Physics 1020: Introductory Physics I

Text: **College Physics-A Strategic Approach (Knight, Jones and Field)**

Chapter	Title	Sections	Lectures	Notes
1	Representing Motion-Introduction and Mathematical Concepts, Vectors	1 to 6	5.0	
2	Motion In One Dimension	1 to 7	4.0	
3	Motion in Two Dimensions	1 to 8	4.0	
4	Forces and Newton's Laws of Motion	1 to 7	4.0	
5	Applying Newton's Laws	1 to 8	3.0	
6	Circular Motion, Orbits and Gravity	1 to 6	3.0	
7,8*	Rotational Motion, Equilibrium and Elasticity-Torque	7.3,7.4,8.1,8.2	3.0	Torque and Static Equilibrium
9	Momentum	1 to 7	3.0	
10	Energy and Work	1 to 8	4.0	
7	Rotational Motion	1,2,7	2.0	
			Total: 35.0	

LABORATORIES

Normally there will be six laboratory sessions per semester and 3 problem solving sessions held during the laboratory time slot on weeks when no laboratory is scheduled.

	Experiment Title
1	Measurement and Uncertainty
2	Motion in One Dimension
3	Acceleration of Falling Objects
4	Force and Acceleration
5	Impulse and Momentum
6	Equilibrium of a Rigid Body

Physics 1021: Introductory Physics II

Text: **College Physics-A Strategic Approach (Knight, Jones and Field)**

Chapter	Title	Sections	Lectures	Notes
14	Oscillations	1 to 6	5.0	Review Sect 8.3 Hooke's Law
15	Travelling Waves and Sound	1 to 7	5.0	
16	Superposition and Standing Waves	1 to 7	4.0	
13	Fluids	1 to 7	8.0	
20	Electric Forces and Fields	1 to 5	4.0	
21	Electric Potential	1-5	2.0	
22	Current and Resistance	All	2.0	
23	Circuits	All	2.0	
24	Magnetism	1,2,5,6	3.0	
			Total: 35.0	

LABORATORIES

Normally there will be six laboratory sessions per semester and 3 problem solving sessions held during the laboratory time slot on weeks when no laboratory is scheduled.

	Experiment Title
1	Introduction to Simple Harmonic Motion
2	Standing Waves
3	Sound and Resonance
4	Buoyancy
5	Vector Nature of Magnetic Fields
6	Ohm’s Law

Physics 1050: General Physics I – Mechanics

Text: **Young and Freedman, University Physics.**

TOPIC	Chapters From Textbook	Number of Lectures
Introduction	**1.2-1.10**	**2.5**
1.2 Solving Problems in Physics 1.3 Standards and Units 1.4 Using and Converting Units 1.5 Uncertainty and Significant 1.7 Vectors and Vector Additions 1.8 Components of a Vector 1.9 Unit Vectors 1.10 Products of Vectors: The Scalar Product		
Motion Along a Straight Line	**2.1-2.6**	**3.5**
2.1 Displacement/Distance 2.2 Instantaneous Velocity 2.3 Average and Instantaneous Acceleration 2.4 Motion with Constant Acceleration 2.5 Freely Falling Objects 2.6 Velocity and Position by Integration		
Motion in Two or Three Dimensions	**3.1-3.5**	**3.5**
3.1 Position and Velocity Vectors 3.2 The Acceleration Vector 3.3 Projectile Motion 3.4 Motion in a Circle 3.5 Relative Velocity		
Newton’s Laws of Motion	**4.1-4.6**	**2**
4.1 Force and Interactions 4.2 Newton’s First Law 4.3 Newton’s Second Law 4.4 Mass and Weight 4.5 Newton's Third Law 4.6 Free Body Diagrams		
Applying Newton’s Laws	**5.1-5.5**	**3.5**
5.1 Using Newton's First: Particles in Equilibrium 5.2 Using Newton's Second Law: Dynamics of Particles 5.3 Frictional Forces 5.4 Dynamics of Circular Motion 5.5 The Fundamental Forces of Nature		
Work and Kinetic Energy	**6.1-6.4**	**2.5**
6.1 Work 6.2 Kinetic Energy and the Work-Energy Theorem		

6.3 Work and Energy with Varying Forces 6.4 Power		
Potential Energy and Energy Conservation	**7.1-7.5**	**2.5**
7.1 Gravitational Potential Energy 7.2 Elastic Potential Energy 7.3 Conservative and Nonconservative Forces 7.4 Force and Potential Energy 7.5 Energy Diagrams		
Momentum, Impulse, and Collisions	**8.1-8.5**	**3**
8.1 Momentum and Impulse 8.2 Conservation of Momentum 8.3 Momentum Conservation and Collisions 8.4 Elastic Collisions 8.5 Center of Mass		
Rotation of Rigid Bodies	**9.1-9.6**	**2**
9.1 Angular Velocity and Acceleration 9.2 Rotation with Constant Angular Acceleration 9.3 Relating Linear and Angular Kinematics 9.4 Energy in Rotational Motion 9.5 The Parallel-Axis Theorem 9.6 Moment of Inertia Calculations		
Dynamics of Rotational Motion	**10.1-10.7**	**2.5**
10.1 Torque 10.2 Torque and Angular Acceleration for a Rigid Body 10.3 Rigid Body Rotation About a Moving Axis 10.4 Work and Power in Rotational Motion 10.5 Angular Momentum 10.6 Conservation of Angular Momentum 10.7 Gyroscopes and Precession		
Equilibrium and Elasticity	**11.1-11.3**	**1**
11.1 Conditions for Equilibrium 11.2 Center of Gravity 11.3 Solving Rigid-Body Equilibrium Problems		
Gravitation	**13.1-13.5, 13.7**	**2**
13.1 Newton's Law of Gravitation 13.2 Weight 13.3 Gravitational Potential Energy 13.4 The Motion of Satellites 13.5 Kepler's Laws and the Motion of Planets 13.7 Apparent Weight and the Earth's Rotation		
Periodic Motion	**14.1-14.8**	**3.5**
14.1 Described Oscillations 14.2 Simple Harmonic Motion (SHM) 14.3 Energy in Simple Harmonic Motion 14.4 Applications of Simple Harmonic Motion 14.5 The Simple Pendulum 14.6 The Physical Pendulum 14.7 Damped Oscillations		

14.8 Forced Oscillations and Resonance		
Relativity (time permitting)	**37.1-37.9**	?
37.1 Invariance of Physical Laws 37.2 Relativity and Simultaneity 37.3 Relativity of Time Intervals 37.4 Relativity of Length 37.5 The Lorentz Transformation 37.6 The Doppler Effect for Electromagnetic Waves, 37.7 Relativistic Momentum 37.8 Relativistic Work and Energy 37.9 Newtonian Mechanics and Relativity		

Number of lectures = 34
2 lecture for midterms
Total lectures = 36

LABORATORIES

Normally there will be six laboratory sessions per semester and 2-3 problem solving sessions held during the laboratory time slot on weeks when no laboratory is scheduled. Also, normally, within the last few weeks of classes there is a Laboratory Skills Test or Lab Exam (see note on Laboratory Skills Test or Lab Exam, after list of experiments).

Experiment Title

1 Introduction to Measurement and Uncertainty
2 Acceleration of Falling Objects
3 Force and Acceleration
4 Conservation of Energy and Projectile Motion
5 Impulse and Momentum
6 Moment of Inertia

Laboratory Skills Test or Lab Exam:

Using the laboratory skills developed over the course of the semester, students are posed with a problem in which they utilize these skills, on an individual basis, to determine some physical parameter(s) in a laboratory environment.

Physics 1051: General Physics II – Oscillations, Waves, Electromagnetism

In 2020/2021, the Undergraduate Studies Committee worked with Engineering to modify P1051, shifting emphasis on topics from waves and the heavier side of E&M-related integral calculus to circuits. The following lecture schedule reflects the updated suite of topics, and the timing of delivery in S2021.

Schedule based on University Physics with Modern Physics by Young and Freedman, 15th ed.

Lecture number and Topics	**Y&F Sections**
1. Introduction, Review of Simple Harmonic Motion	
2. Types of Mechanical Waves, Periodic Waves	15.1-15.2
3. Mathematical Description of a wave, Speed of a Transverse Wave	15.3-15.4
4. Energy in a Wave Motion, Wave Interference, Boundary Conditions, and Superpositions	15.5-15.6
5. Standing Waves on a String, Normal Modes of a String, Sound Waves, Speed of Sound Waves	15.7-15.8 16.1-16.2
6. Standing Sound Waves and Normal Modes, Resonance and Sound	16.4-16.5
7. Interference of Waves, Beats Electric Charge, Conductors, Insulators, and Induced Charges	16.6-16.7 21.1-21.2
8. Coulomb's Law, Electric Field and Electric Forces	21.3-21.4
9. Electric field definition, electric field of point charge, electric field as superposition of point charges	21.4-21.5
10. Electric Field of a Continuous Charge Distributions	21.5
11. Electric field of planes of charge, capacitors, and electric field lines	21.5-21.7
12. Electric Flux and Calculating Electric Flux	22.1-22.2
TERM TEST 1	
13. Flux with variable Fields, Gauss's Law	22.2-22.3

14. Applications of Gauss's Law	22.4
15. Applications of Gauss's Law, Charges on Conductors	22.4-22.5
16. Charges on Conductors, Electric Potential Energy	22.5, 23.1
17. Electric Potential Energy	23.1
18. Electric Potential	23.2
19. Calculating Electric Potential, Equipotential Surfaces and Potential Gradient	23.3-23.5
20. Potential Gradient, Current, Resistivity, Resistance, EMF and Circuits	23.5, 25.1-25.4
21. Energy and Power in Circuits, Resistors in series and Parallel	25.5-25.6, 26.1
22. Kirchoff's Laws, Capacitors and Capacitance, Capacitors in Series and Parallel	26.2, 24.1-24.2
23. R-C Circuits	26.4
TERM TEST 2	
24. Magnetism, Magnetic Field, Magnetic Force, Magnetic Flux, Motion of Charged Particles in Magnetic Field	27.1-27.4
25. Magnetic Force on a Current Carrying Conductor, Torque on Current Loop	27.5-27.9
26. Magnetic field of moving charge, current element, current carrying conductor, force between parallel conductors	28.1-28.4
27. Magnetic Field of Circular Current Loop, Ampere's Law, Applications, Magnetic Materials	28.5-28.8, 29.8
28. Induction, Faraday's Law, Lenz's Law	29.1-29.3
29. Lenz's Law. Motional EMF. Induced Electric Fields, Eddy Currents, Displacement Current, Maxwell's Equations	29.4-29.7
30. Mutual Inductance, Self-Inductance and Inductors, Magnetic-Field Energy	30.1-30.3
31. The R-L Circuit, The L-C Circuit, The L-R-C Series Circuit	30.3-30.6
32. Examples: The R-L Circuit, The L-C Circuit, The L-R-C Series Circuit	30.3-30.6
33. Examples: The R-L Circuit, The L-C Circuit, The L-R-C Series Circuit	30.3-30.6

Time permitting, optional topics at the instructor's discretion could be included, e.g. superconductivity (Section 29.8 – as done above), the nature of light (Section 33.1), interference (Sections 35.1-35.2) and diffraction (from Ch. 36).

LABORATORIES

Normally there will be nine or ten laboratory sessions combining experimental work and problem-solving per semester.

	Experiment Title
0	Laboratory Introduction
1	Introduction to Simple Harmonic Motion
2	Standing Waves
3	Introduction to FFT Analysis
4	Sound and Resonance
5	Introduction to Circuits
6	Electric Field and Electric Potential
7	Vector Nature of Magnetic Fields
8	Magnetic Field of a Solenoid
9	The Simple DC Motor

An alternative scheme for labs – only bench experiments not integrated with problem solving + one lab skills test. Problem Sets are separate.

Lab 0 Introduction
Lab 1 Standing Waves
Lab 2 Sound and Resonance
Lab 3 Electric Filed and Potential
Lab 4 Kirchoff's Laws
Lab 5 Capacitor Charge and Discharge
Lab 6 DC Motor
Lab Skills Test

Physics 2053: Fluids and Thermodynamics

Preamble. Beginning in the Fall 2016, some material recently covered in PHYS 3400 will be moved into 2053. PHYS 2053 is based on four chapters of *Principles of Physics* by Serway and Jewett, the same text as is used in PHYS1050/51. Note that each of these first year courses covers about 10 chapters. Feedback from students in physics is that PHYS 2053 is an easy course. It should be a fun course – one of the most liked by students in our offerings.
PHYS 3400 has recently been based on *An Introduction to Thermal Physics* by Schroeder. The material covered in the first four sections of Ch. 2 of Schroeder will now be formally covered in PHYS 2053. PHYS 3400 will begin with a review (one or two weeks) of the basic material covered in 2053 (chapters 1 and 2 of Schroeder). Note also that Fluid Mechanics is covered in PHYS 1021 but not in PHYS1051. Occasionally, a student in PHYS 1021 will have taken both of these first year courses.

