To:	Our colleagues
From:	Curriculum committee
Subject:	Undergraduate majors curriculum
Date:	June 1, 2006

To understand, and hopefully, appreciate the attached draft curriculum for physics majors at the University of Washington, it may be helpful first to summarize the approach employed by the Curriculum Committee. After spending the autumn quarter hearing from many people (including the chairs of other teaching-related committees) about the overall status of curricular issues in the Department at all levels, the Committee decided to focus for the remainder of the year on the Undergraduate Majors curriculum. We viewed our charge as first and foremost to "think out of the box," *i.e.*, to try to define a vision for an "ideal" undergraduate physics curriculum, largely ignoring practical issues in the first pass, and focusing instead on trying to form a consensus about what we'd like our curriculum to look like in the future.

It is essential to recognize that this constitutes a multi-dimensional problem and that any discussion of the undergraduate majors' curriculum must address a broad array of issues. Our concerns involve both thematic issues and skills issues. Our sense is that the features that distinguish a BS in physics from, say, a BSE in mechanical engineering include an understanding of the broad underlying (physics) principles, an ability to use this understanding to develop simple first-approximations models of a variety of physical systems, an ability to perform straightforward order-of-magnitude estimates of how a system should behave, an ability to teach oneself more as needed, plus the more conventional ability to describe a physical system in terms of second order differential equations with boundary conditions that can be solved quantitatively. We feel these skills are essential for those going directly to industry and for those continuing their education, either in physics or in allied fields. At the same time, a BS in physics should imply some understanding of physics as a living subject with vital frontiers. Our goal is to develop a curriculum that allows us to convey these qualitative and quantitative skills in the context of courses that introduce our students to the important physics concepts of the 19th, 20th and 21st centuries.

We believe that we must actively engage our students in understanding and appreciating connections between different areas of physics (and other sciences), applying basic physical principles in diverse settings, and developing skill with order-of-magnitude estimates and physical reasoning, throughout the curriculum. One can, of course, use many different applications as examples for discussing physical principles, or developing analytical and calculational skills. But where possible, we believe that it is desirable to use important themes of current interest as a vehicle for conveying physical principles and developing skills, particularly estimates and physical reasoning, while simultaneously conveying an appreciation that physics did not stop 50+ years ago. With this in mind, we are suggesting classes which would introduce students to the Standard Model (with an emphasis on using simple estimates and symmetries to understand issues involved in current and upcoming experiments), use physics of the early universe as an arena in which to discuss statistical physics and basic kinetics, and incorporate substantially more condensed matter physics into the junior year. We also hope to enhance our students' experiences in the laboratory. To provide some level of broadening of the undergraduate curriculum, while maintaining essentially the same number of courses/instructors, we hope to achieve some increased "efficiency" through a more detailed description of that curriculum. As the intellectual interconnections between the various courses become clear, we expect to observe less duplication and unnecessary repetition (although some repetition of essential concepts is, of course, appropriate).

We believe that the broad based curriculum laid out in the following pages is a useful first step towards these goals. We have attempted to be detailed enough that discussions over the summer can lead to a useful level of convergence on both the overall goals and the specific details. We encourage you to consider not only the roles and contents of individual courses but also to pay special attention to the implied correlations. We hope you will consider the broad issues, including your sense of what constitutes a suitable curriculum for this century. We seek input especially on some challenging questions we have not yet fully addressed. How can we best address the needs of the wide variety of students we currently see in our courses? While some are clearly graduate school bound and need to be prepared for the GRE, others are here because they were not accepted into mechanical engineering. How do we address these differing needs and motivations? Is the current model of a broad curriculum with quite low requirements the best choice? Would it be more effective to offer a range of degrees, or tracks, as some departments do? Which of the following courses should be optional and which required? As you will notice, we make assumptions about the content of the introductory (first year) physics course that are distinct from what is currently covered in Physics 12X. These assumptions have implications both for the preparation of students entering the program (*e.g.*, transfer students) and for the overall introductory physics sequence that have not yet been addressed.

The following draft proposal is comprised of:

- an introductory description of the underlying goals and assumptions;
- a table of the proposed curriculum past the introductory sequence;
- individual detailed descriptions of the courses;
- a summary of the changes from the current curriculum.

The individual course descriptions contain a statement of course goals, an approximate weekly syllabus, prerequisites and assumed preparation (this is meant to be used to see how the student's preparation evolves in detail and how the courses are interconnected), possible textbook choices (to provide a sense of the intended level), and in many cases suggestions of possible applications (which could be homework examples) to help convey a sense of the envisioned course content.

This document is definitely a "work-in-progress" with which we hope you will help us. Our expectation is that informal discussions involving all faculty will occur over the summer. Everyone is encouraged to address questions and comments to the members of the Committee. We hope that this process will culminate in a open discussion at a dedicated faculty meeting in the autumn when we can decide how to proceed.

In summary, points clearly needing further discussion include:

Which courses are required for a degree in physics?
Are minimum grade requirements (> 2.0) appropriate in some 2nd year courses?
Should we define different degrees or tracks?
Associated changes in the introductory sequence.

