introduction to Quantum Mechanics, 2nd ed. by David J.Griffiths
- Applied quantum mechanics by AFJ Levi.
- Quantum Mechanics by Shankar.
- Quantum Mechanics by Merzbacher.

b. (Other supplemental materials): Nil

Specific course information

a. Brief description of the content of the course (catalog description)

Brief Review of Quantum Mechanics I, First and Second Quantization, Time-Independent perturbation theory, Variational methods, WKB Approximation, Time-Dependent Perturbation Theory, Scattering, Many particles systems, Dirac's Relativistic Equation, Green Function Method.

b. Prerequisites or Co-requisites

Quantum mechanics I, Classical Mechanics, Mathematics for Physics.

Specific goals for the course (in terms of outcomes by the student)

- The student will be able to use quantum mechanics and apply it to related fields.
- The Student will be able to solve non-exactly solvable problems by means of perturbation theory.
- The Student will be able to deal with Green Function Methods.

Brief list of topics to be covered

- Brief review of Quantum Mechanics I.
- Review of Mathematical Description of Quantum Mechanics.
- Symmetry in Quantum Mechanics.
- Harmonic Oscillator: Introduction to creation and annihilation operators.
- Fermions and Bosons .

- Time-Independent Perturbation Theory.
- Variational Principle.
- WKB Approximation.
- Time-Dependent Perturbation Theory.
- Adiabatic Approximation.
- Scattering.
- Identical Particles: Second Quantization.
- Green Function Method for many body particles.

COURSE NAME – MSE 813: Electronic Properties of Materials

References

a. (Text book, title, author, and year)

- S O Kasap, “Principles of Electronic Materials and Devices”, McGraw-Hill. Rolf E Hummel.
- “Electronic Properties of Materials”, 4rd Edition, Springer, New York.

b. (other supplemental materials)

- Principles of Semiconductor Devices by Neamen, C Kittle.
- “Introduction to Solid State Physics”, John Wiley & Sons Inc.

Specific course information

a. Brief description of the content of the course (catalog description)

This course offers an overview of the electronic, optical, magnetic and thermal properties of Materials, not limited to solid states. It covers the fundamental concepts of band structure and bonding of materials, electrical and thermal conduction in metals, semiconductors and dielectric. Specifically, it describes how electrons interact with each other, electromagnetic radiation and the crystal lattice to give the material its inherent electrical, optical and magnetic properties. Semiconductors, metals, insulators, polymers are discussed, Finally magnetism is introduced.

b. Prerequisites or Co-requisites

Foundations of Mathematics, basics in electronic materials and solid states physics.

Specific goals for the course (in terms of outcomes by the student)

- This course offers an overview of the electronic properties of materials.
- There is an emphasis on fundamental physical models to understand the crystal structure and bonding, band structure of solids, carrier properties and p-n junctions.
- The primary aim is to introduce fundamentals underpinning electronic properties of materials. This spans everything from the basics of electron behavior in solids to the design of magnet and optoelectronic devices.

Brief list of topics to be covered

- Crystal Structure & Diffraction.
- Structure of Atom.
- Bonding in Materials.
- Energy Band Formation.
- Electron and Holes.
- Thermal Properties and Phonons.
- Electrical Current and Metal-Semiconductor & Semiconductor-Semiconductor Junctions.
- Semiconductor Devices.
- Novel Materials.
- Applications