1. Ch. 15. Fluid Mechanics.

Solids and Fluid Statics I: Pressure, density, buoyancy, Archimedes principle. Solids and Fluids Statics II: Surface and Interfacial Phenomena. Fluids Dynamics I: Steady flow, Bernoulli principle, Viscous Flow. Fluid Dynamics II: Reynolds number, turbulence. Mixing & entropy.

2. Ch 16. Temperature and the Kinetic Theory of Gases.

Temperature, heating, thermal equilibrium. Ideal Gas. Kinetic Theory of gases, equipartition of energy. Thermal expansion.

3. Ch. 17. Energy in Thermal Processes. First law of thermodynamics.

Heat and internal energy. Specific and latent heat. Work and the First Law of thermodynamics. Thermal and mechanical properties of materials. **Energy transfer mechanisms in thermal processes (heat transfer via conduction and radiation in single- and double-paned windows).**

4. Ch. 18. Heat Engines, Heat Pumps. Second Law of thermodynamics.

Heat engines (**supplemented with Ch. 4 of Schroeder**, sections on "**Real Heat Engines**" and "**Real Refrigerators**"), Carnot Cycle, heat pumps and refrigerators. Entropy and irreversible processes and the Second Law of thermodynamics. **From Ch. 2 of Schroeder. The Second Law**
2.1 The two-state system (paramagnet). 2.2 The Einstein model of a solid. 2.3. Interacting systems. 2.4. Large systems (Stirling approximation, multiplicity).

Physics 2055: General Physics IV– Electricity and Magnetism

This course serves as a prerequisite for PHYS 3500, Electromagnetic Fields I. The traditional text for 3500 has been *Introduction to Electrodynamics* (Griffiths). Continuity between 2055 and 3500 is desirable. It is important to note that many of the basic concepts covered in 2055 have been introduced in 1051. Although the same text is recommended, instructors are encouraged to use supplementary material (or choose a distinct textbook at the second-year level). 2055 is intended to be a much more formal introduction, using more advanced examples.

The detailed outline given below is based on R. A. Serway & J. E. Jewett, Jr. *Physics for Scientists and Engineers with Modern Physics, 9th Edition* [SEE NOTE 1] and is intended to serve as a guide to the topics covered – even if a different text is actually recommended to students. A motivation to use the same text as was used by the students for 1051 is cost. Judicious use of handouts and Supplementary material on D2L can be used to accommodate the inclusion of more advanced treatments of the topics.

TOPIC	**Chapters From Textbook**	**Number of Lectures**
Review: Electric Fields [SEE NOTE A]	**23.1-23.7**	**1**
Coulomb's Law Electric Field of a Point Charge Electric Field of a Continuous Charge Distribution Particle in an Electric Field		
Electric Flux and Gauss's Law [SEE NOTE A]	**24.1-24.4**	**2**
Electric Flux Gauss's Law Applications of Gauss's Law to Various Charge Distributions Conductors in Electrostatic Equilibrium		
Electric Potential [SEE NOTE B]	**25.1-25.6**	**2**
Electric Potential and Electric Potential Difference Potential Difference in Uniform Electric Field Electric Potential and Potential Energy due to Point Charges Electric Potential due to Continuous Charge Distribution Obtaining Electric Field from Electric Potential Electric Potential Due to a Charged Conductor		
Capacitance and Dielectrics [SEE NOTE C]	**26.1-26.6**	**2**
Definition of Capacitance Combination of Capacitors Energy Stored in a Charged Capacitor Capacitors with Dielectrics Electric Dipole in Electric Field		
Electric Current	**27.1-27.6**	**2**
Electric Current Resistance A Model for Electrical Conduction		

Resistance and Temperature Superconductors Electrical Power		
Direct Current Circuits	**28.1-28.4**	**2**
EMF Combination of Resistors Kirchhoff's Rules RC Circuits		
Magnetic Fields [SEE NOTE 2**]** [SEE NOTE D]	**29.1-29.6** **30.1-30.6**	**3**
Particle in a Magnetic Field Current-Carrying Conductors in a Magnetic Field The Hall Effect Biot-Savart Law Magnetic Force Between Two Parallel Conductors Ampere's Law Magnetic Field of a Solenoid Gauss's Law in Magnetism Magnetism in Matter		
Faraday's Law [SEE NOTE E]	**31.1-31.6**	**1**
Faraday's Law of Induction Lenz's Law Induced EMF Eddy Currents		
Inductance [SEE NOTE E]	**32.1-32.6**	**3**
Self-Induction and Inductance Energy in Magnetic Field RL, RC and RLC Circuits		
AC Circuits	**33.1-33.9**	**3**
AC Sources Circuit Elements in AC Circuits Rectifiers and Filters		
Electromagnetic Waves	**34.1-34.7**	**4**
General Form of Ampere's Law Maxwell's Equations Plane EM Waves Energy, Momentum and Radiation Pressure in EM Waves Spectrum of EM Waves		
The Nature of Light and Principles of Ray Optics	**35.1-35.8**	**2**
Geometric Optics	**36.1-36.5**	**2**
Image Formation by Mirrors and Lenses Lens Aberration		
Wave Optics	**37.1-37.6**	**2**
Young's Experiment Wave's Interference Change of Phase Due to Reflection		

Interference in Thin Films		
Diffraction and Polarization	**38.1-38.6**	**2**
Diffraction Patterns Diffraction Grating Diffraction of X-Rays by Crystals Polarization of Light Waves		

LABORATORIES [SEE NOTE 3]

#	**Experiment Title**
1	Introduction to the Laboratories
2	Linear and Nonlinear Resistors
3	Charge and Discharge of a Capacitor
4	E/M for Electrons
5	The RC Circuit
6	RL Filter Circuit
7	Resonance in LRC Series Circuit
8	*EM Experiment - [SEE NOTE 3a]*
9	*Optics Experiment – In Development*

NOTES AND DISCUSSION ITEMS:

1) *Following a meeting on Dec. 7th, 2015it was decided that "Principle of Physics" by Serway and Jewett does not cover entire content of the course. If this textbook is used, supplementary material from higher level texts is recommended.*

2) *Even though the chapters are extensive, some the material have been covered in PHYS1051, so part of it can be treated as a review (same way "Electric Forces and Fields" are in the beginning of the semester). Hall Effect and Gauss's Law for Magnetism are the only new items in this section. As students are more advanced in math skills, the Biot-Savart section can include more complicated examples.*

3) *Currently students do two introductory labs: general and introduction to the oscilloscope – those two could be combined into one introductory lab. In addition, to accommodate two new* *laboratories related to the course content, it may be necessary to either remove "Kirchhoff's Circuit Laws" OR/AND redesign/remove the lab exam "Black Box Problem" OR/AND increase number of the laboratory experiments performed by students.*

a. *Suggestions are required but the experiment could include temperature resistance of conductors and semiconductors, LED diodes, observation of hysteresis loop ...*

COMMENTS ON GRIFFITHS' CONTENT FOR CREATING CONTINUITY BETWEEN PHYS 1051 and PHYS 3500 THROUGH PHYS 2055

A) Griffiths starts *Electrostatics* with an introduction of E and F vectors with proper unit vector notation, followed by continuous charge distribution and Gauss's Law in differential form.
  - **a.** Section on *Conductors* starts with discussion of the properties of conductors in electrostatic equilibrium.

B) Griffiths starts *Electric Potential* by reintroducing the definition and follows with the $\vec{E} = -\nabla V$.

C) Polarization of a dielectric is introduced (with net E field and induced charge density); Gauss' Law for dielectrics can be used to derive capacitance change in presence of a dielectric (Mazur does it that way, Serway and Jewett don't, but it could be introduced).

D) Magnetostatics in Griffiths start with a brief review of that section and a lot of equations are derived using the same mathematical tools while expanding others (and keeping consistent notation). Students have proper background to continue to more complicated issues.
  - **a.** Biot-Savart Law – some examples (straight current-carrying wire, loop or portion of it) covered in PHYS2055 (and earlier in PHYS1051) reappear with different mathematical notation
  - **b.** Ampere's Law - some examples (solenoid, thick wire, sheet of current) covered in PHYS2055 reappear with different mathematical notation.

E) Concepts introduced in PHYS2055 are derived; many familiar concepts are re-introduced with emphasis on principles and understanding the theory rather than application and/or final equation.

Physics 2151: Stellar Astronomy and Astrophysics

Overview

For the last several years, the course has been largely built around Chaisson & McMillan's *Astronomy Today, Volume 2: Stars and Galaxies, 8th edition* (Pearson Education, 2014). The course continues to follow the text pretty closely, with relevant additions and shifts in emphasis - drawn largely from the Internet and the scientific literature - as new developments in astronomy and astrophysics warrant. The level of mathematical ability required of students is entirely pre-calculus, but basic algebra, trigonometry, logarithms and how to work with exponents, in the context of doing physics (maintaining units in equations) is expected. Treatment of "Material Covered" below is cursory and introductory.

Material Covered

I - ASTRONOMY AND THE UNIVERSE

1. Charting the Heavens: The Foundations of Astronomy
    - 1.1 Archeo-astronomy, constellations, asterisms
    - 1.2 Celestial sphere; Right Ascension and Declination
    - 1.3 Precession of the Earth's axis
    - 1.4 Eclipses

2. The Copernican Revolution: The Birth of Modern Science
    - 2.1 Heliocentrism versus the Ptolemaic model; Kepler's Laws
    - 2.2 The Astronomical Unit; stellar parallax
    - 2.3 Newton's Laws; circular orbits, escape velocity

3. Radiation: Information from the Cosmos
    - 3.1 Nature of EM radiation; Double-slit experiment
    - 3.2 Atmospheric opacity
    - 3.2 Blackbodies; Wien's Law, Stefan-Boltzmann Law
    - 3.3 Doppler shift

4. Spectroscopy: The Inner Workings of Atoms
    - 4.1 Dispersion; prisms, diffraction gratings
    - 4.2 Fraunhofer lines; Kirchhoff's "Laws"
    - 4.3 Orbitals and energy levels; energy of a photon
    - 4.4 Hydrogen spectrum; Bohr atom; Rydberg formula
    - 4.5 "Metals" and metal ions; "nebulium", forbidden lines
    - 4.6 Molecular band spectra; thermal and bulk-motion line broadening
    - 4.7 Zeeman splitting

5. Telescopes: The Tools of Astronomy
    - 5.1 Refracting telescopes; Galilean, Keplerian; achromatic lenses

- 5.2 Reflecting telescopes; Newtonian, Cassegrain, Nasmyth, SCTs
- 5.3 Diffraction due to apertures; Airy Disk, angular resolution
- 5.4 “Seeing”, adaptive optics
- 5.5 Detectors; photographic plates, CCDs, image scale, sampling
- 5.6 Photometry; filters, Johnson and Cousins photometric standards
- 5.7 Radio telescopes; single-dish, interferometry
- 5.8 Infrared astronomy; ground-based, space-based
- 5.9 High energy astronomy; EUV, X-ray and gamma-ray telescopes

III - STARS AND STELLAR EVOLUTION

16. The Sun: Our Parent Star

- 16.1 Basic properties, solar structure; hydrostatic equilibrium
- 16.2 Helioseismology; solar monitoring satellites; space weather
- 16.3 Radiative and convective energy transport
- 16.4 Photosphere; granulation, line formation, limb darkening
- 16.5 Chromosphere, corona; “coronium”
- 16.6 Magnetic fields, sunspots, solar cycle
- 16.7 Solar activity; prominences, solar flares, CMEs
- 16.8 Solar energy production; nuclear strong and weak forces; p-p chain
- 16.9 Solar neutrino problem, neutrino detectors, neutrino oscillation

17. The Stars: Giants, Dwarfs and the Main Sequence

- 17.1 Nearest stars; distances from parallax, proper motion, space velocities
- 17.2 Stellar magnitudes, distance modulus; relation to luminosities
- 17.3 Colours/spectral indices; spectral classification
- 17.4 Stellar radii
- 17.5 Hertzsprung-Russell diagram; main sequence, “spectroscopic parallax”
- 17.6 Spectral line widths and Luminosity classes; the Giant branches
- 17.7 Binary stars; determining mass. Eclipsing binaries, light curves
- 17.8 Main sequence lifetimes

18. The Interstellar Medium: Gas and Dust among the Stars

- 18.1 Interstellar grains; composition, Rayleigh and Mie scattering, reddening
- 18.2 Extinction, colour excess
- 18.3 Emission and reflection nebulae; Messier objects
- 18.4 HII regions, photo-evaporation, forbidden line recap
- 18.5 Local Bubble, dark dust clouds/molecular clouds
- 18.6 21.1 cm hydrogen line, molecular hydrogen tracers

19. Star Formation: A Traumatic Birth

- 19.1 Cloud collapse criteria; fragmentation
- 19.2 Hayashi track, Zero-Age Main Sequence
- 19.3 Proplyds, protostars, Herbig-Haro objects
- 19.4 Open clusters, globular clusters; main sequence turn-off age

