Department of Physics

Chairperson:	Touma, Jihad R.
Professor Emeritus:	Mavromatis, Harry A.
Professors:	Antar, Ghassan Y.; Chamseddine, Ali H.; Isber, Samih T.; Kazan, Michel J. ; Klushin, Leonid I.; Sabra, Wafic A.; Tabbal, Malek D.; Touma, Jihad R.
Assistant Professors:	Haidar, Mohammad J.; Najem, Sara A.
Lecturers:	Al-Sayegh, Amara A.; Harajli, Zainab ; Malaeb, Ola; Rahbani, Nancy

The department provides courses and facilities for graduate work leading to the MS and PhD degrees. The research activities of the department include material science, condensed and soft matter physics, plasma physics, paramagnetic resonance, nonlinear dynamics, astrophysics, high-energy physics, superstring theory and quantum gravity.

MS in Physics

Admission Requirements

Refer to the Faculty of Arts and Sciences section.[1]

Course Work

The MS program requires the completion of 21 credits of courses and a research thesis. The courses consist of four core courses: PHYS 301, PHYS 302, PHYS 303 and PHYS 305, and 9 credits of physics graduate electives. After completion of the four core courses, the student must pass the GRE subject test[*], considered by the Physics Department as the Master's Comprehensive Exam.

Master Thesis Proposal and Thesis Defense

Refer to the section on Thesis Proposal, Thesis Format and Thesis Defense under General University Academic Information.

Residence Requirements

Refer to Residence Requirements section under General University Academic Information.

*) Due to the pandemic and the prevailing circumstances, the GRE subject test is replaced by an internal comprehensive exam.

Doctor of Philosophy in Theoretical Physics

Mission Statement

The PhD program in the Department of Physics is intended to produce competent, independent researchers who are able to make original contributions to physical sciences. The program prepares students for careers in research, teaching or industry and thus provides qualified scientists for Lebanon and the region. It serves the AUB mission of promoting research and participating in the advancement of knowledge.

Admission

Admission to the PhD program is done on a competitive basis. To be eligible for admission, applicants must have an excellent academic record and must demonstrate exceptional motivation and ability to pursue research in physics. The following items are required for an application:

- Degrees:
  - For the Regular Track[1], a Master of Science (MS) degree in Physics or related fields from an institution recognized by AUB is required.
  - For the Accelerated Track[2], a Bachelor of Science (BS) degree in Physics or related fields from an institution recognized by AUB is required.
- Three letters of recommendation
- GRE General Test as per AUB requirements. Subject GRE is required as per Physics Department requirements (No GRE is required for applicants to the MS program.)
- For English, refer to the Readiness for University Studies in English (RUSE) section in this catalogue.
- A statement of purpose
- A recommendation for admission by the AUB Department of Physics. A departmental committee may require an interview with the applicant before giving a recommendation.

Governance

Refer to the section on the Supervision of Doctoral Thesis under General University Academic Information.

Supervision of PhD Thesis

Refer to the section on the Supervision of Doctoral Thesis under General University Academic Information.

PhD Publication Requirements

Refer to PhD Publication Requirements under General University Academic Information.

Course Work

The PhD program requires the completion of at least 39 credit hours of course work for students admitted on the accelerated track (BS holders) and a minimum of 18 credit hours of course work for students admitted on the regular track (MS holders).

1) Refer to the Study Section under General University Academic Information.

The required courses for students admitted on the regular track are PHYS 306 and 308 (6 credits) and at least 12 credits beyond the core program, out of which one course must be in the concentration area, while the others can be taken as electives. Students may take relevant courses outside the department provided they secure departmental approval.

The required courses for students admitted on the accelerated track are PHYS 301, PHYS 302, PHYS 303, PHYS 305, PHYS 306 and PHYS 308 (18 credits) and at least 21 credits beyond the core program, out of which one course must be in the concentration area, while the others can be taken as electives. Students may take relevant courses outside the department provided they secure departmental approval.

PhD Qualification Exam Part I and Part II

Upon completion of a minimum of 15 credits of graduate courses with a cumulative GPA of 3.7 or above in the four core courses, the student should sit for PhD Qualification Exam Part I (written comprehensive examination) to determine whether s/he has acquired the background necessary to continue in the PhD program.

