2025-26

BIOPHYSICS

Degree Offered: Doctor of Philosophy

Program Description

The Biophysics Graduate Program encourages applications from students with strong backgrounds in chemistry, biology, biochemistry, biomedical engineering, physics, or mathematics and an enthusiasm for carrying out scientific research. The Program consists of two major areas—Molecular Biophysics and Magnetic Resonance Imaging. The faculty in the Molecular Biophysics section utilize biophysical techniques to study structural biology, free radicals in biology, and membrane protein systems. For example, current research includes studies on protein structure, functional dynamics, free radicals in biology, and magnetic resonance technology development. Students wishing to pursue this track should apply directly to the Biophysics Graduate Program or to the Interdisciplinary Program in Biomedical Sciences (IDP). The Magnetic Resonance Imaging section emphasizes research in the areas of cognitive neuroscience, signal processing, statistical analysis, image production, and hardware development. Students wishing to pursue this track should apply directly to the Biophysics Graduate Program or through the Neuroscience Doctoral Program (NDP). Applicants to this track are expected to have a high level of competence in physics and mathematics. Both tracks accept students from the Medical Scientist Training Program (MSTP).

Admission Requirements

In addition to the general Graduate School admission requirements, this program has additional specific requirements.

Students should have a strong foundation in quantitative, behavioral, and biological sciences

Fields of Study

- Protein structure and functional dynamics studies using site-directed spin labeling EPR spectroscopy.
- Structure-function relationships for membrane proteins; protein folding and dynamics; antibiotic peptides.
- Structure and function of protein-lipid assemblies relevant to human pathology.
- Structure and function of proteins embedded in cellular membranes using NMR spectroscopy.
- Molecular mechanisms of membrane protein function; role of protein conformational heterogeneity; GPCRs.
- Magnetic resonance (EPR, NMR, MRI) technology development.
- Molecular modeling and simulation integrating diverse experimental data
- Computational structural biology, molecular dynamics in mitochondrial processes
- Biological chemistry of nitric oxide and related species in physiology and pathology. Oxidative biology of sickle cell disease.
- Spin label studies on membrane dynamics and organization (raft- domain formation); spin label oximetry.
- Electron spin resonance studies of oxygen radicals and reactive nitrogen species in biological

systems; cardiovascular and neuro-degenerative pathologies (atherosclerosis, hypertension, ALS, Alzheimer's disease, etc.), free radicals in apoptosis and signal transduction, and chemotherapeutic drug-induced toxicity.

- Investigation of pathophysiological mechanisms enhancing free radical formation from nitric oxide synthase in vascular cells and their relation to the tetrahydrobiopterin pathway.
- Mapping of human brain language systems with magnetic resonance imaging (MRI).
- Development and employment of MRI techniques to diagnose and monitor injuries and diseases of the central nervous system.
- Mapping of activity in human brain visual systems with MRI.
- Characterization of brain cancer tumor cellularity and vascularity through diffusion and perfusion MRI; development of image processing techniques to help clinicians plan surgery and map out brain function for epilepsy.
- Functional MRI study of mechanism of anesthesia with respect to loss and return of consciousness as studied by electrophysiological and brain imaging methods, and of Alzheimer's disease and drugs of abuse.
- Address engineering challenges in diagnostic imaging to achieve higher sensitivity and specificity to the pathophysiology of various diseases, through of novel hardware and imaging protocols for MRI systems.
    - Metal artifact reduction methods for MRI; quantitative susceptibility mapping in MRI.
- Development of multiband or simultaneous multislice imaging technology.
- In vivo quantification of tissue perfusion using exogenous and endogenous contrast agents coupled with MRI.
- Development of MRI methods to assess brain tumor angiogenesis and invasion.

Credits Required to Graduate

60 credits minimum

Required Courses

BIOE 10222 Ethics and Integrity in Science. *1 credit.*
This course provides the basis for understanding the ethical issues related to basic scientific and medical research, including animal and human subject research, fraud, and misconduct, and governmental, institutional, and researcher responsibilities. Bioethics 10222 is offered during the spring and summer terms only.

BIOE 10444 Research Ethics Discussion Series.
1 credit.
Prerequisite: 10222 Ethics and Integrity in Science.
The course is directed by members of the Bioethics Faculty and provides facilitated discussions of a series of topics in research ethics. Discussions are led by members of the Basic Science faculty and are focused on ethical issues that commonly come up in biomedical research. The course is meant to not only reinforce the basic ethics taught in the online course Ethics and Integrity in Science, which is a prerequisite, but also to explore the gray areas of the individual topics. The intent is to offer students illustrative examples of ethical issues that might arise in their careers, to emphasize the ethical principles that apply in such situations, and the provide practical guidance on how these types of situations should be correctly handled. This course is offered as a discussion series. Students are expected to attend and participate in the discussion. Bioethics 10444 is offered during the spring terms only.