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Physics Majors Courses

Goals:

Convey understanding of physics as a living subject, including some appreciation of current frontiers, open questions, and status of confrontations between theory and experiment.

Help students appreciate the inter-connected nature of physics by emphasizing broadly applicable concepts and connections between different subfields.

Help students acquire facility with order-of-magnitude estimates and physical reasoning.

Where possible, emphasize applications of basic formalism to applications of current interest.

Make efficient use of our limited personnel and physical resources while improving, where possible, the breadth of our curriculum.

These goals are viewed as important for all majors, regardless of their future plans. It is important to retain a flexible program, which accommodates a variety of students, including many double majors, with varied career goals. The required (new) courses for a degree are still to be decided.

Assumptions:

First year physics for prospective majors will include basic thermal physics (including second law and entropy), basic relativity (including simultaneity, spacetime diagrams, and relativistic energy and momentum), and basic quantum concepts (matter waves and de Broglie wavelength, superposition and interference).

Suggested Courses:

	Autumn	Winter	Spring
Year 2:	Math Methods I Statistical Physics Electronics Lab	Math Methods II Quantum Dynamics I Experimental Physics I Intro Computational Phys	Classical Dynamics Std. Model & Beyond Experimental Physics II
Year 3:	Electromagnetism Quantum Dynamics II	Kinetics & Early Universe Quantum Dynamics III	Macroscopic E&M Condensed Matter Optics Lab
Year 4:	Modern Physics Lab I Senior Seminar I Atomic & Molecular Appl. of Computers	Modern Physics Lab II Senior Seminar II Biological Physics Relativity & Gravitation	Modern Physics Lab III Senior Seminar III Nuclear & Particle/QED Intro String Theory

Descriptions of the envisioned content of these courses is presented below. Once again, which courses should be required for a degree is an issue which has not yet been addressed.

Further possibilities:

Possible additional offerings include Computational Physics; Scaling, Universality, and Critical Phenomena; Advanced Mechanics; and Quantum Information. These suggestions are not fully developed, and will obviously be limited by available resources and both faculty and student interest. But brief sketches of these possibilities are also included below.

Mathematical Methods of Physics I (3 credits, 2nd year)

Mathematical techniques essential for the formulation and analysis of physical theories.

Goals:

Acquire familiarity with mathematical techniques essential to physics. Examine a variety applications including damped driven oscillators and particle motion in potentials.

Possible Weekly Topics:

Infinite series
Complex numbers
Mechanics and ordinary differential equations
Driven systems: Fourier series, Fourier and Laplace transforms
Green's functions, delta functions
Basis sets in function spaces
Basic complex analysis
Contour integrals, inverting Laplace transforms

Assumes:

Facility with algebra, standard elementary functions, and calculus.
Understanding of Newton's laws and potential energy.

Prerequisites: First year physics.

Corequisite: Math 308

Possible Text: M. Boas, *Methods of Mathematical Physics*

Some Potential Applications:

Driven harmonic oscillators
Linear circuits
Will introduce and use some numerical methods as in Mathematica.

Mathematical Methods of Physics II (3 credits, 2nd year)

Mathematical techniques essential for the formulation and analysis of physical theories.

Goals:

Acquire familiarity with mathematical techniques essential to physics. Examine a variety applications including constrained mechanical systems, and oscillating strings and membranes.

Possible Weekly Topics:

Linear analysis: vector spaces, matrices, determinants
Linear analysis: eigenvalues and eigenvectors
Coordinate transformations & basic group theory: Orthogonal, Lorentz and unitary transformations
Review of vector calculus: gradients, curls, line integrals, including Maxwell's equations in differential form
Intro to calculus of variations and Lagrangian dynamics
Series solutions of differential equations, Legendre & Bessel functions
Linear partial differential equations, including Fourier analysis and Green's functions for wave equation, dispersion of wave packets

Assumes:

Prior exposure to linear algebra.

Prerequisites: Math Methods I, Math 308 (matrix algebra)

Possible Text: M. Boas, *Methods of Mathematical Physics*

Some Potential Applications:

Electrostatic (and other) boundary value problems in 3D
Constrained mechanical systems
More numerical/computer exercises

Classical Dynamics and Mathematical Physics (3 credits, 2nd year)

Newtonian and Lagrangian dynamics, including an introduction to chaotic systems.

Goals:

Acquire familiarity with variational formulations of classical dynamics. Explore a variety of applications including orbital dynamics, constrained systems, rigid body motion, and chaotic systems.

Possible Weekly Topics:

Nonlinear oscillators: flows in phase space, Liouville's theorem
Introduction to chaos
Lagrangian dynamics: constrained motion, forces of constraint
Lagrangian dynamics: generalized coordinates, symmetries and conserved quantities
Hamiltonian dynamics: Hamilton's equations
Newtonian dynamics: central forces, orbits, scattering
Newtonian dynamics: non-inertial reference frames, Foucault pendulum
Rigid body motion, moment of inertia tensor, angular momentum, tops
Coupled oscillators and continuous systems
Fluid dynamics

Assumes: Basic understanding of Newtonian dynamics and coordinate transformations. Familiarity with ordinary and partial differential equations.