20. Stellar Evolution: The Life and Death of a Star

- 20.1 Solar-mass star evolution; shell-burning, subgiant and red giant branches

- 20.1 Triple-alpha process, helium flash, electron degenerate matter
- 20.2 Horizontal and asymptotic giant branches; planetary nebulae, white dwarfs
- 20.3 Blue stragglers in globular clusters

21. Stellar Explosions: Novae, Supernovae and the Formation of the Elements
    - 21.1 Mass transfer in close binaries; Algol, Roche lobes
    - 21.2 Novae, Chandrasekhar Limit, Type Ia supernovae
    - 21.3 Massive star evolution; binding energy curve, core-collapse (Type II) supernovae
    - 21.4 Light curves, photo-dissociation, r-process and s-process elements

22. Neutron Stars and Black Holes: Strange States of Matter
    - 22.1 Neutron stars, pulsars; in binaries, x-ray bursters and milli-second pulsars
    - 22.2 Gamma-ray bursts; short (merger) and long (hypernovae) types
    - 22.3 Black holes; Schwarzschild radius, Lorentz contraction, Equivalence Principle
    - 22.4 Event horizon, tidal forces; “spaghettification”
    - 22.5 Gravitational redshift, time dilation, light deflection, curved space
    - 22.6 Examples; Cygnus-X1, Sag-A*

IV - GALAXIES AND COSMOLOGY

23. The Milky Way Galaxy: A Spiral in Space
    - 23.1 Historical; morphology from star counts
    - 23.2 Variable stars; Cepheids, RR Lyraes, instability strip, period-luminosity relation
    - 23.3 Shapley and globular clusters; Hubble and M31
    - 23.4 Milky Way morphology; bulge, thick and thin disks, halo
    - 23.5 Dynamics; differential rotation
    - 23.6 Spiral arm formation; spiral density waves, flocculent versus “grand design”
    - 23.7 Light to mass ratio; rotation curve, dark matter, micro-lensing, WIMPs

24. Galaxies: Building Blocks of the Universe
    - 24.1 Galaxy classification; Hubble “Tuning Fork”, de Vaucouleurs types
    - 24.2 Distribution of galaxies; Tulley-Fisher relation, Local Group, galaxy clusters
    - 24.3 Virgo cluster, intracluster gas
    - 24.4 Hubble “Law”, Hubble flow, cosmological redshift
    - 24.5 Active Galactic Nuclei (AGN); super-massive black holes
    - 24.6 Examples; Seyfert, radio galaxies, quasars, blazars

25. Galaxies and Dark Matter: The Large-Scale Structure of the Cosmos
    - 25.1 Mass to light ratio versus cluster size
    - 25.2 Galaxy interactions, blackhole growth, quasar epoch
    - 25.3 Large-scale structure; reshift surveys, voids, “Great Wall”, Lyman-alpha forest

26. Cosmology: The Big Bang and the Fate of the Universe
    - 26.1 Cosmological Principle, Olber's Paradox

26.2 Cosmic microwave background (CMB), Big Bang, decoupling epoch
26.3 Density parameter and space curvature; open, closed and critical universe
26.4 Type Ia supernovae as cosmological yardsticks; dark energy
26.5 Constraints on age of Universe; globular clusters

27. The Early Universe: Toward the Beginning of Time
27.1 Overview; Radiation, matter, and dark energy –dominated eras
27.2 Radiation era; Planck epoch, Grand Unified Theory (GUT) epoch
27.3 Pair production, Standard model; quarks, leptons, bosons
27.4 Primordial nucleosynthesis; deuterium abundance
27.5 Inflation; Horizon Problem, Flatness Problem

28. Life in the Universe: Are We Alone?
28.1 Definition of "life"; Stanley-Miller experiment
28.2 Meteorites
28.3 Extremophiles; possibilities re: Mars, Europa
28.4 SETI; Drake equation, exoplanet discoveries, radio telescope searches

PHYSICS 2300: Introductory Oceanography.

Preamble: This course will enable students studying in different disciplines to learn about the ocean from a physical prospective. This course will provide a general introduction to ocean processes with a primary focus on the physical ocean. The course will review how oceans form and how they evolve on a planetary scale. Topics that will be discussed include: the properties of seawater, elementary dynamics of fluid on the rotating Earth; key features of ocean circulation, wind-forcing in the ocean, waves and tides. The role that physical and chemical processes play in mediating biological activity will be presented. Contemporary methods used in oceanographic study will be covered including satellite oceanography.

The mathematics used in presenting the physical concepts in this course is greatly simplified to enable students with different backgrounds to understand these concepts and to solve problems. Students will learn to do simple calculations and reasonable physical estimates. This course also provides an opportunity for students to refresh their memory on some concepts they learned in their first year physics including velocity, acceleration, the Newton's second law, rotation etc. The course instructor can also provide supplementary reading materials where these concepts are considered within a calculus based approach to students who feel more comfortable with math.

Topics:

1. Formation of the Oceans (origin of the atmosphere and oceans, ocean basin formation and plate tectonics, hydrostatics, isostasy)

2. Properties of Seawater (physical and chemical properties, equation of state and nonlinearity, density and water structure)

3. Elementary dynamics of water on the rotating Earth (Coriolis effect, inertial motion)

4. Currents with and without friction (hydrostaticity, geostrophy, Ekman dynamics)

5. Atmosphere and Ocean general circulation (large scale wind, oceanic gyres, upwelling, El Nino, deep ocean circulation)

6. Ocean waves (gravity waves, internal waves, Kelvin and Rossby waves)

7. Tides

8. Marine Ecology and Biological productivity

Textbook: Paul Pinet, Invitation to Oceanography, 7th Edition Jones & Bartlett Publishers, 2013, 615pp.

P2750 General Physics VI: Modern Physics

Numerous textbooks could be used for this course. In the past, the same textbook used for 1050/1051 had also been used for 2750, with supplementary material added. Frequently, both 2053 and 2055 also use the first-year text. The decision to use a stand-alone *Modern Physics* text is driven by the perceived need for more depth than what is covered in the first-year texts. (This decision is entirely up to the instructor.) This point is noteworthy in view of the fact 2750 is a prerequisite for 3750. It has also been noted that the calculus skills required for 2750 are limited to knowledge of a few simple one-dimensional integrals and thus knowledge of calculus need not be a firm PR. In general, 2750 should cover special relativity in more depth than what is done in first year, serve as an introduction to the fundamental concepts of quantum physics, the Schrodinger equation, atomic, nuclear and particle physics.

Recommended Text: *Modern Physics* (3rd edition) by Serway/Moses/Moyer

Special Relativity : Chapter 1 and 2

- Galilean transformation
- Properties of EM waves: Michelson-Morley Exp.
- Postulates of special relativity
- Consequences of special relativity: simultaneity, time dilation, length contraction, twin paradox, relativistic Doppler shift
- Lorentz transformation, relativistic momentum, relativistic form of Newton equation, relativistic energy
- Mass energy: $E = m c^2$ and fission

Quantum theory of light: Chapter 3

- Properties of electromagnetic waves and x-rays
- Quantization of light: black body radiation and Planck's hypothesis, photoelectric effect, Compton scattering

Wave nature of matter: Chapter 5

- de Broglie postulates
- Davisson-Gerner experiment
- Double-slit experiment
- Properties of matter waves and interpretation: probability, expectation values, boundary conditions
- Uncertainty principle
- Wave-particle duality

Quantum mechanics in one dimension: Chapters 6 and 7

- Schrodinger equation
- Expectation values, transmission and reflection coefficient
- Free particle, step potential, infinite and finite well potential, harmonic potential, tunneling, STM and AFM

Composition of atoms: Chapters 4 and 9

- Early model of atoms
- Rutherford’s scattering experiment
- Rutherford’s model
- Atomic spectrum
- Bohr’s model

Quantum mechanics in three dimensions: Chapter 8

- Schrodinger equation in 3D
- Hydrogen atom
- Quantum numbers
- Electron spin

Nuclear Physics: Chapters 13 and 14

- Nuclear binding energy
- Nuclear fission and fusion
- Radioactivity and detection

Particle physics: Chapter 15

- Fundamental forces and particles
- Quarks model

Physics 2820: Computational Mechanics

Preamble. Since its inception circa 2005, P2820 has served to introduce computers as a useful problem-solving tool to physics undergraduates. Central themes include numerically solving problems that have no analytical solution, and being able to translate the physics problem and the method of its solution into working computer code. In the context of classical mechanics, this means that students are introduced to basic numerical methods for taking derivatives, integrals and solving second order ODEs. Given the importance of being able to work with data, some time is devoted to opening files, fitting, plotting and otherwise manipulating data. This course thus serves as a fine prerequisite to PHYS 3800.

While students are exposed to more complex mechanics problems (e.g. drag forces, driven, nonlinear and coupled oscillators), the focus is on obtaining and analyzing the solution to the problem, rather than cultivating a deep understanding of the formulation or analytical treatment of the solution. Therefore, the coverage of the classical mechanics material serves as a preview to the coverage of some of the material in P3220.

Up until (and including) W2016, Mathematica has been the programming environment. With broad functionality, relative ease of use and a uniform interface across computer platforms, Mathematica allowed students to focus more on the physics and less on lower level programming, at least at first. Mathematica also then became a tool students could use for computational tasks in subsequent courses.

The course has been taught in two parts, with the first part focusing on solving mechanics problems using Mathematica's built-in numerical and analytic capabilities (differentiation, integration and solving of ODEs), and the second part delving into algorithms and lower level coding of numerical solutions.

The following outline reflects the course taught with Mathematica (number of 1.5h lectures in parentheses):

Introduction to Mathematica (1)
Reexamining some physics problems from first year mechanics (3)
Projectile motion (2)
Central forces (2)
Numerical differentiation and integration (2)
Numerical solution of ODE's; Euler, midpoint, Runge-Kutta (2)
Oscillators: SHO, damped and driven oscillators, pendulum, coupled oscillators (3)
Wave Equation (2)
Curve fitting; working with data (2)

with a few lectures left unaccounted for in order to allow for TA- and instructor-assisted work periods and/or tutorials.

Recently, however, the rising cost of the Mathematica licence to prohibitive levels and a stated desire from the Department of Earth Sciences for the course to better serve their programs' need of a “programming course”, the course will be offered using Python. Python is free, flexible, widely used within and outside academia and is growing in popularity. While Python will be introduced to students within use-friendly Mathematica-like iPython notebooks, the flavor of the course will change somewhat to be more thoroughly hands-on, with lecture time being used (exclusively) for tutorial-style working through of material with students at terminals or laptops following along with the instructor.

In terms of textbooks for the course, there are many textbooks in computational physics, but it is difficult to find a single one that covers the topics in P2820 at the second year level. It is therefore incumbent on the instructors to collect material from various sources. In the past, we have indicated Nino Boccara’s *Essentials of Mathematica with Applications to Mathematics and Physics* as the recommended text. It is available electronically for free from our library and served as a Mathematica language reference. But the reality is that online language resources are abundant and convenient, and that the course notes developed by the instructors of P2820 (originally by Brad de Young) serve the purposes of covering the material.

The following proposed outline includes topics that have been covered in P2820 in recent offerings, with the exception of the wave equation, but adds geophysical examples. The notes will take on the form of iPython notebooks that introduce students both to the physical concepts and to programming (syntax, control structures etc). Some of the material and how it is presented immediately through a computational approach is inspired from the first few chapters of Giordano and Nakanishi’s *Computational Physics* (2nd edition). Otherwise, existing Mathematica material will be converted and adapted for the Python offering.

Weekly labs will continue to be an important part of the course. During labs, students independently work through tasks (though assistance from TA’s and instructor will be available) that serve as a bridge between material taught in class and assignments. Approximate number of 1.5h lectures in parentheses.

1. Introduction (2)
    - Solving problems numerically
    - Python/NumPy/Matplotlib
    - Radioactive decay

2. Projectiles (3)
    - Second order differential equations
    - Drag forces
    - Problem formulation
    - Plots and interpretation

3. Oscillations (5)
    - Pendulums and simple harmonic oscillators
    - Euler and Euler-Cromer methods
    - Coupled oscillators
    - Chaotic motion (*)

4. Numerical Analysis (2)
    - Taylor series and error estimation
    - Numerical differentiation
    - Numerical Integration
    - Runge-Kutta methods

5. Geophysical Methods (5)
    - Data processing and visualization
    - Time of travel of seismic waves
    - Gravitational prospecting

6. N-Body Problems (5)
    - Celestial mechanics and/or molecular dynamics
    - Verlet method
    - Larger/longer simulations (*)
    - Working with file input/output
    - Animations

7. Computer Algebraic Systems (2)
    - SymPy
    - Symbolic integration

Since F2016 will be the first offering with Python, it is expected that adjustments will be made subsequently. A star (*) indicates material with less certainty of being covered.

