Illinois Mathematics and Science Academy®

igniting and nurturing creative, ethical scientific minds that advance the human condition

Comprehensive Course Syllabus

Modern Physics

Course Description:
Modern Physics is a one-semester course covering major concepts of twentieth-century physics. The course focuses on special relativity, nonrelativistic quantum mechanics, and elementary particle physics. The class includes a large-scale research project and a presentation to physicists at the Fermi National Accelerator Laboratory.

Instructor:

- Peter Dong
- Office: B117
- Phone: (630) 907-5476
- e-mail: pdong@imsa.edu

Meeting Days, Time and Room(s):
A, B, C, and D days, 10:00 a.m. and 2:20, room B101

Text(s) / Materials:
Some of the material is covered in David Morin's *Relativity for the Enthusiastic Beginner* (which should be arriving soon). Notes and various study aids are available on Moodle. Most material is disseminated electronically, and students are expected to have their computers during class.

Student Learning Objectives:
This course aims to enhance student learning and understanding in special relativity, simple nonrelativistic quantum mechanics, and basic elementary particle physics. This requires exposing and correcting unconscious misconceptions about the nature of space and time, absolute motion, simultaneity, gravity, geometry, position, observation, determinism, probability, causality, the nature of matter, force, nothingness, the role of mathematics, and virtually everything else that most people believe instinctively—and then replacing these misconceptions with a deeper understanding of the behavior of the universe based on experiment. By the end of the course, students should be able to:

- Consider the reference frame of the events in a problem, determine whether it is necessary to consider relativistic corrections, and perform the proper calculations if necessary;
- Understand the importance of eigenstates of quantum-mechanical operators, calculate the probabilities of discrete outcomes in simple systems, and express the effect of measurement on a wavefunction in terms of eigenstates of noncommuting operators;

- Explain the basic interactions of elementary particles described in the Standard Model and describe their behavior with Feynman diagrams; and
- Know part of the process involved in designing and carrying out a particle physics experiment and presenting the results to other scientists.

I.A. Students expected to demonstrate automaticity in skills, concepts, and processes that enable complex thought by:

- Completing assigned problem sets and
- Demonstrating competence on quizzes and exams.

I.B. Students expected to construct questions which further understanding, forge connections and deepen meaning by:

- Analyzing conceptual problems to draw conclusions,
- Discussing problems with peers,
- Modeling systems supported by observations, and
- Performing independent research on the project.

I.C. Students expected to precisely observe phenomena and accurately record findings through:

- Analysis of data in laboratory activities.

I.D. Students expected to evaluate the soundness and relevance of information and reasoning by:

- Drawing conclusions from experimental data,
- Evaluating the soundness of models in light of new information, and
- Performing independent research on the project.

II.A. Students identify unexamined personal assumptions and misconceptions that impede and skew inquiry by:

- Discussing and confronting logical and experimental contradictions that arising from implicit assumptions in scientific thought.

III.A. Students use appropriate technologies as extensions of the mind through use of tablets for completing work and referencing resources by:

- Using computers for information acquisition and analysis of modeled behavior and
- Using computers to analyze data for the project.

III.B. Students recognize, pursue, and explain substantive connections within and among areas of knowledge by:

- Connecting previous concepts in physics to current concepts through problem sets,
- Applying content knowledge to alternative scenarios or new problems on tests, and
- Forming connections between different parts of an experiment in the final project.

III.C. Students recreate beautiful conceptions that give coherence to structures of thought by:

- Exploring the development of models (mathematical and conceptual) and
- Understanding surprising or counterintuitive results that change our view of the universe.

IV.A. Students construct and support judgments based on evidence by:

- Drawing appropriate conclusions from experimental data.

IV.B. Students write and speak with power, economy, and elegance by:

- Explaining problems and asking questions during group discussions,
- Showing work to clearly communicate problem solutions,
- Creating slides to rapidly communicate information to others, and
- Giving a presentation to a Fermilab audience for the project.

IV.C. Students identify and characterize composing elements of systems by:

- Breaking down a complicated problem in order to solve it and
- Understanding connections and relationships between elements of the project.

V.A. Students identify, understand, and accept the rights and responsibilities of belonging to a diverse community by:

- Learning to cooperate as physicists working on a large-scale experiment.

Teaching and Learning Methodology and Philosophy:
Because modern physics lends itself to few classroom experiments, this course is not centered on laboratory activities like many other physics classes. Because the most significant advances in twentieth-century physics were conceptual, rather than experimental, this class focuses on the development of the conceptual framework needed to think about modern physics questions. An emphasis on conceptual, rather than purely computational, problems on the homework and tests facilitates the construction of this framework.