Prerequisite: Math Methods II

Possible Text: Thorton & Marion, *Classical Dynamics of Particles and Systems*

Some Potential Applications:

Perturbative, fully numerical studies of damped, driven oscillators, observing chaos
Parametric resonance
Orbital dynamics, perturbations of orbits
Relativistic particle dynamics

Statistical Physics (3 credits, 2nd year)

Thermodynamics and basic statistical mechanics.

Goals:

Understand the basic principles of thermodynamics and statistical mechanics, including applications to heat engines, blackbody radiation, phase transitions, and cooling near absolute zero.

Possible Weekly Topics:

Equilibrium, energy, heat conduction, viscosity
Second law, multiplicity, entropy in gases, Gibbs paradox
Entropy and heat, mechanical and diffusive equilibrium
Engines and refrigerators, Carnot and other cycles
Free energies, phase diagrams, Clausius-Clapeyron relation
Boltzmann statistics, partition functions, distribution functions
Quantum statistics, density of states, blackbody radiation
Approach to absolute zero and third law

Assumes:

Previous introduction to basic thermo, microstates & macrostates, entropy, ideal gases, Maxwell-Boltzmann distribution

Possible Texts:

D. V. Schroeder, *An Introduction to Thermal Physics*
R. Baierlein, *Thermal Physics*

Some Potential Applications:

Evaporative cooling in atomic gases
Cooling via adiabatic demagnetization

Electronics Lab (3 credits, 2nd year)

An introduction to practical electronics emphasizing physical measurement applications.

Goals:

Students will learn to design and use electronics for tasks such as amplification, filtering, and signal level discrimination, plus bit storage, counting and other digital logic operations. Applications include opto-electronics, light production and detection, as well as the use of modern oscilloscopes, transmission lines, and other instrumentation. The course emphasizes both techniques of measurement using electronics and the physics governing the devices themselves.

Possible Weekly Topics:

Voltage, current, power, resistors, capacitors
LC resonances, complex impedance, diodes, power supplies, transmission lines
Bipolar transistor circuits: emitter follower, transistor current gain, etc.
The operational amplifier, basic feedback networks
More op-amp techniques (*e.g.*, sample-and-hold, active filter)
Digital logic, building an FET logic gate, multiplexors, flip-flops
Transducers and their amplifiers: photodiodes, thermocouples, piezo-electrics, etc.
Radio-frequency techniques, oscillators and modulation, mixers, heterodyne technique.

Assumes: Some concurrent study of complex numbers (*e.g.*, in Math Methods I)

Prerequisites: 1st year physics

Possible Texts:

Horowitz and Hill, *The Art of Electronics*
Robert Pease, *Analog Circuit Design: Art, Science, and Personalities*

Experimental Physics I (1 credit, 2nd year)

Data acquisition and analysis using experiments illustrating fundamental phenomena.

This is envisioned as an adjunct to the second year Quantum I class, requiring a relatively modest amount of student time.

Goals:

Perform two, flexibly scheduled, experiments per quarter illustrating quantum phenomena under discussion in Quantum I. Develop experience with proper data analysis and presentation.

Possible Experiments:

NMR (continuous and pulsed). Analysis of unknown material. Produce writeup with explanation of physics in style suitable for popular press (NYT or Sci Am).

Properties of semiconductors?

STM of graphite?

Experimental Physics II (1 credit, 2nd year)

Data acquisition and analysis using experiments illustrating fundamental phenomena.

This is envisioned as an adjunct to the second year classes Standard Model and Classical Dynamics, requiring a relatively modest amount of student time.

Goals:

Perform two, flexibly scheduled, experiments per quarter illustrating phenomena under discussion in associated lecture courses. Develop experience with proper data analysis and presentation.

Possible Experiments:

Muon lifetime. Full data analysis including background and systematics.

Muon spin precession. Design target, magnet, estimate or simulate result, write proposal.

Driven pendulum. Produce Poincaré maps showing regular and chaotic regions.

Introduction to Computational Physics (3 credits, 2nd year)

Mathematica-based introduction to computational techniques of wide utility in physics.

Goals:
Built skills in computational problem solving.

Current Topics:
Expressions, lists, functions, iterators and variables
Symbolic manipulation, functional programming, graphics, curve-fitting
Numerical solutions of differential equations, visualizing fields, multipole moments
Graphics and animation: iterative maps and period-doubling
Random walks and partial differential equations
Fractals and recursion
Symmetry, crystals and quasicrystals
Symbolic manipulation, perturbations, waves, eigenfunctions
Fourier transforms: algorithms, differential equations, and graphics
Algorithms, sorting, and decision trees

Assumes: No prior programming experience.

Prerequisites: Math Methods I

Texts:
B. Torrence and E. Torrence, *The Student's Introduction to Mathematica: A Handbook for Precalculus, Calculus, and Linear Algebra*,
H. Ruskeepaa, *Mathematica Navigator: Mathematics, Statistics, and Graphics*

Selected Applications:
Distance traveled by projectile on uneven surface
Shape of chair suspended from two ends
Forced oscillators and optimization: playground swings
Visualizing electric field from arbitrary set of point charges
Visualizing chaos
Numerical solution of Laplace's equation
Two-point resistance in lattice of resistors
Random accretion of particles onto surface
Penrose tilings and related quasicrystals
Harmonic oscillators with anharmonic perturbations
Visualizing quantum dynamics of particle in potential energy well
Fourier transform power spectra and voices
FFTs
Complex computing from neural networks

The Standard Model and Beyond (3 credits, 2nd year)

An introduction to the fundamental constituents of matter and their interactions, highlighting current and upcoming experiments probing physics beyond the standard model.