Physics 3000:Physics of Device Materials

Preamble: Since 2013, the textbook has been *An Introduction to Semiconductor Devices*, Donald A. Neamen (McGraw-Hill, 2006). This course was initially taken by physics students but since 2009 it has been a required course for Term III students in the Electrical and Computer Engineering Program and enrolments are now in the 50-80 range. The course closely follows the text for the first 6 chapters: (1) The crystal structure of solids; (2) Theory of solids; (3) The semiconductor in equilibrium; (4) Carrier transport and excess carrier phenomena; (5) The pn junction and metal-semiconductor contact; and (6) Fundamentals of the Metal-Oxide-Semiconductor Field-Effect transistor. There is then one lecture on MOSFET scaling and non-ideal effects from chapter 7, a lecture on minority carrier distribution in the pn junction from chapter 9, and a lecture on bipolar transistors from chapter 10. Four lectures are devoted to the physics of optical devices including solar cells, photodetectors, light-emitting diodes, and solid state lasers. The last lecture typically introduces microelectromechanical devices and other topical subjects such as charge-coupled devices or blue diodes (both recognized by recent Nobel prizes). Material on device fabrication from the ends of Chapters 3 and 5 is also introduced throughout the semester.

Introduction (1 lecture): Course organization, motivation, historical perspectives

Crystal Structure of Solids (Chapter 1 and Section 3.7, 3 lectures):

- semiconductor materials, types of solids
- Space lattices, atomic bonding
- Imperfections and Impurities in Solids
- Growth of semiconductor materials, device fabrication techniques

Electrons in Solids (Chapter 2, 3 lectures):

- Principles of Quantum Mechanics, Energy Quantization and Probability Concepts
- Energy-Band Theory
- Density of States Function,
- Statistical Mechanics,
  - Fermi-Dirac Distribution Function, Fermi Energy, Maxwell-Boltzmann Approximation

The semiconductor in Equilibrium (Chapter 3, 5 lectures):

- Charge Carriers in Semiconductors
- Dopant Atoms and Energy Levels, Carrier Distribution in the Extrinsic Semiconductor
- Statistics of Donors and Acceptors
- Carrier Concentrations - Effects of Doping
- Position of the Fermi Energy Level - Effects of Doping and Temperature

Carrier Transport and Excess Carrier Phenomena (Chapter 4, 3 lectures):

- Carrier Drift
- Carrier Diffusion, Graded Impurity Distribution
- Carrier Generation and Recombination, The Hall Effect

The pn Junction and Metal-Semiconductor Contact (Chapter 5, 4 lectures):

- Basic Structure of the pn Junction, Zero Applied Bias
- Reverse Applied Bias
- Metal-Semiconductor Contact
- Rectifying Junction, Forward Applied Bias
- Metal Semiconductor Ohmic Contacts

Fundamentals of the Metal-Oxide-Semiconductor Field-Effect Transistor (Chapter 6, Section 7.1, and Section 7.2, 5 lectures):

- The MOS Field-Effect Transistor Action
- The Two-Terminal MOS Capacitor
- Potential Differences in the MOS Capacitor
- Capacitance-Voltage Characteristics
- Basic MOSFET Operation
- MOSFET Scaling, Nonideal effects

More on the pn junction (Sections 9.1, 9.2, 1 lecture):

- Ideal I-V characteristic
- Minority carrier distribution

Introduction to the bipolar transistor (Section 10.1):

- Currents in a bipolar transistor biased in the forward-active mode
- Simplified current relations
- Simplified bipolar transistor operation

Optical Devices (Chapter 12, 4 lectures):

- Optical Absorption
- Solar Cells
- Photodetectors (Photoconductor, Photodiode, PIN Photodiode)
- Light-emitting diodes
- Laser Diodes

Other Multi-material devices (Chapter 11 and other sources, 1 lecture):

- Microelectromechanical systems (MEMS)
- Charge coupled devices
- Blue LEDs

Physics 3150: Astrophysics I

Preamble: The original outline for this course, and the previous calendar entry, are based on *The Physical Universe, An Introduction to Astronomy*, Frank H. Shu, (University Science Books, 1982). For the last several years, the text has been *An Introduction to Modern Astrophysics*, Second Edition, Bradley W. Carroll and Dale A. Ostlie (Pearson Addison-Wesley, 2007). The course deals primarily with the properties of stars and the evolution of stars. One objective in the original design of this course was that it should integrate concepts from a range of physics topics and this continues to be an important element. The early part of the course introduces or reviews material from quantum mechanics, atomic physics (the hydrogen atom and spectroscopy), thermal physics (blackbody radiation and radiation pressure, equations of state), statistical mechanics (fermion and boson statistics and degeneracy), mechanics (hydrostatic equilibrium, conservation of mass), nuclear physics, and the Standard Model. Some astrophysical concepts are also introduced early (magnitude and luminosity, effective temperature, parallax, spectral classification, the Hertzsprung-Russell diagram). These concepts are then applied to understanding energy production in stars, the transport of energy out of stars, models for the density profile of stars, the relationship of mass, effective temperature, and luminosity on the main sequence, nucleosynthesis and the synthesis of heavy elements, star formation, evolution of stars after they leave the main sequence, and the end states of stars with different initial masses. The current offering of the course makes use of material, more or less in order, from chapters 7-16 of the text but this is heavily supplemented with material from other sources including other texts and online material from sources like NASA and the European Space Agency.

1. Introduction: Objectives, Course Organization, Outline, Orientation

2. Some Nomenclature:

- **2.1** Constellations and star designation
- **2.2** Full-Sky Catalogs
- **2.3** Variable stars
- **2.4** Non-stellar objects

3. Kinds of observations that can provide insight into stellar properties

- **3.1** Distance measurements
  -Parallax, definition of a parsec (C&O 3.1), Cepheid Variables
- **3.2** Magnitude and Luminosity (C&O 3.2)
- **3.3** Temperature
  -Blackbody Radiation (C&O 3.4), Colour (C&O 3.6)
- **3.4** Mass
  -Importance of binary systems (C&O 7.2)

4. Gravity

5. Other forces

6. The Virial Theorem

7. Light and Matter

7.1 An interesting chronology
7.2 Light and Electromagnetic Waves
7.3 Blackbody radiation (C&O 3.4)
7.4 Quantization, the Planck Function, and Radiation Pressure (C&O 3.4)
7.5 Quantum Mechanics, Wave-Particle Duality, and Uncertainty (C&O 5.4)
7.6 Photons (C&O 5.2)
7.7 The Hydrogen spectrum (C&O 5.3)
7.8 Bohr Model of the Atom (C&O 5.3)
7.9 Absorption Lines and Kirchoff's Laws (C&O 5.1)
7.10 Indistinguishable Particles, Fermions and Bosons
7.11 Particle Statistics
7.12 The Standard Model of Particle Physics

8. Stellar Spectra and the Classification of Stars

8.1 Harvard Spectral Classification (C&O 8.1)
8.2 Hertzsprung-Russell Diagrams (C&O 8.2)
-Main Sequence, Off the Main Sequence
8.3 Luminosity Classes and Morgan-Keenan Classification (C&O 8.2)
8.4 Spectral Class Abundances
8.5 Stellar Mass, Stellar Lifetimes, Stellar Radii
8.6 Examples of Stars in Different Spectral Classes

9. Radiation in the stellar atmosphere

9.1 Radiation pressure (C&O 9.1)
9.2 Opacity and Optical Depth (C&O 9.2)
9.3 Radiative Transfer (C&O 9.3)

10. Star Interiors – parameters, properties, and relationships

10.1 Plasma
10.2 Equations of stellar structure and constitutive relations
10.3 Hydrostatic Equilibrium (C&O 10.1)
10.4 Conservation of Mass (C&O 10.7)
10.5 Luminosity Gradient (C&O 10.3)
10.6 Numbers of Particles and mean molecular weight (C&O 10.2)
10.7 Equation of State (C&O 10.2)
10.8 Sphere of constant density

11. Star Interiors – Energy sources, energy transport, models

- **11.1** Stellar Energy Sources (C&O 10.3)
    - -Gravitation and the virial theorem (Kelvin-Helmholtz timescale)
    - -Nuclear Reactions (nuclear timescale, tunneling, Gamow peak, temperature dependence
- **11.2** Stellar nucleosynthesis in MS dwarfs
    - -General Comments
    - -Hydrogen burning in MS dwarfs (PP chains and CNO cycle)
    - -Proton-proton Chains
    - -CNO cycle
- **11.3** Stellar nucleosynthesis in post MS stars
    - -Helium burning in very hot stars – the Triple alpha process
    - -Carbon and Oxygen burning
    - -Binding Energy per nucleon
- **11.4** Energy transport (C&O 10.4)
    - -Radiation, Convection, conduction
    - -Radiative Temperature Gradient
    - -Adiabatic Temperature Gradient
- **11.5** Stellar Models (C&O 10.5)
    - -Summary of constitutive equations
    - -Polytropic Models, Lane-Emden Equation
- **11.6** The Eddington Standard Model
- **11.7** The Main Sequence (C&O 10.6)
    - -Eddington Luminosity Limit
    - -Correlation of stellar mass with position on the Main Sequence

12. Star Formation

- **12.1** Pre-Main Sequence Evolution (C&O 12.3)
- **12.2** Zero-Age main sequence

13. Stellar Evolution

- **13.1** Description of evolutionary Tracks ($1M_\odot$and $5M_\odot$)
- **13.2** Evolution on the Main sequence (C&O 13.1)
- **13.3** The Schönberg-Chandresekhar limit - Leaving the Main Sequence
- **13.4** Late stages of Stellar evolution (C&O 13.2)
    - -Evolution off of the Main Sequence
    - -Asymptotic Giant Branch
    - -Post Asymptotic Giant Branch
    - -Planetary Nebulae
- **13.5** Summary of evolutionary stages for $1M_\odot$ star
- **13.6** Further nucleosynthesis in massive stars
- **13.7** Stellar Clusters

14. Neutrinos

15. Variable Stars
- **15.1** Pulsation
- **15.2** Three variable-rich regions of the HR diagram
- **15.3** Possible mechanisms for pulsation
- **15.4** Eddington's valve

16. Fate of Massive Stars
- **16.1** Post-Main-Sequence Evolution of Massive Stars (C&O 15.1)
- **16.2** Supernovae (C&O 15.2, 15.3)
- **16.3** Gamma-Ray Bursts (C&O 15.4)

17. Degenerate Remnants
- **17.1** Four possible end states of stars
- **17.2** Fermion degeneracy and the Fermi energy
- **17.3** White Dwarfs (C&O 16.2)
- **17.4** Electron degeneracy conditions and degeneracy pressure (C&O 16.3)
- **17.5** Chandrasekhar Limit (C&O 16.4)
- **17.6** Cooling of White Dwarfs (C&O 16.5)
- **17.7** Neutron Stars (C&O 16.6)
- **17.8** Pulsars (C&O 16.7)

Physics 3151: Astrophysics II

Preamble: This course discusses some of the more important topics in objects larger than stars – star clusters, galaxies – which are largely governed by gravity. The text is *An Introduction to Modern Astrophysics*, Second Edition, Bradley W. Carroll and Dale A. Ostlie (Pearson Addison-Wesley, 2007). Other useful sources are *Black Holes, White Dwarfs and Neutron Stars: The Physics of Compact Objects* by Stuart L. Shapiro and Saul A. Teukolsky, *Galactic Dynamics, Second Ed.* By James Binney and Scott Tremaine, and *Galactic Astronomy* by James Binney and Michael Merrifield. All of these are available in the QEII library. This course deals with astrophysical and cosmological topics that are of active and current interest and the course will evolve to include discussion of pertinent discoveries as they occur.

Astrophysics at large scales (C&O Chaps 24-26): Galaxies including types, Hubble classification and modern variants, Rotation of disk galaxies, Dark matter (C&O Chap 30), Tully-Fisher relations for disk galaxies, The Fundamental Plane for elliptical galaxies, and Structure of the Milky Way Galaxy in detail; Globular and open star clusters.

Compact objects (C&O Chaps 16 & 18): Compact binary systems; Dwarf novas, Recurrent novas, Classical novas, and Type Ia supernovas; Pulsars; Magnetars; X-ray binaries.

Black holes (C&O Chap 17): The Kerr metric; Stellar-mass black holes; Cyg X-1 in detail; Supermassive black holes; Active galactic nuclei; Quasars; Quasar spectra as a function of redshift; The Lyman forest and the Gunn-Peterson trough.

Introduction to cosmology (C&O Chaps 29-30): The cosmic microwave background radiation; The FLRW metric and the Friedmann equations; Cosmological expansion; Dark energy.