Molecular Biophysics Track

After completing the first year IDP or MSTP curriculum, students will take the following required courses:

BIOP 03223 Electron Spin Resonance. *3 credits.*
The aim of the course is to provide an introduction to the theory and practical applications of modern electron spin resonance (ESR) spectroscopy. Basic ESR theory, biological free radical spectroscopy, relaxation and motional phenomena, spin labeling, and transition metal ESR are among the topics covered.

BIOP 03226 Biophysical Techniques in Biochemistry. *3 credits.*
This course will introduce the basic theory and practical applications of an array of biophysical techniques commonly used in biochemical research. Optical and magnetic spectroscopies, X-ray crystallography, and kinetics techniques are a sampling of the topics covered in this comprehensive course.

BIOP 03290 Biophysics Journal Club. *1 credit.*
A journal article or topic of interest focused on general biophysics topics will be presented and discussed each week, led by a faculty expert. The learning objectives include a broader understanding of how biophysical approaches are applied in biomedical science research, improved critical thinking skills and critical literature assessment, and gaining experience in preparing and delivering oral presentations.

BIOP 03298 Journal Club: EPR. *1 credit.*
EPR Journal Club introduces students to the various aspects of EPR via published studies in the scientific literature. Students present selected papers to the class, along with any introduction to the area of study, and the class critically discusses each paper. Students will encounter aspects of EPR that they may not have previously encountered through either classes or their research, but which may be of value to their doctoral research or future research, teaching, or other careers.

BIOP 03295 Reading and Research. *1-9 credits.*
The course of study for Reading and Research is designed by each student with his/her advisor to focus on readings in literature in the student's field, to build bibliographic resources for the dissertation, and to conduct supervised, independent research.

BIOP 03300 Seminar. *1 credit.*
Weekly invited seminar speakers present their research on Molecular Biophysics and Magnetic Resonance Imaging topics.

BIOP 03399 Doctoral Dissertation. *1-9 credits.*
This course is required for the completion of the PhD degree. The PhD candidate must submit a dissertation based on original research of a high scholarly standard that makes a significant contribution to knowledge in their chosen field.

Magnetic Resonance Imaging Track

After completing the first year NDP or MSTP curriculum, students will take these required courses:

BIOP 03230 Nuclear Magnetic Resonance. *3 credits.*
This course is designed as an introduction to NMR and nuclear MRI. Emphasis will be given to theory and application of modern MRI techniques.

BIOP 03239 Functional MRI Contrast Mechanisms and Applications. *3 credits.*
The use of MRI to evaluate tissue function will be described. The course will be dedicated to discussing functional MRI methods that use both endogenous contrast (labeled water, deoxygenated blood and exogenous (injectable) MR contrast agents to image tissue function. The theory and physiology necessary for understanding the MR contrast mechanisms, together with the practical knowledge necessary for performing the MR experiments, will be discussed. Demonstrations of functional MRI experiments will be included.

BIOP 03295 Reading and Research. *1-9 credits.*
The course of study for Reading and Research is designed by each student with his/her advisor to focus on readings in literature in the student's field, to build bibliographic resources for the dissertation, and to conduct supervised, independent research.

BIOP 03297 Journal Club: MRI. *1 credit.*
Selected papers in theory, practice, and applications of electron and NMR will be read and discussed.

BIOP 03300 Seminar. *1 credit.*
Weekly invited seminar speakers present their research on Molecular Biophysics and Magnetic Resonance Imaging topics.

BIOP 03399 Doctoral Dissertation. *1-9 credits.*
This course is required for the completion of the PhD degree. The PhD candidate must submit a dissertation based on original research of a high scholarly standard that makes a significant contribution to knowledge in their chosen field.

Required Courses as Needed

BIOP 03002 Master's Thesis Continuation. *1-6 credits.*
This is a form of registration available to students who have completed all of the required coursework, including thesis credits but have not yet completed the writing of the Thesis. Continuation status is limited to three consecutive terms following the completion of Thesis credits.

BIOP 03003 Doctoral Dissertation Continuation. *6-9 credits.*
This is a form of registration available to students who have completed all of the required coursework, including dissertation credits but have not yet completed the writing of the Dissertation. Continuation status is limited to three consecutive terms following the completion of Dissertation credits.