Goals:

Learn about the "building block" aspects of the current standard model and the key experimental evidence on which it is based, as well as various upcoming and proposed experiments probing possible extensions beyond the standard model. Students will gain extensive experience making order of magnitude estimates relevant for interpreting and/or judging the feasibility of a variety of modern physics experiments.

Possible Weekly Topics:

Known particles (atoms, electrons, protons, neutrons, antimatter)
Quarks and quark model of hadrons
EM processes & charged particle interactions with matter
Weak interactions & neutrinos
Symmetries & conservation laws. Limits on baryon/charge/Lorentz symmetry
Force carriers (photons, gluons, W & Z, Higgs)
Neutrino masses & oscillation, Super-K, SNO, Katrin, Majorana, T2K, ...
Dark matter. Indirect evidence, candidates, possible direct detection
Collider physics. Accelerators, detectors, typical events, rare events
Non-constant constants of nature?

Assumes:

Previous introduction to particle/wave duality, significance of de Broglie wavelength, electron spin, two state systems, basic special relativity.

Prerequisite: Quantum I

Possible Texts:

Portions of D. Griffiths, *Introduction to Elementary Particles*, or
A. Garcia, *S*ubatomic Physics (forthcoming).

Some Potential Applications:

average electron speed in light atoms & size of relativistic corrections
muonic atoms (scaling, dimensional analysis)
mass versus strangeness: Gell-mann Okubo
decays of light mesons (what's strong, weak, EM, or impossible?)
GKZ cutoff in cosmic rays
Lorentz violation: possibility of $p \to p + \gamma$, limits from observation of UHE cosmic rays
kaons & two-state QM: K_L & K_S, mass eigenstates/weak eigenstates
estimate neutrino mean free path in earth, sun
dark matter detection: estimate requirements for cryogenic detectors
basic scaling of linear versus circular accelerators
relations between cross sections, luminosity, & event rates
b decays, time-dilation & displaced vertices in collider experiments.
invariant mass plots

Quantum Dynamics I (4 credits, 2nd year)

Principles and applications of quantum mechanics.

Goals:

Learn basic principles of quantum mechanics and fundamental quantum phenomena including spin dynamics, entanglement, and tunneling.

Possible Weekly Topics:

Review polarized light, photons, force & torque on magnetic moments
spin-1/2, Stern-Gerlach
State vectors, probability, operators
Eigenstates, expectation values, basic postulates of QM
Time development, Schrodinger equation, spin precession
Rabi resonance, magnetic resonance
Two spins, entangled states, EPR
One-dimensional Schrodinger equation, time dependence, wells & barriers
tunneling, delta function wells
double wells, ammonia

Assumes:

First year physics covers basic quantum concepts, including de Broglie wavelengths, spin, and superposition

Co-requisite: Math Methods II

Possible Text: D. Griffiths, *Introduction to Quantum Mechanics*

Some Potential Applications:

Quantum cryptography
NMR and MRI
STM

Quantum Dynamics II (4 credits, 3rd year)

Principles and applications of quantum mechanics.

Goals:

Learn basic principles and calculational techniques of quantum mechanics. Understand fundamental quantum phenomena including energy levels in hydrogenic atoms and periodic potentials.

Possible Weekly Topics:

1-D QM review, wave packets
Momentum representation, finite square wells, barriers
Simple harmonic oscillator, raising and lowering operators
Commutation relations and uncertainty principle
Schrodinger equation in spherical coordinates
Hydrogenic atoms, radial equation
Angular momentum
Adding angular momentum, Clebsch-Gordon coefficients
Two particle systems
Periodic potentials

Prerequisite: Quantum I

Possible Text: D. Griffiths, *Introduction to Quantum Mechanics*

Some Potential Applications:

Isospin, selection rules in particle reactions
Band structure, metals vs. semiconductors, etc.
Diatomic molecules: rotational and vibrational bands
Reflection & refraction from potential step, Snell's law for atoms
Landau levels

Quantum Dynamics III (4 credits, 3rd year)

Principles and applications of quantum mechanics.

Goals:

Learn basic principles and calculational techniques of quantum mechanics. Understand fundamental quantum phenomena including scattering, decoherence and approach to the classical limit.

Possible Weekly Topics:

Time-independent perturbation theory, non-degenerate
Degenerate perturbation theory
Fine and hyperfine structure
Variational principle
Time-dependent perturbations, Fermi's golden rule
Potential scattering, identical particle scattering
Quasiclassical regime, WKB techniques
Radiation, lasers
Quantum statistics
Decoherence and real measurements

Prerequisite: Quantum II

Possible Text: D. Griffiths, *Introduction to Quantum Mechanics*

Some Possible Applications:

Stark and Zeeman shifts
Neutron star crusts: atoms in very strong magnetic fields
(In)feasibility of cold fusion
Quantum dots and Coulomb blockade
Lasers
Bose condensation
Rydberg states

Electromagnetism and Radiation (4 credits, 3rd year)

Theory and applications of classical electromagnetism, focusing on electromagnetic fields in vacuum and radiation from moving charges.