Physics 3220: Classical Mechanics I

Preamble: The recommended textbook for this course is *Classical Mechanics* by J.R. Taylor. This book contains a good balance of topics suitable for a third year level course including Newtonian based topics as well as introductions to Lagrangian and Hamiltonian dynamics. As a result this book can also be used for PHYS 3230. An excellent reference text for this course is *Analytical Mechanics* by Fowles and Cassiday. The proposed outline follows the numbered chapters in Taylor. Chapter 1 is largely a review and can be covered quickly, apart from coordinate transformations. Alternatively some sections from this chapter can be assigned as a reading assignment followed by a quiz. Chapters 2 and 3 build on material from PHYS 1050/1051 and PHYS 2820. Chapter 2 introduces the concept of velocity dependent resistive forces provided by the surrounding medium such as air resistance. This chapter gives an excellent opportunity to discuss parameters which can be theoretically derived or empirically determined to model the resistive effect of a fluid. Chapter 3 introduces students to the motion of objects with variable mass. The analysis is conducted by considering both Newton's second law and the momentum of the system allowing for complicated systems to be investigated. Chapter 4 is largely a review of work and energy concepts introduced in first year but in a three dimensional framework. The student is also exposed to line integrals for calculating work done. Chapter 5 from the book builds on concepts of oscillations already covered in first year physics and PHYS. Chapter 6 is an introduction to Calculus of Variations and gives the student an excellent explanation and justification for the Lagrangian formalism discussed in Chapter 7. Chapter 8 is indicated as additional material that can be covered if time permits.

Ch. 1 Review of Vector geometry and Newton's Law of Motion

- Units
- Scalars and Vectors
- Vector Operations
- Coordinate Transformations
- Derivative of Vectors
- Fundamental Concepts of Physics
- Newton's Laws of Motion
- Momentum
- Differential Equations
- Alternative Coordinate Systems

Ch. 2 Projectile Motion and Resistance

- Air Resistance
- Linear Air Resistance – Horizontal and Vertical Motion
- Quadratic Air Resistance – Horizontal and Vertical Motion
- Terminal Velocity

Ch. 3 Momentum and Angular Momentum

- Conservation of Momentum
- Rockets
- Center of Mass Systems
- Angular Momentum
- Moment of Inertia

Ch. 4 Energy

- Kinetic Energy and Work
- Potential Energy and Conservative Forces
- Forces as the Gradient of Potential Energy
- Time Dependent Potential Energy
  Energy for One-Dimensional Systems
- Curvilinear One-Dimensional Systems
- Central Forces
- Energy of Interacting Particles
- Energy of a Multiparticle System.

Ch. 5 Oscillations

- Hooke's Law
- Simple Harmonic Motion
- Two-Dimensional Oscillators
- Damped Oscillations
- Driven Damped Oscillations
- Resonance
- Fourier Series
- Fourier Series Solutions for the Damped Oscillator

Ch. 6 Calculus of Variations

- Euler-Lagrange Equation
- Applications of the Euler-Lagrange Equations
- More than two variable systems

Ch. 7 Lagrange's Equation

- Lagrange's Equation for Unconstrained Motion
- Constrained Systems
- Examples of Lagrange's Equations
- Generalized Momenta and Ignorable Coordinates
- Conservative Laws

Ch. 8 Two Body Central Force Problems (time permitting)

- Center of Mass and Relative Coordinates; Reduce Mass
- The Equations of Motion
- The Equivalent One-Dimensional Problem
- The Equation of the Orbit
- The Kepler Orbit
- The Unbounded Kepler Orbit.

Physics 3230: Classical Mechanics II

Preamble: The recommended textbook for this course is *Classical Mechanics* by J.R. Taylor which is the same book used for the previous course PHYS 3220. The topics in this course are slightly more challenging than those covered in PHYS 3220 in part because they are mostly new concepts not seen before. Some of the sections in this course are more advanced than what can be covered in a third year course and so are treated a little superficially such as Euler angles and the motion of a spinning top. Chapter 11 discusses couple oscillations. Chapter 12, on Nonlinear Mechanics and Chaos, is mostly descriptive and can easily be assigned as independent reading on which the students can be asked to write a 5 page report on what they have learned. This allows time to be spent covering additional material more suited to a lecture room setting. Chapter 13 on Hamiltonian Dynamics is completely new and found interesting by the students. Chapter 14 on collision theory is a classical interpretation of particle collisions which is in contrast to the quantum mechanical approach taken in PHYS 3751. We no longer propose to cover relativistic mechanics in this course since it is covered in other courses. We instead offer Chapter 16 as an alternative, time permitting.

Ch. 9 Mechanics in Noninertial Frames

- Acceleration without Rotation
- The Tides
- The Angular Velocity Vector 336
- Time Derivatives in a Rotating Frame
- Newton's Second Law in a Rotating Frame
- The Centrifugal Force
- The Coriolis Force
- Free Fall and the Coriolis Force
- The Foucault Pendulum
- Coriolis Force and Coriolis Acceleration

Ch. 10: Rotational Motion of Rigid Bodies

- Properties of the Center of Mass
- Rotation about a Fixed Axis
- Rotation about Any Axis; the Inertia Tensor
- Principal Axes of Inertia
- Finding the Principal Axes; Eigenvalue Equations
- Precession of a Top due to a Weak Torque
- Euler's Equations
- Euler's Equations with Zero Torque
- Euler Angles
- Motion of a Spinning Top

Ch. 11 Coupled Oscillators and Normal Modes

- Two Masses and Three Springs
- Identical Springs and Equal Masses
- Two Weakly Coupled Oscillators
- Lagrangian Approach: The Double Pendulum
- The General Case
- Three Coupled Pendulums
- Normal Coordinates

Ch. 12 Nonlinear Mechanics and Chaos
- Linearity and Nonlinearity
- The Driven Damped Pendulum DDP
- Some Expected Features of the DDP
- The DDP: Approach to Chaos
- Chaos and Sensitivity to Initial Conditions
- Bifurcation Diagrams
- State-Space Orbits
- Poincare Sections
- The Logistic Map

Ch. 13 Hamiltonian Mechanics
- The Basic Variables
- Hamilton's Equations for One-Dimensional Systems
- Hamilton's Equations in Several Dimensions
- Ignorable Coordinates
- Lagrange's Equations vs. Hamilton's Equations
- Phase-Space Orbits
- Liouville's Theorem

Ch. 14 Collision Theory
- The Scattering Angle and Impact Parameter
- The Collision Cross Section
- Generalizations of the Cross Section
- The Differential Scattering Cross Section
- Calculating the Differential Cross Section
- Rutherford Scattering
- Cross Sections in Various Frames
- Relation of the CM and Lab Scattering Angles

Ch. 16 Continuum Mechanics (time permitting)
- Transverse Motion of a Taut String
- The Wave Equation
- Boundary Conditions; Waves on a Finite String
- The Three-Dimensional Wave Equation
- Volume and Surface Forces
- Stress and Strain: The Elastic Moduli
- The Stress Tensor
- The Strain Tensor for a Solid
- Relation between Stress and Strain: Hooke's Law
- The Equation of Motion for an Elastic Solid
- Longitudinal and Transverse Waves in a Solid
- Fluids: Description of the Motion
- Waves in a Fluid

Physics 3300: Intermediate Physical Oceanography

Preamble: Intermediate Physical Oceanography is an opportunity to integrate several previous topics in physics and mathematics together to study a complicated physical system: the ocean. Equations of motion are developed (physically motivated) by conservation laws of mass, momentum, and energy. Primary dynamics topics are geostrophy, Ekman dynamics, basin scale circulation, and non-rotating wave dynamics. PHYS3300 introduces a fairly substantial list of physical oceanographic nomenclature and terms. Knowledge about the oceans that are more qualitative and descriptive is also taught e.g. ocean profiles, water masses, deep circulation. This course is also a required course for third-year Ocean and Naval Architecture Engineering students. While previous coursework in ODEs, PDEs, and vector calculus are useful, they are not required for this course. It is assumed students will be familiar with the solution of second order, constant coefficient, ordinary differential equations (e.g. simple harmonic motion). Solutions to any other differential equations are given and students are only asked to verify that the solution satisfies the DE. Multivariable calculus (MATH2000) is required. Integrals and derivatives with respect to different variables are used extensively. The gradient operator is reviewed and used. Vector calculus topics of divergence and curl are introduced in this course as needed. No major theorems from vector calculus (e.g. Stokes' or Gauss's theorems) are used. Phys2053 on fluids and thermodynamics is not strictly required for this course but would be helpful. First year material on kinematics, Newtonian dynamics, and waves are essential. This course does not assume previous knowledge of fluid dynamics. However, it does introduce topics covered more fully in courses on continuum mechanics and fluid dynamics. The Navier-Stokes equations are motivated physically and explained but not mathematically derived.

1. **Equations of Motion**

- Scales of motion and scale analysis
- Derivation of mass conservation
- Material derivative
- Rotating reference frame
- Motivation of momentum conservation equations
- Turbulence and eddy diffusivity
- Conservation of energy and salinity; density equation

2. **Physical Properties of Seawater**

- Pressure and hydrostatic balance
- Temperature, Potential Temperature
- Salinity
- Equation of State, Potential Density
- Field instrumentation, historic and modern
- CTD and bottle data from ocean profiles
- Buoyancy frequency, static stability
- SOFAR channel

3. Geostrophic Flow

- Geostrophic equations
- Geostrophic velocity
- Cyclonic and anti-cyclonic flow
- Sea surface slope and geostrophy
- Satellite altimetry
- Local and planetary vorticity
- Conservation of potential vorticity
- Taylor-Proudman theorem
- Thermal wind equations
- Baroclinic and barotropic flow

4. Wind Forcing and Ekman Layers

6. Dominant zonal wind patterns
7. Wind stress
8. Surface Ekman layer, Ekman spiral
9. Ekman volume transport
10. Ekman pumping
11. Wind stress curl

5. Wind Driven Circulation

- Mean, anomaly, and synoptic currents
- Identify major surface currents
- Sverdrup balance, beta plane
- Western boundary currents

6. Water Masses and Deep Circulation

- Ocean sections
- T-S plots, including mixing
- Water masses and T-S plots
    - MW, AABW, AAIW, NADW
- Ventilation, surface heat flux, buoyancy flux
- Meridional overturning circulation
    - Deep water formation
    - Deep western boundary currents
    - Abyssal mixing
- ‘Great Conveyor Belt’ models including role of Southern Ocean
- Significance to climate change modelling

7. Waves and Tides

- Surface gravity waves
- Dispersion relation and dispersive waves
- Deep water and shallow water waves
- Phase velocity and group velocity
- Equilibrium tide theory
- Tidal harmonic analysis and constituents

8. Additional Topics (optional)

1. El Nino/Southern Oscillation
2. Numerical ocean modelling
3. Internal Waves

Textbook: Robert H Stewart, Introduction to Physical Oceanography, 2009, 315pp

Physics 3340: Principles of Environmental Physics

Preamble: Principles of Environmental Physics will look at the environment of our planet through the understanding provided by physics. The course draws on ideas and principles from many different areas of physics including mechanics, electricity and magnetism, thermodynamics and particle physics. The key areas covered will include those of primary concern to people today, issues like climate change and energy production.

(1) Environmental physics
Introduction and background, connections between science and social-science, range of problems, scaling humans on the planet

(2) Atmospheric structure and climate
Solar input, radiation balance, environmental spectroscopy, ozone layers, CO_2 and CH_4 greenhouse effect

(3) Ocean structure and climate
Role of ocean in climate, production in the oceans, modeling dynamics of oceans and atmospheres

(4) Energy production and use
Fossil fuels, thermodynamics issues, different sources, renewable energy sources, nuclear energy

(5) Information and decision making
Science information in guiding public decision making (especially when dealing withcomplex non-linear phenomena with large uncertainties), the role of science and scientists, risk analysis, uncertainty assessment, credibility, and responsibility.

Optional topics (depending on class interest) include : pollutant transport, the physics of ice sheets, sea level change, and groundwater hydrology.

Textbook: E. Boeker and R. van Grondelle. Environmental Physics 3rd Edition. Wiley and Sons, 2011. 448 pp

Physics 3400: Thermal Physics

Preamble. The thermal physics stream, given the present degree of overlap of material between P2053 and P3400, offers an opportunity to introduce more flexibility in the Honour Physics program by removing P4400 as a *required* course. Feedback from physics students was that P2053 was too thin and the overlap between P2053 and P3400 was too great.

To address these issues, beginning already in Fall 2016, some material covered in P3400 was added to P2053. This will decrease the overlap between these two courses. Specifically, material from Chapter 2 in the P3400 course textbook (Thermal Physics by Daniel V. Schroeder), which builds up to entropy and the Second Law starting from counting microstates of simple model systems, is now being included in P2053. This will allow us to start P3400 with a quick review of Chapters 1 and 2 of Schroeder (~2 weeks instead of ~4), reviewing and incrementally building on the basic concepts that will have been covered in P2053.