After choosing a thesis advisor, the student should pass the PhD Qualification Exam Part II; the student must formulate, submit and defend a thesis research proposal to demonstrate a capacity to pursue and complete a doctoral research project.

For more information, refer to the section on PhD Qualifying Exam under General University Academic Information.

Candidacy

Refer to the section on Admission to Candidacy under General University Academic Information.

PhD Thesis and Thesis Defense

Refer to the section on PhD Thesis Format and PhD Thesis Defense under General University Academic Information.

Residence Requirements

Refer to Residence Requirements section under General University Academic Information.

Graduation Requirements

A student is granted the PhD degree upon approval of the PhD thesis committee in a public session. In addition to the general graduation guidelines specified by the university, the Physics Department also requires that part of the PhD thesis work be published or accepted for publication in a refereed journal by the time of graduation.

Timetable

A student is expected to abide by the following timetable:

- Finish the graduate course work (a minimum of 39 credits after the BS) within 8 terms of starting the graduate study program
- Pass the qualifying exam upon completion of 15 credits, within 3 terms of starting the graduate study program
- Students in the accelerated track should choose a thesis advisor within four terms of starting the graduate study program

- Defend the PhD thesis proposal within 6 terms and advance to candidacy within 7 terms of starting the graduate study program
- Present research work by submitting her/his thesis to the thesis committee and defending it in a public session. The total length of the PhD should not exceed 7 years.

Financial Support

The Physics Department offers, on a competitive basis, substantial financial support. For full-time students, it covers tuition and includes a monthly stipend. There are also some funds available to support participation in two international conferences during PhD study. In return, students help in teaching undergraduate labs and recitations of introductory courses. Their duties may also include help in proctoring and correcting exams.

Course Descriptions

PHYS 301 Classical Mechanics 3.0; 3 cr.
D'Alembert's principle, variational principles and Euler Lagrange's equations, rigid bodies and small oscillations, Hamilton's mechanics, canonical transformations and Hamilton- Jacobi theory, stability, integrable systems and chaotic motion. *Annually.*

PHYS 302 Statistical Mechanics 3.0; 3 cr.
Statistical ensembles, Boltzmann distribution, density matrix, Fermi-Dirac and Bose-Einstein statistics and applications, phase transitions, mean-field theory and applications. *Annually.*

PHYS 303 Electromagnetic Theory 3.0; 3 cr.
Boundary-value problems in electrostatics, multipoles, dielectrics, magnetostatics, time-varying fields and Maxwell's equations, electromagnetic waves. *Annually.*

PHYS 305 Quantum Mechanics 3.0; 3 cr.
Hilbert space formulation of quantum mechanics; theory of angular momentum; Euler rotation; addition of angular momenta; symmetries and conservation laws: time reversal, parity, discrete symmetry, path-integral formulation of quantum mechanics, approximation methods, identical particles, elementary scattering theory. *Annually.*

PHYS 306 Introduction to Quantum Field Theory 3.0; 3 cr.
Unifying quantum theory and relativity; relativistic quantum mechanics: Klein-Gordon equation, scalar field, second quantization, Dirac's equation and Dirac's field. Interaction fields and Feynman diagrams, quantization of the electromagnetic field. *Prerequisite: PHYS 305.*

PHYS 307 Mathematical Methods of Physics 3.0; 3 cr.
The course provides an intensive overview of mathematical methods which are essential to the toolbox of any graduate student of physics, whether pursuing experimental or theoretical research. Topics covered include: Complex Variable Techniques, Special Functions, Integral Transforms, Hilbert Spaces, Ordinary and Partial Differential Equations, Green's Functions, Calculus of Variations, Transformation Groups. The course is open to graduates and advanced undergraduates in mathematics, the natural sciences and engineering with instructor permission.