Goals:

Understand Maxwell equations, including their relativistically covariant formulation. Understand basic electromagnetic phenomena such as EM waves and radiation from moving charges. Use electromagnetic theory to understand polarization, light scattering, synchrotron radiation and other EM phenomena.

Possible Weekly Topics:

Review of Maxwell's equations
Electromagnetic plane waves, polarization
Green's functions, retarded potentials
Static & quasi-static fields from localized sources
Scattering from free electrons, atoms
Fields of moving charge, Lorentz covariance
Covariant formulation
Radiation from relativistic motion
Synchrotron radiation

Assumes:

Previous exposure to Maxwell's equations in differential form

Prerequisite: Math. Methods II.

Possible Text: D. Griffiths, *Introduction to Electrodynamics*

Some Potential Applications:

Interpreting synchrotron radiation from astrophysical sources
Raleigh scattering, blue skies
Intensity vs. photon numbers, limits of classical description

Kinetics and the Early Universe (3 credits, 3rd year)

Statistical physics and kinetic theory applied to gaseous or plasma phases of matter, with applications to the physics of the early universe.

Goals:

Learn basic aspects of non-equilibrium statistical mechanics and kinetic theory as applied to gases and plasmas. Use basic physical principles to understand properties of matter in the early universe, and possible observable consequences.

Possible Weekly Topics:

Ideal bose & fermi gases, equations of state, thermal photon & neutrino radiation
Plasmas, screening, conductivity
Phase space distributions, free streaming, Boltzmann equation
Adiabatic expansion & cooling, expansion rate versus scattering rate
(When are interactions important? What if basic constituents change?)
Cosmic expansion, observed baryon/photon ratio
Thermal history of the early universe (quark-gluon plasma, hadron gas, nucleosysthesis, neutrino decoupling, recombination and photon decoupling)
Nucleosysthesis signatures: He/H ratio
CMB radiation, spectrum, fluctuations, acoustic oscillations

Assumes:

Previous exposure to quantum statistics, basic equilibrium thermodynamics and statistical mechanics, meaning of cross-sections & collision rates, constituents and basic interactions of matter.

Prerequisites: Statistical Physics, Standard Model

Possible Texts: *(Needs more investigation)*

Portions of A. Liddle, *An Introduction to Modern Cosmology*; S. Dodelson, *Modern Cosmology*; Kolb and Turner, *The Early Universe*; J. Bernstein, L. Brown, G. Feinberg, *Cosmological helium production simplified*, RMP (1989).

Some Potential Applications:

Equations of state, relativistic and non-relativistic matter
Photon propagation in plasmas vs. neutral fluids
Friedmann equation, expansion of radiation versus NR matter
First order phase transitions (t versus T, homogeneous nucleation)
Antimatter annihilation — when? how much survives?
Collisionless Boltzmann equation in expanding system
Origins of CMB polarization

Macroscopic E&M (3 credits?, 3rd year)

Macroscopic electromagnetism in material bodies.

Goals:

Understand macroscopic electrodynamics, including dielectric, magnetic and optical properties of materials.

Possible Weekly Topics:

Macroscopic fields, electric polarization, linear response, electric susceptibility
Dielectric screening, energy of charged dielectrics
Magnetic response, magnetic polarizability
Ferromagnetism
EM waves in materials, index of refraction
Frequency dependent response, dispersion, Kramers-Kronig, Kubo relations
Wave guides and optical fibers
"Left-handed" materials

Assumes:

Familiarity with electrodynamics in vacuum

Prerequisites: Math. Methods II

Possible Text: D. Griffiths, *Introduction to Electrodynamics*

Some Potential Applications:

Method of images
Force on dielectric in inhomogeneous field
Energy loss and attenuation in media
Reflection & refraction at interfaces
Skin depth of conductors
Rectangular & cylindrical waveguides
Cavities

Condensed Matter Physics (3 credits, 3rd year)

Introduction to condensed matter physics.

Goals:

Understand how basic properties of various forms of matter emerge from the dynamics of the underlying constituents (atoms and electrons). Learn about novel phases of matter such as superconductivity and quantum Hall liquids.

Possible Weekly Topics:

Crystal structure and methods of determination
Lattice dynamics, phonon spectra, thermal properties of harmonic crystals
Free electrons: classical and quantum
Electron energy levels in a crystal: weak potential and tight-binding limits
Classification of solids: metals, semiconductors, and insulators
Semiconductors and impurity states
Electron dynamics and transport
Electronic states in magnetic field and the quantum Hall effect
Magnetism
Superconductivity

Assumes:

Familiarity with basic quantum and statistical mechanics, Landau levels, quantum statistics, scattering

Prerequisites: Statistical Physics, Quantum III

Possible Text: C. Kittel, *Introduction to Solid State Physics*

Optics Lab (3 credits, 3rd year)

Exploration of optical phenomena including diffraction, interferometry, holography, and non-linear harmonic generation.