Moreover, starting F2016, the coverage of heat engines (Chapter 4) is being taken out of P3400, since heat engines are covered at some length in P2053 already. These adjustments on Chapters 2 and 4 allow the inclusion of Boltzmann and quantum statistics (Chapters 6 and 7), thus providing a substantial introduction to statistical mechanics that should render P3400 as an adequate terminal *required* course in thermal physics for the honours program. Students keen on pursuing statistical mechanics may elect to take P4400, which will be geared to students who may be inclined to pursue research in areas that lean heavily upon statistical mechanics. Students not electing to take P4400, may end up taking P3400 in 4th year, alleviating a rather congested third year schedule in the Honours program.

2-1. Quick Review of Chapters 1 and 2: Energy in Thermal Physics, The Second Law (i.e. P2053 material). (~ 2 weeks). Thermal equilibrium, the ideal gas, equipartition of energy, heat and work, enthalpy, heat capacity, rates of processes, two-state processes, Einstein model of a solid, interacting systems, large systems, the ideal gas, entropy.

2-2. Chapter 3: Interactions and Implications (~ 2 weeks). Temperature, entropy and heat, paramagnetism, mechanical equilibrium and pressure, diffusive equilibrium and chemical potential.

2-3. Chapter 5: Free Energy and Chemical Thermodynamics (~ 3 weeks). Free energy as available work, free energy as a force towards equilibrium, phase transformations of pure substances. Time permitting: phase transformations of mixtures, dilute solutions, chemical equilibrium.

2-4. Chapter 6. Boltzmann Statistics. (~ 2 weeks). Review of probability and entropy, Boltzmann factor and the partition function, Maxwell speed distribution, free energy, ideal gas.

2-5. Chapter 7. Quantum Statistics (excluding Section 7.5) (~ 3 weeks). Gibbs factor and grand partition function, quantum statistics: bosons and fermions, degenerate Fermi gas, density of states, blackbody radiation, Bose-Einstein condensation.

Physics 3500: Electromagnetic Fields I

Preamble: This is a traditional course on Electromagnetic Fields in "vacuum" and materials. It deals exclusively with electro and magneto-static conditions and serves as an introduction to the second part (P4500 Electromagnetic Fields II) that treats the dynamic aspects (electromagnetic waves). While some results might not be new to students (P2055) they are derived rigorously using fundamental theorems (divergence and curl).

Proposed text book: *Introduction to Electrodynamics* (Griffiths)

Chapter 1: Vector Analysis

- Gradient, Divergence, and Curl (1.2 – 1.2.5)
- ∇ Operators and product rules (1.2.6 – 1.2.7)
- Integral Calculus: (line, Surface, and Volume integrals) (1.3.1)
- Fundamental Theorem (Gradient, Divergence, Stoke) (1.3.2 – 1.3.6)
- The theory of vector fields (1.6)
- Delta functions (1.5)

Chapter 2: Electrostatics

- Electric field of charge distribution (2.1)
- Flux, divergence, and curl of electrostatic fields (2.2.1 – 2.2.2)
- Applications of Gauss's law (2.2.3)
- Electric potential of charge distribution (2.3)
- Boundary conditions (2.3.5)
- Work and energy in electrostatics (2.4)
- Conductors (2.5)

Chapter 3: Special Techniques

- Multipole expansion (monopole, dipole, and quadrupole moment) (3.4)
- Solving Laplace's equation and Fourier series (Cartesian, cylindrical, and spherical coordinates) and separation of variable (3.1&3.3)

Chapter 4: Electric field in matter

- Mechanisms of electric polarization and alignment of dipole moments (4.1)
- Field of polarized object (bound charges) (4.2)
- Electric displacement field, Gauss's law, and boundary conditions (4.3)
- Linear dielectrics and boundary conditions (4.4)
- Capacitances (1.5 & 4.4)
- Force and energy in dielectrics (4.4.3)

Chapter 5: Magnetostatics

- Lorentz force (5.1)
- Force on a wire with current and Charge conservation (5.1.3)
- Biot-Savart law (5.2)
- Divergence and curl of B (5.3)
- Magnetic vector potential and boundary conditions (5.4)
- Multipole expansion (5.4.3)

Chapter 6: Magnetic field in matter

- Magnetic moment: orbital and spin contribution
- Field produced by magnetized objects (6.2)
- Boundary conditions (6.3)
- Linear Medium (6.4)

Chapter 7: Electrodynamics

- Electromagnetic Force (7.1)
- Electromagnetic Induction (7.2)

Physics 3600: Optics and Photonics I

Preamble: Together with PHYS 4600 and PHYS 6012, PHYS 3600 is the first of the three courses on optics and photonics with a focus on geometrical and physical optics. This course covers fundamental topics in geometrical and physical optics including thin lenses, mirrors, optical instruments, two-beam and multiple-beam interference, Fraunhofer diffraction, Maxwell's Theory (reflection, transmission, and polarization), fibre-optic light guides, modulation of light waves, and optical communication systems.

Textbook: *Introduction to Optics*, 3rd Edition, by Pedrotti, Pedrotti, and Pedrotti.

Chapters Covered: Text Sections Covered: 2-2, 2-3, 2-4, 2-5, 2-6 (Read), 2-7, 2-8, 2-9, 19-3 (Read), 19-4, 19-5 (Myopia and Hyperopia), 3-5, 3-6, 3-7, 3-2, Chapter 20 (Qualitative), 4-1, 4-2, 4-3, 4-4, 4-5, 4-8, 5-1, 5-2, 7-1, 7-2, 7-3, 7-4, 7-5, 7-6 (Read), 8-1, 8-2 (Read), 7-8, 7-9, Chapter 9 (Coherence - Material covered in lecture notes), 11-1, 11-3, 11-4 (Read), 11-5, 11-6, 12-1, 4-8, 4-9, 23-1, 23-2, 23-3, 10-1, 10-2 (Read), 10-4, 10-5, 10-6, 10-7, 24-1, 24-2, 24-3, 24-4, 24-5

- Geometrical Optics (~ 7 lectures)
- Interference (~ 6 lectures)
- Diffraction (~ 4 lectures)
- Maxwell's Theory and Polarization (~ 5 lectures)
- Fibre-optic Light Guides (~ 5 lectures)
- Modulation of Light Waves (~4 lectures)
- Optical Communication Systems (~ 3 lectures)

Geometrical Optics. Chapter 2.

- 2-2 Fermat's principle
- 2-2 to 2-5 Reversibility, reflection and refraction at planes
- 2-6 Imaging (for students to read)
- 2-7 to 2-8 Reflection and refraction at spherical surfaces.
- 2-9 Thin lenses

Optics of the eye. Chapter 19

- 19-3 (for students to read)
- 19-4 and 19-4 Myopia and Hyperopia

Optical Instruments. Chapter 3

- 3-5 Magnifiers
- 3-6 Microscopes
- 3-7 Telescopes
- 3-2 Aberrations

Aberration Theory Chapter 20

- A qualitative description

Wave Equations. Chapter 4

- 4-1 1D wave equations
- 4-2 Harmonic waves
- 4-3 Complex numbers
- 4-4 Harmonics as complex functions
- 4-5 Plane waves
- 4-8 Electromagnetic waves
- 4-9 Light polarization

Superposition of waves. Chapter 5.

- 5-1 Superposition principle
- 5-2 superposition of waves at the same frequency

Interference of light. Chapter 7.

- 7-1 Two-beam interference
- 7-2 Young's double slit experiment
- 7-3 Double slit with virtual sources
- 7-4 Interference in dielectric films
- 7-5 Fringes of equal thickness
- 7-6 Newton's rings (students to read)
- 7-8 Stokes relations
- 7-9 Multiple beam interference in a parallel plate

Optical Interferometry. Chapter 8.

- 8-1 The Michelson Interferometer
- 8-2 …with applications (students to read)

Coherence. Chapter 9 (using lecture notes)

- Fourier analysis, partial coherence, spatial coherence.

Fraunhofer diffraction. Chapter 11

- 11-1 Diffraction from a single slit
- 11-3 Rectangular and circular apertures
- 11- 4 Resolution (students to read)
- 11-5 Double-slit diffraction
- 11-6 Diffraction from many slits

Fresnel equations. Chapter 23

- 23-1 The equations
- 23-2 External and internal reflections
- 23-3 Two-layer anti-reflecting films

Fiber optics. Chapter 10

- 10-1 Applications
- 10-2 Communications systems (students to read)
- 10-4 Optics of propagation
- 10-5 Allowed modes
- 10-6 Attenuation
- 10-7 Distortion

Nonlinear optics and modulation of light. Chapter 24

- 24-1 The nonlinear medium
- 24-2 Second harmonic generation
- 24-3 Electro-optic effects
- 24-4 Faraday effect
- 24-5 Acousto-optic effect

Physics 3750: Quantum Physics I

There is general consensus that no ideal textbook exists that covers the desired syllabus. Several have been used in the recent past, the most popular being

A. *Introduction to Quantum Mechanics* (2nd edition), David J. Griffiths (Pearson Prentice Hall)

Material from other texts (some out of print) have been used extensively in developing course notes, including

B. *Quantum Physics of Atoms, Molecules, Solids, Nuclei and Particles* (2nd edition), R. Eisberg and R. Resnick (Wiley).

C. *Quantum Physics* (3rd edition), S. Gasiorowicz (Wiley).

D. *Introduction to the Structure of Matter*: *A Course in Modern Physics*, J. Brehm and W. J. Mullin (Wiley).

E. *Quantum Mechanics*, D. H. McIntyre (Pearson). A more advanced treatment.

F. *Quantum Mechanics*, B. Cameron Reed (1st edition) Jones & Bartlett

Quantum Physics I is mainly intended to be an extension of the basic concepts, formalism and applications covered in Modern Physics, PHYS 2750. It provides an opportunity for students to learn details concerning basic quantum physics concepts (wave functions, Schrodinger equation, potentials and operators) that will be also useful in PHYS 4850. Noteworthy is that the average enrollment between 2005 and 2015 in 3750 has been 19, and in 4850 it has been 6, so that about 2/3 of the 3750 students do not continue on to a formal Quantum Mechanics course. Formal matrix operator formalism is generally considered too advanced for this introduction to quantum physics, the goal of 3750.

Although useful for subsequent quantum mechanics courses, the (linear algebra) *Formalism* contained in chapter 3 of book **A**, for example, is not recommended and not used in subsequent section of the material covered in 3750.

A collection of topics roughly in order of collective preference is outlined below:

Module 1: The Wave Function [**A**-Ch1, **B**-Ch5, **C**-Chs2&3, **D**-Ch5,**F**-Ch2] Schrodinger equation, probabilities and statistical interpretation, uncertainty principle, expectation values.

Module 2: Time-independent Schrödinger's equation [**A**-Ch2, **B**-Ch6, **C**-Chs3&4, **D**-Ch5, **E**-Chs5&6,**F**-Chs.3&5]

Stationary states, particle in one-dimensional potential wells (including the infinite potential well, the finite potential well, tunneling, and the harmonic oscillator), parity operator.

Module 3: Schrödinger's equation in three dimensions and angular momentum [**A**-Ch4, **B**-Ch7, **C**-Ch8, **D**-Chs6&7, **E**-Chs7&8,**F**-Chs6&7]

Separation of variables, particles in a 3D box, spherical potentials, angular momentum operators, the hydrogen atom, a brief introduction to spin, free particle.

Project Module: Students choose a term project to get an introduction to an advanced topic, which is presented in class as well as via a written report. Students get close guidance and are allowed to iterate on the presentations with the instructor prior to the final presentation, thus mimicking the style of a research project. Also, a connection to atomic spectroscopy (including a trip to the 3rd year laboratory) is made.

Past term project topics have included:

1. Early Results in Quantum Physics
Measurement of electron charge, fine structure of hydrogen
2. Quantum Physics inspired Experimental Methods
Magnetic Resonance, Electron and Neutron Diffraction, Quantum teleportation
3. Quantum Statistics and Macroscopic Quantum Phenomena
Fermions and bosons, Superfluidity, Superconductivity, Bose-Einstein Condensation, Spin and the Stern-Gerlach experiment
4. Quantum Theory Fundamentals and Quantum Information
Bell's Theorem, Quantum computing, Quantum cryptography

Additional Modules:

1. Magnetic field effects: Stern-Gerlach experiment, spin-orbit coupling, Zeeman effect, fine structure, relativistic correction to the hydrogen atom (**A**-Ch6, **B**-Ch8, **C**-Ch12, **D**-Ch8, **E**-Ch12,**F**-Ch8).

2. Multi-electron atoms, electron-electron potential, Pauli exclusion, Helium atom, exchange interaction (**A**-Chs5&7, **B**-Chs9&10, **C**-Chs13&14, **D**-Ch9, **E**-Ch13,**F**-Ch.8)

Physics 3751: Quantum Physics II

Preamble: Initially, Phys3751 was designed as an introduction to the physics of many-particle systems, and later it turned into a particle physics course. The standard course textbook was "Introduction to elementary particles" by Griffiths. This book will remain the main textbook in this course.