PHYS 308 Advanced Mathematical Methods for Physics 3.0; 3 cr.
The course will equip students with the requisite mathematical tools in analysis, algebra, geometry and topology to appreciate current developments and pursue research in theoretical physics.It covers elements of topology, group theory, linear algebra, Lie groups, Lie algebras and their representations, differentiable manifolds, tensor analysis, differential forms, pseudo-Riemannian geometry, connections and covariant derivatives, curvature and torsion. Computational skills acquired after reading the course will surely prove essential for research in gravitational and theoretical high energy physics, but also for working through fundamental problems in the fields of dynamical systems theory, fluid mechanics and/or thermodynamics. The course is of natural interest to graduate and advanced undergraduate students of physics, but should be equally relevant to students in mathematics, the natural sciences and engineering.

PHYS 309 Advanced Experimental Physics 1.6; 3 cr.
A weekly lecture on laboratory techniques and data analysis, and a selection of three experiments based on current research at AUB: fluid dynamics, thin films and nanostructured materials, Plasma physics, Thermal physics and opto-thermal techniques, magnetism and magnetic resonance, Microscopy for material characterization.

PHYS 311 Astrophysics I 3.0; 3 cr.
Stars: observational properties, population, spectra analysis; stellar matter: atomic processes, equation of state including degeneracy effects; stellar structure: differential equations of stellar structure, radiative and convective energy transport, thermonuclear reactions nuclear fusion processes; stellar evolution: discussion of the evolutionary phases of stars, stellar stability and pulsations; final stages of stars: supernovae, white dwarfs, neutron stars and black holes; star formation.

PHYS 312 Astrophysics II 3.0; 3 cr.
Close binary stars and accretion disks. Physics of interstellar medium: heating, cooling, radiative transfer, physics of interstellar dust grains. Dynamics of stellar systems: morphology and dynamics of stellar populations in Galaxies, N-body simulation, spiral structure. Galaxies: galactic morphology, stellar content of galaxies, general properties of galaxies. Galactic evolution: formation of galaxies, stellar populations. Expanding universe: cosmological models, primeval fireball, cosmological red shift.

PHYS 313 Differential Geometry and General Relativity 3.0; 3 cr.
Differential manifolds. Tangent vectors. Vectors and tensor fields. Lie derivatives. Differential forms. Affine connections: covariant derivatives. Curvature and torsion Tensors. Principal of equivalence. Einstein filed equations. Schwarzschild solutions and classical test of general relativity. Weak gravitational fields. Post-Newtonian approximation.

PHYS 314 Non-Equilibrium Statistical Mechanics 3.0; 3 cr.
Phenomenological description of transport processes: diffusion, thermal conduction and Brownian motion. General microscopic approaches: Liouville's and von Neumann's equations. Boltzmann's equation and H-Theorem. Linear response theory: time-dependent correlation function, Green-Kubo formula, fluctuation-dissipation theorems. Stochastic evolution: Markoff process and master equation, correspondence between Langevin and Fokker-Planck pictures, kinetics of phase transitions. *Prerequisite: PHYS 302.*

PHYS 315 Particle Cosmology 3.0; 3 cr.
Relativistic cosmology: Friedmann equations and their solutions, Hubble diagram. Hot Big Bang model: statistical mechanics of the expanding universe, microwave background, primordial nucleosynthesis, GUT model for baryon asymmetry. Structure formation: Newtonian perturbation theory, gauge invariant relativistic perturbation theory, the large-scale structure of the universe. Inflation theory. *Prerequisite: PHYS 313.*

PHYS 316 Physics of Soft Matter 3.0; 3 cr.
Overview: liquid crystals, polymers, colloids. Statistical mechanics of correlation and order: scattering, structure factor, response function. Application to liquid crystals: generalized elasticity, nematic-to-smectic transitions. Application to polymers: random and self-voiding walks, coil-to-globe transitions, self-organization of amphiphylic macromolecules. Application to colloids and foams. *Prerequisite: PHYS 302.*

PHYS 317 Group Theory and Symmetry in Physics 3.0; 3 cr.
Group theory: subgroups, conjugate cases, direct products. Group representation: unitary spaces, unitary representations, Shur's Lemma, orthogonality, tensor products, conjugate classes, Young tableaux. Group theory and quantum mechanics. Point groups: proper rotation group, crystallographic point groups. Space groups. Continuous groups: transformation groups, generators, Lie groups and algebras, Yacobi identity. Application of SU(2). Isospin. Tensor products. Tensor methods: irreducible representations and symmetry, invariant tensors, Clebsch-Gordon decomposition. Application of Lie groups to particle classifications: SU(5) and SO(10).