Goals:

Complimenting their formal study of electromagnetism, students will observe and make measurements of linear optical phenomena such as coherence, interference, diffraction, as well as basic non-linear phenomena. Students will also gain experience working with very useful technologies such as lasers and fiber optics.

Possible Weekly Topics:

Velocity of light
Diffraction gratings and spectrometry
The Fabry-Perot interferometer, optical spectrum analysis
The Michelson interferometer: a measurement of n_{air} or "putting physics in one arm"
Fraunhofer and Fresnel diffraction
Polarization, reflection from an air-dielectric interface
Faraday rotation
Optical waveguides, multi- and single-mode fiber optics
Non-linear optics: materials with gain (*e.g.*, Nd:Yag), optical harmonic generation (frequency doubling) crystals
Holography

Prerequisites: Math Methods II, Electromagnetism and Radiation

Possible Texts:

E. Hecht, *Optics*
P. Hobbs, *Building Electro-Optical Systems*

Modern Physics Lab I (3 credits, 4th year)

Experiments in atomic, molecular and optical physics.

Goals:

In this capstone lab course, students will make a variety of measurements in atomic, molecular, and optical physics. The lab focuses on more advanced techniques which build on previous lab experience. Students will also acquire practice in the art of reporting experimental results: error analysis, visual display of quantitative information, and coherent scientific writing.

Possible Weekly Topics:

Review of oscilloscope techniques
Optical spectra of hydrogen and deuterium
The Franck-Hertz effect in mercury and neon
Pulsed NMR
Inversion spectrum of ammonia
Optical pumping in rubidium
Normal and anomalous Zeeman effects in mercury
X-ray spectra of atoms
The Hanle effect
The lock-in detector
Lamb shift in hydrogen
Nonlinear optics (e.g. frequency doubling, parametric down-conversion)

Prerequisites: Electronics Lab, Optics Lab, Quantum III

Possible Texts:

P. Hobbs, *Building Electro-Optical Systems*
D. Budker *et al.*, *Atomic Physics*
A. C. Melissinos and J. Napolitano, *Experiments in Modern Physics*
D. W. Preston and E. R. Deitz, *Art of Experimental Physics*

Modern Physics Lab II (3 credits, 4th year)

Experiments in condensed matter physics.

Goals:

In this capstone lab course, students will make a variety of measurements in condensed matter physics. The lab focuses on more advanced techniques which build on previous lab experience. Students will also acquire practice in the art of reporting experimental results: error analysis, visual display of quantitative information, coherent scientific writing.

Possible Weekly Topics:

Review of oscilloscope techniques
The lock-in detector and techniques
e^- charge determination from Johnson noise and shot noise measurements
Hall effect in conductors and semiconductors
Low temperature superconductivity
Surface plasmon resonance
The Mössbauer effect
Physical adsorption of nitrogen and argon on graphite
Continuous-wave nuclear magnetic resonance (NMR)
Pulsed NMR

Prerequisites: Electronics Lab, Condensed Matter, Quantum III

Possible Text:

A. C. Melissinos and J. Napolitano, *Experiments in Modern Physics*
D. W. Preston and E. R. Deitz, *Art of Experimental Physics*

Modern Physics Lab III (3 credits, 4th year)

Techniques in experimental nuclear and particle physics.

Goals:

In this capstone lab course, students will learn and apply measurements techniques used in nuclear and elementary particle physics. The lab focuses on more advanced techniques which build on previous lab experience. Students will also acquire practice in the art of reporting experimental results: error analysis, visual display of quantitative information, coherent scientific writing.

Possible Topics:

Review of oscilloscope techniques
Laboratory apparatus: multichannel analyzers, NIM units, etc.
Proportional tubes and drift velocity
Compton scattering
Muon lifetime

Prerequisites: Electronics Lab, Std. Model & Beyond, Quantum III

Possible Texts:

W. R. Leo, *Techniques for Nuclear and Particle Experiments*
G. F. Knoll, *Radiation Detection and Measurement*

Applications of Computers to Physical Measurements (3 credits, 4th year)

Introduction to the use of computers and advanced electronics for physical measurement.

Goals:

In this capstone lab course, students will learn and apply techniques involving transducers, computer data acquisition, and data processing to problems involving physical measurement. The lab focuses on more advanced techniques which build on previous lab experience. Students will also acquire practice in the art of reporting experimental results: error analysis, visual display of quantitative information, coherent scientific writing. The class features hands-on application development using an industry-standard environment, such as CVI or LabVIEW.

Possible Topics:

Analog-to-digital and digital-to-analog conversion
Transducers: photodiodes, thermo-couples, piezo-electrics, motors, etc.
Automated acquisition and display of signals, timing
Control of commercial instruments: the GPIB bus and others
Computer-aided feedback control systems: *e.g.*, an oven controller
Digital signal processing, filters, data post-processing, and storage

Prerequisites: Electronics Lab, at least one other advanced lab

Possible Texts:

Bruce Mihura, *LabVIEW for Data Acquisition*
John Moore *et al.*, *Building Scientific Apparatus, 3rd Ed.*
Horowitz and Hill, *The Art of Electronics*
Philip Hobbs, *Building Electro-optical systems*

Relativity and Gravitation (3 credits, 4th year)

An introduction to general relativity.