However, Griffiths' text assumes that the student has solid preliminary knowledge of quantum mechanics and electrodynamics, and refers to the corresponding texts for the derivation of a number of intermediate results. There is clearly a need to supplement the course based on Griffiths' book with additional literature, which provides these derivations and explanations. For this reason, six supplementary texts have been selected to fill in this gap. Although some of them are graduate-level texts, their chapters relevant for this course can be understood by an undergraduate student.

1. **Special relativity**
   [1] Ch. 3, [2] App. A; [5] Ch. 1
   - Lorentz transformations
   - Four-tensors
   - Energy-momentum of a free particle

2. **Relativistic quantum mechanics**
   [1] Ch. 7, [2] Sec. 8-3, [4] Ch. 1 and 2; [5] Ch. 3 and 4, [6] Ch. 13
   - Postulates of quantum mechanics
   - Klein-Gordon equation for a free particle
   - Phase invariance of the wave function and electromagnetic field (minimal coupling)
   - Particles and antiparticles
   - Dirac equation for a free particle
   - Dirac equation for an electron in an electromagnetic field; 4-current density
   - Dirac's theory of spin
   - Solution of a free Dirac equation

3. **Theory of decay and scattering**
   [1] Ch. 6, [2] App. K; [3] Ch. 10
   - Fermi's golden rule
   - Scattering cross-section and lifetime
   - Feynman diagrams

4. **Elementary particle physics**
   [1] Ch. 1, 2, 4; [2] Ch. 18; [3] Ch. 9; [7] Ch. 13
   - Yukawa interaction between nucleons; pions
   - Elementary particles and quantum numbers: barion number, strangeness, isospin
   - Quark structure of hadrons
   - Strong interaction: color and gluons
   - Fermi theory of beta decay
   - Leptons
   - Weak interaction: W- and Z-bosons
   - Nonconservation of parity in weak interactions
   - Charge conjugation and CP-transformation
   - CPT theorem
   - Standard model

Literature:

Main textbook:
[1] D. Griffiths. Introduction to elementary particles. Wiley, 1987. **QC793.2 .G75 2008**
Supplementary literature:
[2] R. Eisberg and R. Resnick. Quantum physics of atoms, molecules, solids, nuclei, and particles. Wiley, 1985. **QC174.12 .E34 1974.**
[3] H. Frauenfelder and E. Henley. Subatomic physics. Prentice Hall, 1991. **QC776 .F723 1991.**
[4] W. Greiner. Relativistic quantum mechanics: wave equations. Springer, 1990. **QC174.26 .W28 G7413 2000**
[5] P. Strange. Relativistic quantum mechanics. Cambridge Univ. Press, 1998. **QC174.24 .R4 S87 1998**
[6] L. Schiff. Quantum mechanics. McGraw-Hill Book Co, 1949. **QC174.1 .S34**
[7] W. Williams. Nuclear and particle physics. Oxford Univ. Press, 1991. **QC776 .W55 1992**

Physics 3800: Computational Physics.

Preamble: This course arose from the recognition of the growing use of computational tools to perform research by both theoreticians and experimentalists. Indeed, the majority of research activity executed by theoreticians in physics is computational in nature. Academic job postings now frequently appear that specify a search for a Computational Physicist. The assumption of a basic knowledge of rudimentary numerical analysis and programming is implied by the prerequisites of CS1510 and P2820. Some of the numerical techniques covered in P2820 are reviewed in P3800, such as low-order Euler and Runge-Kutta discretization of ODEs. Tutorials are a major component of the course where initially students are presented with hands-on learning of basic Unix commands and scripting. This component later evolves into help sessions where students get assistance while working on projects. Evaluation is achieved through assignments (which typically have programming components) as well as two major programming projects, with detailed write-ups as in P3900/4900. Latex is required for the write-ups, with the student's computer code and batch files submitted also for evaluation. There is no final exam. The initial part of the course relies on regular lectures but later focuses more on the projects. Help sessions and tutorials (given by the TA) can often be held during regular class lectures times. The course syllabus typically includes ODEs, PDEs, Matrices and Stochastic Methods (e.g., Monte Carlo). Fortran and C/C++ are the preferred languages. Error analysis is emphasized. There is no one good textbook. Several possibilities, from which the syllabus and course notes are partially followed, include *Computational Physics: An Introduction*. (F. Vesely, Kluwer 2001) and *Introductory Computational Physics*, by A. Klein and A. Godunov. (Cambridge University Press, 2006). In addition, there are numerous useful documents available online. These are made available to students via D2L.

I. <u>Review of Unix and Numerical Calculus.</u>

- Basic Unix commands.
- Basic Latex.
- Use of Scripts.
- Editing and plotting software.
- Review of numerical differentiation and integration

II. <u>Ordinary Differential Equations (ODEs).</u>

- Euler, Leap Frog.
- Runge-Kutta.
- Adaptive time steps.
- Order and Accuracy.

III. <u>Matrices and Eigenvalues.</u>

- Gaussian elimination.
- Poisson's equation.
- Eigenvalue problems.
- Library Subroutines.

IV. Monte Carlo Simulations.

- Random number generators.
- Random walk.
- MC integration.
- Metropolis method.
- Molecular dynamics.

V. Partial Differential Equations (PDEs).

- Laplace, Wave and Diffusion equations.
- Euler and Lagrangian methods.
- Matrix forms.

Physics 3820: Mathematical Physics I

Preamble: The preferred textbooks have been Mathematics for Physicists, S. M. Lea. (Thomson, 2004). and later editions of Arfken. Students generally found Arfken at a level beyond the typical third-year student and Lea has been used as the main text 2013-5. Arkfen is, however, a valuable secondary text, and is the preferred textbook for P4820. The course material follows closely a number of chapters in Lea, with the course naturally divided into four sections. The prerequisites are M2260 (ODEs) and M3202 (Vector Calculus) so that substantial sections of the course will serve as a review for the students and can be covered fairly quickly. For these sections of the course, the focus should be applications involving physics-type equations and problems. In addition, these and other sections of the course should emphasize more sophisticated notation such as summation conventions and the Levi-Civita symbol. Most students will have only a cursory knowledge of complex numbers and functions. This should be considered the principal part of the course – material they will not have seen before and that is considered core knowledge for any physics major – in particular complex integration. Students will have seen a lot of ODEs in M2260, but not PDEs. PDEs are only briefly covered in Lea. In addition, M2260 typically does not cover the all important series solutions. The main focus of this section is separation of variables to yield ODEs, which students are familiar with, as well as series solutions to ODEs. Finally, Fourier series and transformations are covered but only in a cursory manner due to time limitations. The idea of wave vectors is introduced. Series for complex functions are expanded upon.

Ch. 1 & App. A. Review of vectors and matrices.

- Vector calculus (notation, notation, notation): Levi-Civita, Div, Curl, Integration,…
- Tensors (more notation, notation, notation): rank, rotations,…
- Matrices, transformations, more rotations, Euler angles, diagonalization,…

Ch. 2. Complex variables and integration.

- Complex algebra, functions and derivatives.
- Branch points and cuts.
- Cauchy-Riemann conditions.
- Cauchy integral formula.
- Complex series.
- Residues and integration using residues.
- Gamma factorial function.

Ch. 3. Partial and ordinary differential equations - mostly from Kreyszig and Arfken.

- Classification of PDEs.
- Separation of variables.
- Series solutions.

Chs. 4 & 7. Fourier series and transforms.

- Series for real functions.
- Series for complex functions.
- Fourier transforms (briefly).
- Solutions to ODEs using Fourier series.

Physics 3900: Experimental Physics I

Preamble: This is a lab-based course with no text book. Each experiment has a short set of background and instructions. Students spend three (3-hour each) lab periods on each experiment, for a total of 6 separate experiments per term. Grading has been based on lab notebooks (turned in after each experiment), two full-length manuscript-style written lab reports, and one oral presentation.

Typical Outline

- Introduction (1 lab): Course organization, motivation, overview of different experiments
- Diffraction gratings (3 labs)
- Speed of light (3 labs)
- Fluids (student choice, 3 labs)
- Material characterization (student choice, 3 labs)
- Optics (student choice, 3 labs)
- Student choice from any category (3 labs)
- Student Presentations (1 lab)

Physics 4000: Introduction to Solid State Physics

Preamble: Since 2013, the textbook has been *Condensed Matter Physics*, Michael P. Marder (McGraw-Hill, 2012). This course is designed to share lectures with PHYS 6000: Condensed Matter Physics so that graduate students with mixed backgrounds can all get up to speed. The course follows selected chapters from the text. In recent years, the course format has students read the text and submit questions to the instructor prior to class, and then the class periods focus on discussing student questions related to the reading and/or problem sets.

Outline

Ch1-2 Crystal structure and symmetry (3 classes)
* Unit cells: primitive cell, proper cell, lattice, basis
* 7 crystal systems, 14 Bravais lattices
* From 2D to 3D lattices: designating atom positions, conventional unit cells, Wigner-Seitz cells, coordination number
* Miller indices

Ch 3 Reciprocal lattice (2 classes)
* Diffraction of waves by crystals, Scattered wave amplitude
* Brillouin zones, Fourier analysis of the basis

Ch 6 Free electron models (3 classes)
* Density of states in k space, Fermi-Dirac distribution function, Electronic density of states
* Density of states at the Fermi energy, electronic heat capacity, failures of the Sommerfeld model

Ch 7 Periodic potentials (3 classes)
* Periodic potentials and energy gaps
* Born-von Karman boundary conditions, Schrodinger equation in a periodic potential, Bloch's theorem

Ch 8,10 Tightly bound electrons and realistic calculations (3 classes)
* Consequences of the nearly free electron model
* Band arising from a single electronic level
* Comparison of tight binding and nearly free electron bandstructure, importance of k, Holes
* Realistic calculations

Ch 13 Phonons (4 classes)
* Classical dispersion relations, monatomic and diatomic 1D crystals
* Debye and Einstein models
* Measuring phonon dispersion relations

Ch 16 Dynamics of Bloch Electrons (3 classes)
* Why scattering is important, thermal and electrical conductivity of metals
* Semiclassical model of electron dynamics
* Beyond the relaxation time and independent electron approximations

Physics 4205: Introduction to fluid mechanics

Preamble: This course is a basic introduction to the subject of fluid mechanics and is intended for undergraduate and beginning graduate students of applied mathematics and physics. This course introduces the general equations, both integral and differential, that result from the conservation of mass principle, Newton's second law, and the first law of thermodynamics. From these a number of particular situations will be considered that are of special interest. After completing this course the students should be able to apply the basic principles and methods of mechanics to new and different situations. Classical hydrodynamics is largely a subject in mathematics, since it deals with an imaginary ideal fluid that is completely frictionless. Much of the mathematics is classical, being more than one hundred years old. Fluid mechanics is the combination of classical hydrodynamics and the study of real fluids. In modern fluid mechanics the basic principles of hydrodynamics are combined with experimental data. The experimental data can be used to verify theory or to provide information supplementary to mathematical analysis. With the advent of the computer the entirely new field of computational fluid mechanics (CFD) has developed. Various numerical methods such as finite differences, finite elements, and boundary elements are used to solve advance problems in fluid mechanics. The business of CFD applications alone now employs several tens of thousands of people and has a turnover of some billions of dollars a year.

Kinematics
Conservation Laws
Vorticity Dynamics
(4) Irrotational Flow
(5) Gravity Waves

Physics 4300: Advanced Physical Oceanography

Preamble: PHYS4300 is an introduction course in theoretical geophysical fluid dynamics. Equations of motion are developed from conservation laws of mass, momentum, and energy. Analytical solutions for geostrophic flows, Ekman layers, and linear non-rotating and rotating waves are derived and explored in detail. A firm grasp of both ordinary and partial differential equations is required. Special topics are introduced depending on the research interests of the students taking the graduate PHYS6310 version of the course.

1. Introduction
2. The Coriolis Force
3. Equations of Fluid Motion
4. Equations Governing Geophysical Flows
5. Diffusive Processes
6. Transport and Fate
7. Geostrophic Flows and Vorticity Dynamics
8. The Ekman Layer
9. Barotropic Waves

Textbook: Benoit Cushman-Roisin & Jean-Marie Beckers Introduction to Geophysical Fluid Dynamics, 2nd Ed., Academic Press, 828pp

Physics 4340: Modeling in Environmental Physics

Preamble: This course is an introduction to the basic principles of environmental modelling. It covers the equations of dynamics of oceanic, atmospheric and terrestrial dynamics and methods of their numerical solution and analysis. The focus is on the basic characteristics of linear and non-linear system analysis and different mathematical techniques, such as phase-plane analysis, used to explore the equilibrium states and dynamics of environmental systems. Free and forced dynamical systems, transition to chaos and some aspects of chaotic dynamics. will be discussed with application to uncertainty of model equations and predictability of climate and environmental systems. Examples will be drawn from the preceding course, Physics 3340, and other courses taken as part of the program. Fundamental techniques for numerical modelling will be developed and specific somewhat simplified models will be coded for the atmosphere and ocean and for modelling in ecology and for pollutant dispersal in the atmosphere and ocean. The course will focus on the development and application of numerical models, and the analysis and interpretation of model results.