The project makes the learning process concrete and authentic, as students collaborate on a semester-long project even as they are assessed individually. Students will design an next-generation accelerator and particle detector, with each students having a specific role, and they will present their designs to physicists at Fermilab. This allows them to experience part of what it is like to design a particle physics experiment.

The conceptual framework is essential to doing well in the class, which makes the class competency-driven. Activities such as practice worksheets contribute to the inquiry-based and problem-centered nature of the class, and the project connects classroom material to current particle physics experiments, allowing students to share in the experience of conducting and presenting physics research.

Student Expectations:

Students are expected to:

- Arrive to class promptly, sufficiently rested, and with their computers:
  - A student arriving more than a minute after class begins, according to IMSA's central clock, will be marked tardy; a student arriving more than five minutes late will be marked absent;
- Take notes, as necessary, in class every day,
- Participate in class discussions and activities, and
- Study outside of class, individually or in groups, to understand the material, and ask questions when needed—
  - Most students will find it impossible to understand the material without consulting the instructor or other students outside class.

Assessment Practices, Procedures, and Processes:
This class has daily ungraded homework to help students understand the material properly. Formal assessment of relativity and quantum mechanics is given by biweekly quizzes. There are also two large 90-minute night tests given at the end of each major unit: relativity and quantum mechanics. The project will have assignments integrated into the course, with biweekly major in-class assessments, culminating in the final presentation at Fermilab in November.

Grading will be determined by weighting the assessments as follows: 40% quizzes, 20% examinations, 40% project.

Grades will be assigned on the usual scale:
[90%, 100%] = A   [80%, 90%) = B   [70%, 80%) = C   [0%,70%) = D

The grade scales occasionally will need adjustment so that the letter grades properly reflect the performance of the students in the class. Such adjustment, if it occurs, will only raise grades, not lower them (for example, it could lower the A cutoff to 89%, but would not raise the A cutoff to 91%). Adjustment, if it occurs, will be applied to the class as a whole and not to individual grades, and will be solely at the instructor's discretion.

The Fermilab field trip is an integral and vital requirement of this class, since it includes the final presentation for the final project. Students are expected to take pains to clear up conflicts in advance so that they are able to go at that time.

Sequence of Topics and Activities:
(Dates and topics subject to change)

Week 1 (August 22 – August 25): Galilean relativity, four-vectors, special relativity, time dilation.
Week 2 (August 8 – September 1): Length contraction, quiz on time dilation and length contraction, Lorentz transformations, the twin paradox.
Week 3 (September 5 – September 8): Velocity transformation, quiz on Lorentz transformations, light.

Week 4 (September 11 – September 15): Energy, momentum, mass, invariance, inner products.

Week 5 (September 18 – September 22): The space-time interval, quiz on relativistic kinematics, particle acceleration, accelerator design.

Week 6 (September 25 – September 29): Luminosity, Čerenkov radiation, accelerator project due, train paradox, pole vaulter paradox, simple general relativity.

Week 7 (October 2 – October 5): Redemption quiz, tracking, ionization, motion in a magnetic field.

October 4: Relativity exam

Week 8 (October 10 – October 13): Pseudorapidity, tracking project due, the Standard Model

Week 9 (October 16 – October 20): Feynman diagrams, quantum electrodynamics, quantum chromodynamics, weak interactions, the CKM matrix, hadronization, color

Week 10 (October 23 – October 27): Quiz on Feynman diagrams. Dirac notation, calorimetry

Week 11 (October 30 – November 3): Calorimeter project due, interference, blackbody radiation, the photoelectric effect, wave-particle duality, deBroglie wavelength

Week 12 (November 6 – November 10): Muon detector project due, the formalism of quantum mechanics, commutation, the Heisenberg uncertainty principle

Week 13 (November 13 – November 17): Vote on calorimeter design, assign final detector design groups.

Week 14 (November 14 – November 18): Quiz on the formalism of quantum mechanics, voting on detector, angular momentum, spin, quantum statistics

Week 15 (November 20 – November 21): Prepare final PowerPoint slides.

November 27: Fermilab trip and detector presentation

Week 16 (November 27 – December 1): The Stern-Gerlach experiment, quiz on angular momentum and statistics, entanglement, tunneling.

Week 17 (December 4 – December 8): Redemption quiz, energy levels, radioactivity

December 6: Quantum mechanics exam

Week 18 (December 11 – December 15): Cross section, resonance, algorithms, virtual particles

Week 19 (December 18 – December 19): Nuclear weapons, dark matter and dark energy

Final Exam (not yet scheduled)