This is a proposal for a new upgraded relativity course focused on general relativity. It presumes expanded coverage of special relativity in first year physics, with additional practice with special relativity in 'Standard Model & Beyond' and 'Electromagnetism and Radiation'. Note that Hartle's book is aimed at undergraduates.

Goals:

Learn about basic general relativity, including the physics of black holes, gravitation radiation, cosmology and the large scale structure of spacetime.

Possible Weekly Topics:

Minkowski space physics (review of special relativity, stress-energy tensor, perfect fluids)
Tensors and one-forms
Curved manifolds (parallel-transport, geodesics, curvature tensor)
Physics in curved spacetime
Einstein field equations and weak fields
Gravitational radiation
Stars and gravitational collapse
Black holes
Cosmology

Assumes:

Familiarity with basic special relativity including four-vectors and standard index notation.

Prerequisites: Electromagnetism, Classical Dynamics

Possible Texts:

J. Hartle, *Gravity: An Introduction to Einstein's General Relativity*
B. Schutz, *A First Course in General Relativity*

Atomic, Molecular and Optical Physics (3 credits, 4th year)

An introduction to modern atomic, molecular and optical physics.

Goals:

Understand basic atomic and molecular structure, and the interaction of atoms with light.
Explore a variety of current AMO physics topics.

Possible Weekly Topics:

Hydrogen: fine and hyperfine structure, Lamb shift
He atom
Basic molecular structure
Central field, alkali atoms
Radiative transitions, lasers
Parity violation, EDMs
Laser cooling and trapping
Bose condensation, Fermi degeneracy
Ion traps, atomic clocks
Quantum information

Assumes:

Understanding of quantum mechanical perturbation theory and scattering theory.

Prerequisites: Quantum III

Possible Text: C. J. Foot, *Atomic Physics*

Biological Physics (3 credits, 4th year)

An introduction to biological physics.

This is a proposal for a new course.

Goals: Apply basic physical principles to gain understanding of a variety of fundamental biological processes

Possible Weekly Topics: (*Lifted from P. Nelson's book*)

Inside cells
Random walks, friction and molecular diffusion
Life at low Reynolds number
Entropy, free energy, and entropic forces
Chemical forces and self-assembly
Cooperative transitions in macromolecules
Enzymes and molecular machines
Machines in membranes
Nerve impulses, ion channels

Prerequisites: Statistical Physics

Possible Text: P. Nelson, *Biological Physics: Energy, Information, Life*

Introduction to String Theory (3 credits, 4th year)

An introduction to string theory.

This is a proposal for a new course aimed at both advanced undergraduates and beginning graduate students. Zwiebach's book, designed for undergraduates, is an excellent text for this purpose and is in use at other institutions. Andreas Karch has done a trial run with a group of undergraduates (who approached him, asking for such a class) as independent study.

Goals:

Learn about basic string theory, the most promising approach for combining quantum mechanics with general relativity.

Possible Weekly Topics:

Unification, extra dimensional physics
Relativistic point particle and reparameterization invariance
Relativistic strings, classical dynamics
Light-cone strings
Quantized relativistic point particle
Quantized relativistic strings
D-branes and gauge fields
String thermodynamics and black holes
String duality

Assumes:

Familiarity with quantized coupled oscillators,

Prerequisites: Classical Dynamics, Electromagnetism, Quantum II

Possible Text: B. Zwiebach, *A First Course in String Theory*

Quantum Electrodynamics (3 credits, 4th year)

Introduction to quantum electrodynamics, focusing on the status of current comparisons between theory and experiment.

This is an outline of a possible course aimed at both seniors and beginning graduate students, which could replace 422 (Nuclear and Elementary-Particle Physics). The intended focus is not on how to compute diagrams (as in typical basic QFT classes), but rather on the physics which comes out of QED and, in particular, the highest precision predictions and their experimental tests. The April 2006 issue of Physics Today had a nice review of the Maggiore book.

Goals:

Understand basic processes and predictions of quantum electrodynamics, with particular emphasis on high precision tests of the theory and sensitivity to new physics.

Possible Weekly Topics:

Quantized photons and electrons, free fields
Quantized electromagnetic interactions
Elementary processes: Compton scattering, pair production and e^+e^- annihilation, electron-electron and photon-photon scattering
Interaction of radiation with matter
Hydrogenic fine structure and radiative corrections
Positronium
Electron magnetic moment
Muon magnetic moment
Measurements of α and possible time dependence

Assumes:

Understanding of quantum mechanical perturbation theory and scattering theory.

Prerequisites: Standard Model, Quantum III

Possible Text: M. Maggiore, *A Modern Introduction to Quantum Field Theory*

Computational Physics (3+ credits, 4th year)

Project-oriented computational physics.

This is a possible more advanced computational physics course, based on one in use at UCSD developed by Julius Kuti. For more detail, see
http://physics.ucsd.edu/students/courses/winter2006/physics141/ and
http://physics.ucsd.edu/students/courses/spring2005/physics142/

Goals:
Using a variety of standardized software packages, assemble and apply computational physics software to study of non-trivial large-scale classical and quantum dynamical systems.