BIOP 03299 Master's Thesis. *1-6 credits.*
Students in the Ph.D. degree program who cannot or elect not to complete that program may be allowed to transfer to the Master's program. This transfer must be approved by the student's advisor, the Program Director, the Chair, and the Graduate School. To transfer to the Master's Program, the student must be in good academic standing according to regulations established by the Graduate School

Elective Courses

Molecular Biophysics Track

This track is a component member of the IDP. After completing the first year IDP, students can take the following elective courses:

BIOP 03220 Introduction to Magnetic Resonance. *3 credits.*
The course provides basic knowledge for students who will continue to study ESR or nuclear magnetic resonance (NMR). The material covers MR of the hydrogen and helium atoms, NMR spectra in liquids, basic ESR of radicals in solution, trapped radicals in solids, triplet states, spin relaxation, molecular rate processes, and double resonance. An understanding of matrix elements, eigenvalues, angular momentum, and tensor vector is recommended.

BIOP 03233 Biomolecular NMR of Protein Assemblies: Theory and Applications. *1 credit.*
Solid-state NMR (ssNMR) is a unique technology to study the structure and dynamics of insoluble biomacromolecules in the rigid or semi-rigid forms, such as, membrane proteins, amyloid fibrils, sedimented proteins, and cellular extracts. The course starts with a brief introduction to solution and solid-state NMR spectroscopy with applications ranging from small molecules to macromolecular protein assemblies. We will then work on the NMR spin physics using product operator formalism and average Hamiltonian theory. Basic building blocks of ssNMR experiments consist of polarization transfer between different nuclei. These building blocks will be used to construct triple resonance multi-dimensional experiments for protein analysis. Recent methodological and technological advancements for pushing the limits of sensitivity and resolution will be summarized. Sample conditions and protein dynamics play a significant role in the selection of ssNMR experiments. Several examples from the protein ssNMR literature will be discussed to understand various aspects of sample preparation and NMR probe technology. Example data sets and NMR software (TOPSPIN) will be provided to get hands on experience on data processing.

BIOP 03245 Molecular Modeling and Simulations. *3 credits.*
This course will introduce concepts of advanced molecular modeling and molecular dynamics simulation methods. It will cover topics on protein databases, sequences, protein structure prediction (comparative and de novo, including recent deep-learning algorithms), advanced molecular dynamics simulations, and analysis (electrostatic calculations, enhanced sampling, binding affinities, and integration with experiments). The course will first introduce the concepts and then apply them in weekly hands-on workshops and a final project on a system of the student's choice.

BIOP 03251 Free Radicals in Biology. *3 credits.*
Topics to be discussed include the nature of free radicals; radical initiation, propagation, and termination; free radical reactions of biological interest; and the role of free radicals in physiological and pathological processes.

BIOP 03260 Special Topics in Molecular Biophysics. *3 credits.*
This is an advanced course dealing with special topics including free radicals in biology, spin relaxation, metal ions in biology, X-ray crystallography, and photobiology.

BIOP 03292 Molecular Dynamics Journal Club. *1 credit.*
A journal article or topic of interest focused on molecular modeling and simulations in

structural biology and bioinformatics will be presented by one student and discussed by all each week, led by a faculty expert. The learning objectives include a greater depth of understanding of how molecular dynamics simulations are used in biomedical science research, improved critical thinking skills, critical literature assessment, and gaining experience in preparing and delivering oral presentations.

Magnetic Resonance Imaging Track

BIOP 03238 Magnetic Resonance Imaging. *3 credits.*
This course will provide students with a solid foundation in the basic principles of magnetic resonance imaging (MRI). The focus of the course will be on the basic physical principles underlying the magnetic resonance phenomenon, and how to make an MR image, which will include spatial encoding, pulse sequences, k-space and recent advances in rapid imaging.

BIOP 03240 Fourier Transforms. *3 credits.*
This course provides basic knowledge for students who will continue to study EPR or MRI. Material will cover the theory of Fourier transforms, digital transforms, MRI image generation, Fourier image reconstruction, and digital signal processing. An understanding of calculus and matrix algebra is recommended.

BIOP 03296 NMR Journal Club. *1 credit.*
A journal article or topic of interest focused on NMR spectroscopy of complex assemblies will be presented by one student and discussed by all each week, led by a faculty expert. The learning objectives include a greater depth of understanding of how NMR spectroscopy is used in biomedical science research, improved critical thinking skills and critical literature assessment, and gaining experience in preparing and delivering oral presentations.