PHYS 318 Standard Model of Particle Physics 3.0; 3 cr.
Renormalization and renormalization group. Group theory and the quark model. Chiral anomaly. Gauge theories and quantization. Quantum Chromodynamics. Spontaneous symmetry braking. Electroweak symmetry. Standard model of elementary particles. One loop structure and one loop processes.

PHYS 319 String Theory 3.0; 3 cr.
Classical Bosonic string. Quantized bosonic string. Conformal field theory. String perturbation theory. Classical Fermionic string. Quantized fermionic string. Spin structures and superstring partition functions. Heterotic strings. D-branes. Orbifolds. Calabi-Yau compactification.

PHYS 322 Thin Films Physics 3.0; 3 cr.
Introduction to surface and thin films physics: definitions, importance in basic research, impact on technology and society. Ultra high vacuum techniques and processes: kinetic theory concepts, surface preparation procedures; surface chemical composition: XPS, AES, SIMS, GIXRD. Thin film deposition: evaporation, plasma, laser and ion beam processing; physical and chemical vapor deposition techniques. Surface morphology and physical structure: surface energy, reconstruction, 2-D lattices, nucleation and growth of thin films, microscopy techniques. Theory of surface scattering; inelastic scattering and dielectric theory; electron-based techniques: LEED and RHEED, RBS. Epitaxy: atomistic models and rate equations; steps, ripening and interdiffusion; HRXRD. Conduction and magnetism in thin films; superconductivity; optical and mechanical properties. *Pre- or corequisite: PHYS 302.*

PHYS 323 **Plasma Physics** **3.0; 3 cr.**
The motion of a single particle (electron or ion) subject to electromagnetic forces; fluid equations for electrons and ions; guiding center description; collisional phenomena occurring in plasmas and the resultant diffusion; propagation of high and low frequency electromagnetic waves in plasmas; description of the plasma as a single fluid; the magneto-hydromagnetic (MHD) equations; MHD instabilities and their effects on the plasma; applications of plasma physics. *Pre- or corequisite: PHYS 303.*

PHYS 324 **Electron Paramagnetic Resonance** **3.0; 3 cr.**
The electronic Zeeman interaction and the resonance phenomenon, group theory: the rotation group, the spin-Hamiltonian and the spectrum, the lanthanide 4f group, the actinide 5f, ions of the 3d group in intermediate ligand fields and some experimental aspects of EPR. *Pre- or corequisite: PHYS 305.*

PHYS 330 **Principles of Environmental Physics** **3.0; 3 cr.**
Scope of environmental physics, review of gas laws, transport laws, radiation environment, microclimatology of radiation, momentum transfer, heat transfer, mass transfer, steady state heat balance, crop meteorology, energy for human use and environmental spectroscopy. *Not open to physics graduate students. Prerequisites: PHYS 204 and PHYS 205 or equivalent, and some knowledge of calculus.*

PHYS 391 **Graduate Tutorial** **1-3 cr. (each)**
May not be repeated for credit.

PHYS 395A **Comprehensive Exam** **0 cr.**
Prerequisite: Consent of advisor.

PHYS 399 **Thesis** **9 cr.**

PHYS 480 **Qualifying Exam Part I: Comprehensive Exam** **0 cr.**
Every term.

PHYS 481 **Qualifying Exam Part II: Defense of Thesis Proposal** **0 cr.**
Every term.

PHYS 484[1] **PhD Thesis** **30 cr.**
Every term. To be taken only by regular track PhD students. Taken at first thesis registration, then registered for every subsequent term with sequential letter annotations (A-L; 0 credits) until completion of thesis work.

PHYS 488[3] **PhD Thesis** **42 cr.**
Every term. To be taken only by accelerated track PhD students. Taken at first thesis registration, then registered for every subsequent term with sequential letter annotations (A-L; 0 credits) until completion of thesis work.

1) The choice to register for PHYS 484 or PHYS 488 should be done in consultation with the thesis advisor to ensure that the total number of PhD thesis credits and PhD course credits are met as per AUB rules and regulations.