Possible Projects:
N-body simulations, galaxy formation and dark matter
Quantum Monte Carlo
Fluid dynamics, viscous flows, baseball
Molecular dynamics and lattice Boltzmann gas

Incorporated Topics and Tools:
Restricted three-body problem
Collisionless Boltzmann equation
Feynman path integrals
Navier-Stokes equations
Convection-diffusion
Leapfrog integration
Data visualization: gnuplot, openDX
Random number generators: Mersenne twistor

Prerequisites: Intro Computational Physics, Math Methods and Classical Dynamics, Statistical Physics, Quantum I

Advanced Mechanics (3 credits, 4th year)

Introduction to continuum and fluid mechanics.

This is a sketch of one possibility for an advanced mechanics class, focused on continuum mechanics. Could be made project oriented. If such a class is developed, it should avoid too much overlap with 505.

Goals:

Explore applications of classical dynamics to continuum systems including elasticity and fluids.

Possible Topics:

Motion and deformation of a continuum
Stress and strain tensors
Elasticity
Basic fluid dynamics
Viscous fluids
Solitons
Turbulence and energy cascades
MHD

Prerequisites: Classical Dynamics

Possible Texts: (*needs more investigation*)

Romano, Lancellotta, Marasco, *Continuum Mechanics using Mathematica*
Temam and Miranville, *Mathematical Modeling in Continuum Mechanics*

Scaling, Universality, and Critical Phenomena (3 credits, 4th year)

An introduction to critical phenomena and the renormalization group.

This is a sketch a possibility which could be developed.

Goals:

Learn about critical phenomena. Learn how scaling and the renormalization group may be used to understand the emergence of universality classes and other features of critical phenomena.

Possible Topics:

Phenomenology of phase transitions and critical phenomena
Evidence of universality
Ginzburg-Landau theory
Mean field predictions & failure of mean field theory
Scaling and the renormalization group
Large N models
Dimensional continuation
Soluble $2d$ models
Finite size effects
Critical slowing down

Prerequisites: Statistical Physics

Possible Texts:

N. Goldenfeld, *Lectures on Phase Transitions and the Renormalization Group*
Pfeuty and Tolouse, *Introduction to the Renormalization Group and to Critical Phenomena*

Quantum Information (3 credits, 4th year)

An introduction to quantum information and quantum computing.

This is a sketch a possibility which could be developed.

Goals:

Learn about quantum entanglement, quantum information, and the basic ideas of quantum computing.

Possible Topics:

Decoherence, measurement and environment
Quantum bits
Environment induced decoherence
Quantum entanglement
Quantum operators
Noise
Error correction
Data compression
Entanglement and quantum cryptography
Physical realizations

Prerequisites: Quantum II

Possible Texts: (*needs more investigation*)

M. Le Bellac, *A Short Introduction to Quantum Information and Quantum Computation*;
M. Nielsen and I. Chuang, *Quantum Computation and Quantum Information*;
Ulfig and Heiss, *Fundamentals of Quantum Information: Quantum Computation, Communication, Dechoerence and All That.*

Current Course[1]	**Content goes to:**
224 (Thermal Physics)	Split between 1st year & new 2nd year Statistical Physics
225 (Modern Physics)	Basic concepts in 1st year. Replaced by Quantum I and Std. Model & Beyond in 2nd year.
227/228 (Elementary Math Phys)	*No significant change*
229 (Classical Dynamics)	*No significant change*
231 (Intro Expt Physics)	Experimental Physics I & II, linked to proposed sophomore courses.
232 (Intro Computational Phys)	*No change*
311 (Relativity & Gravitation)	Incorporate basic SR into first year, with further applications in Std. Model and in Electromagnetism. Replace with 400-level Relativity and Gravitation.
315 (Appl. of Modern Phys)	Turn into 2nd year Quantum I.
321/322/323 (E&M)	Replace with Electromagnetism and Radiation and Electrodynamics of Continuous Media (2 qtrs total). Maxwell's equations in differential form and basic electrostatic boundary value problems included in Math Methods II.
324/325 (QM)	Replace with Quantum II & III, building on 2nd year Quantum I.
328 (Stat Phys)	Split between 2nd year Statistical Physics and 3rd year Kinetics and Intro. CM classes.
331 (Optics Lab)	*No change*
334 (Circuits Lab I)	*Update*
335 (Circuits Lab II)	Partly incorporated into Applications of Computers.
421 (Atomic & Molecular)	Slightly updated
422 (Nuclear and Particle)	Replace with QED?
423 (Solid State)	Move into 3rd year Condensed Matter
424 (Math Phys)	Now in 228/229 (or 505).
431/432/433 (Modern Lab)	*No change*
434 (Appl. of Computers)	*Update?*
436 (Nonlinear Dynamics)	*Not currently taught*
485/486/487 (Honors Seminar)	*No change*
494/495/496 (Senior Seminar)	*No change*

[1]Not listed: entry-level, general physics, evening masters, and teacher training courses.