(1) Principles of Modelling Linear and Nonlinear Systems. Examples of equations of environmental dynamical systems - atmosphere, ocean, cryosphere, land and ecology. Introduction to numerical methods.

(2) Understanding Equilibrium Dynamics in Environmental Models. Introduction to the concepts of static, steady state and dynamic equilibrium. Examples of radiative equilibrium in global climate system and equilibrium state of ocean overturning circulation.

(3) Simplified Numerical Models of the Ocean and Atmosphere. Development of models based on shallow water and quasigeostrophic approximations.

(4) Numerical Models of Ecology

(5) Modelling Pollutant Dispersal in the Atmosphere and Ocean

(6) Simplified numerical models of climate.

Physics 4400: Statistical Mechanics

Preamble. Beginning in the Fall 2016, PHYS 4400 will be revised substantially to reflect changes made in the PHYS 3400 curriculum and that it will now be listed as a recommended elective in our core physics program rather than required. Essential aspects of introductory Boltzmann and quantum statistics (Schroeder chapters 6 and 7) are now covered in 3400. 4400 will now be considered a more advanced statistical physics course, including some non-equilibrium phenomena, and as a bridge to graduate-level courses. It is not clear which choice for textbook would be best. Schroeder Chs. 6-8 formed the core of the course over the past decade. Twenty-some years ago, *Introduction to Modern Statistical Mechanics* by D. Chandler was recommended. The 1987 first edition is still in print (as of 2015). This text is viewed by some as being a bit too advanced as an undergraduate text. *Introductory Statistical Mechanics* by Betts and Turner (1992) was used in the more recent past (before Schroeder) and was well-liked by the instructors but is out of print. *Introduction to Statistical Physics* by Huang (second edition 2010) is perhaps a good compromise. Seems to be at the right level and is still in print (and not too expensive). Note that some topics covered in 3400 (e.g., Fermi and Bose statistics) are covered again with a more formal development.

New 4400 Course Outline – Based on Introduction to Statistical Physics, Huang.

Recommend covering chapters 5-9, 11-18.

Ch.1 A Macroscopic View of the World.

Ch.2. Heat and Entropy.

Ch. 3 Using Thermodynamics.

Ch. 4 Phase Transitions.

Ch. 5. The Statistical Approach. (1 week).
The atomic view, random walk, phase space, distribution function, ergodic hypothesis, statistical ensemble, microcanonical ensemble, correct Boltzmann counting, distribution entropy (H), most probable distribution, Shannon's entropy.

Ch. 6. Maxwell-Boltzmann Distribution. (1 week).
Ideal gas, equipartition. Speed distribution, entropy, derivation of thermodynamics, fluctuations, Boltzmann factor, time's arrow.

Ch. 7. Transport Phenomena.(1 week).
Collisionless hydrodynamic regime, Maxwell's demon, non-viscous hydrodynamics, sound wave, diffusion, heat conduction, viscosity, Navier-Stokes equation.

Ch. 8. Canonical Distributions. (1 week).
Review of the microcanonical ensemble, classical canonical ensemble, partition function, connection to thermodynamics, energy fluctuations, minimization of the free energy, classical ideal gas.

Ch. 9. Grand Canonical Distributions. (1 week).
The particle reservoir, Grand partition function, Number fluctuations, Connection with thermodynamics, Parametric equation of state and virial expansion, Critical fluctuations, Pair creation.

Ch. 10 Noise.

Ch. 11 Stochastic Processes. (1 week).
Randomness and probability, binomial distribution, Poisson distribution,Gaussian distribution, central limit theorem, shot noise.

Ch. 12. Time-Series Analysis (1 week).
Ensembles of paths, ensemble average, power spectrum and correlation function, signal and noise, transition probabilities, Markov process, Fokker-Planck, Monte Carlo, Ising model simulation.

Ch. 13. The Langevin equation. (1 week).
The equation and solution, energy balance, fluctuation-dissipation theorem, diffusion coefficient, transition probability, heating by stirring (forced oscillator in a medium).

Ch. 14. Quantum Statistics (1 week).
Thermal wavelength, identical particles, occupation numbers, spin, microcanonical ensemble, Fermi statistics, Bose statistics, pressure, entropy, free energy, equation of state, classical limit.

Ch. 15. Quantum Ensembles. (1 week).
Incoherent superposition of independent states, density matrix, QM canonical ensembles, QM grand canonical ensembles, occupation number fluctuations, photon bunching.

Ch. 16. The Fermi Gas. (1 week).
Energy, ground state, temperature, low-T, particles and holes, electrons in solids, semiconductors.

Ch. 17. The Bose Gas. (1 week).
Photons, Bose enhancement, phonons, Debye specific heat, electronic specific heat, conservation of particle number.

Ch. 18. BE Condensates (1 week).
Macroscopic occupation, The condensate, equation of state, specific heat, how is the phase formed, liquid helium.

Ch. 19. The Order Parameter.

Ch 20. Superfluidity.

Ch 21. Superconductivity.

P4500: Electromagnetic Fields II

Preamble: This course is a continuation of PHYS 3500 with a focus on dynamics and energy considerations. Specific topics follow those covered in the latter chapters of *Introduction to Electrodynamics* (Griffiths), also the recommended textbook for 3500. Starting with a quick review of the major concepts from basic electricity and magnetism (from 3500), new material can begin with either Ch 7 or Ch 8, depending on what was covered in 3500 in that year, ending with Ch 12. A major focus of the course is applications. Instructors are encouraged to use supplementary material from other texts, such as Jackson. The quick review of 3500 material can be aided by an early assignment on material students should already know as a means to force them to review on their own. After an introduction of the course and a brief review, which take about one week, the six sections listed below can be allocated roughly as two weeks for each of the ensuing sections with an exception of three weeks for the section 3.

1. Electrodynamics (Ch 7)
   - Electromotive force
   - Induction, Faraday's law, energy in magnetic fields
   - Maxwell's equations in vacuum and in matter
2. Conservation Laws (Ch 8)
   - Charge and energy
   - Continuity equation
   - Poynting's theorem
   - Conservation of momentum
   - Angular momentum
3. Electromagnetic Waves (Ch 9)
   - Waves in one dimension, boundary conditions, polarization
   - 3D wave equations for E and B, energy and momentum
   - EM waves in matter, propagation, reflection, transmission
   - Guided waves
4. Potentials and Fields (Ch 10)
   - Potentials and gauge transformations
   - Retarded potentials
   - Fields of a moving point charge

5. Radiation (Ch 11)
   - Electric and magnetic dipole radiation
   - Radiation from an arbitrary source
   - Point charges
   - Radiation reactions
6. Electrodynamics and Relativity (Ch 12)
   - Relativistic mechanics, energy, kinematics, dynamics

- Relativistic electrodynamics
- Magnetism as a relativistic phenomenon
- Field tensor
- Relativistic potentials

Physics 4600: Optics and Photonics II

Preamble: This course is a continuation of PHYS 3600 with a focus on the principles, techniques, and applications of lasers. Specific topics covered in this course may follow some chapters of two textbooks, i.e., Photonics: optical electronics in modern communications by Amnon Yariv and Pochi Yeh (sixth edition, Oxford University Press, 2007) and Elements of Photonics by Keigo Iizuka (John Wiley & Sons, 2002). Starting with a quick review of the major concepts from geometrical optics and physical optics (from PHYS 3600), the first half of the courses focuses on the principles and techniques of lasers, and the second half of the course addresses new phenomena and applications with the lasers, including nonlinear optical effects and devices, guided-wave optics, and fibre-optic communication. The eight sections listed below can be allocated roughly as one and a half weeks for each section.

1. Quick Review of basic Optics and Photonics (from PHYS 3600)

- Ray optics
- Wave optics
- Gratings and interferometers

2. Optical Resonators (Yariv and Yeh, Chapter 4)

- Fabry-Perot etalon
- Mode stability criteria
- Modes in optical resonators
- Resonance frequencies
- Losses in optical resonators

3. Interaction of Radiation and Atomic Systems (Yariv and Yeh, Chapter 5)

- Atomic transitions and electromagnetic waves
- Atomic polarizability and dielectric constant
- Dispersion and complex refractive index
- Lineshape function
- Induced transitions
- Gain saturation

4. Principles and techniques of lasers (Yariv and Yeh, Chapter 6)

- Properties of lasers (oscillation frequency, power, output coupling)
- Three- and four-level lasers
- Mode locking and Q-switching in Lasers
- Some specific laser systems

5. Nonlinear optics and devices (Yariv and Yeh, Chapters 8 and 9)

- Nonlinear polarization
- Second-order and third-order nonlinear phenomena
- Linear electro-optic effect and electro-optic modulation
- Third-order nonlinear optical processes

6. Guided-wave optics (Iizuka, Chapters 9 and 10)

- Planar optical guides
- Characteristic equations
- Asymmetric optical guides
- Rectangular optical waveguides
- Waveguide coupling

7. Fiber-optic communication (Iizuka, Chapters 11 and 16)

- Fibre-optic communication systems
- Modulation, multiplexing, and detection
- Modes and dispersion in optical fibers

8. Photonic crystal optics

- Physics of photonic bandgap
- Index gratings
- 1-D, 2-D, and 3-D photonic crystals

Physics 4820: Mathematical Physics III

Preamble: This course material naturally builds on what was covered in Physics 3820 or equivalent mathematics courses. The combination of Lea and Arfken textbooks works well since Lea's textbook acts as a link between Physics 3820 and 4820, and Arfken's textbook expands the material and introduces students to more general and broader treatment of the subjects covered. The large emphasis of this course is on solving differential equations using different methods with many examples and applications taken from as many branches of physics as possible. This is challenging to students since they are used to looking at physics as one stream at a time (e.g. classical mechanics, quantum mechanics, electrical circuit theory etc) and often do not realize that similar mathematics (a common language) underlies many branches of physics. Ultimately, it is the interplay between physics and mathematics that allows us to solve many physics problems.

1. Sturm-Liouville Theory (Ch. 8 (Lea) and Chs. 8 and 9 (AW))

- Hermitian operators
- ODE eigenvalue problems
- PDEs
- Separation of variables
- Laplace and Poisson equations
- Wave equation

2. Bessel Functions (Ch. 8 (Lea) and Ch. 14 (AW))

- Bessel functions of the first-kind
- Orthogonality
- Neumann functions, Bessel functions of the second-kind
- Hankel functions
- Modified Bessel functions

3. Legendre Functions (Ch. 8 (Lea) and Ch. 15 (AWH))

- Legendre polynomials
- Orthogonality
- Physical Interpretation of Generating Function
- Associated Legendre equation
- Spherical harmonics
- Associate Legendre equation
- Legendre functions of the second-kind

4. Integral Transforms: Laplace and Fourier Transforms (Ch. 5 (Lea), Ch. 7 (Lea) and Ch. 20 (AWH))

- Laplace transforms
- Properties of Laplace transforms
- Laplace Convolution Theorem
- Inverse Laplace transform
- Fourier transforms
- Properties of Fourier transforms
- Fourier Convolution Theorem
- Signal-Processing Applications (have not covered so far, maybe important for Phys Oceanog ?)

5. Delta Function, Theory of Distributions, Green's Functions (Ch. 6 (Lea), Chs. 1(1.11) and 10 (AWH))

- Introduction to theory of distributions
- Properties of distributions
- Examples of distributions: delta function and Green's functions

6. Group Theory (Optional Topic B (Lea) and Ch. 17 (AWH))

- Introduction to group theory
- Examples of groups
- Symmetry and Physics
- Representation of groups
- Discrete groups
- Continuous groups

Physics 4850: Quantum Mechanics

Preamble: The goal of 4850 is to provide a mathematically based course in quantum mechanics that covers all of the foundation material normally covered in an undergraduate physics degree and that will prepare students for more advanced, graduate level courses in quantum mechanics. The main themes are Hermitian operators (observables), measurement and probability.
The recommended textbook is Quantum Mechanics by Cohen-Tannoudji, Diu and Laloe; nearly all of the chapters are covered. This textbook is also used in 4851, which is a (optional) continuation of 4850.

1. vectors spaces and kets; orthonormal bases; linear operators; projection operators; Hermitian conjugation
2. x-representation, p-representation, R and P operators
3. matrix representation of kets, bras and operators
4. eigenvalues and eigenvectors of Hermitian operators
5. postulates of quantum mechanics
6. spin
7. two state system with coupling (amonia molecule)
8. harmonic oscillator: ladder operators, eigenvalues, eigenstates
9. angular momentum: J+- operators, basis states, matrix representation
10. orbital angular momentum in real space and spherical harmonics
11. spinor representation
12. addition of angular momentum; spin-orbit coupling
13. time independent perturbation theory
14. degenerate perturbation theory
15. time dependent perturbation theory; example: sinusoidal perturbation and resonance

Physics 4851: Advanced Quantum Mechanics

Preamble: For the last number of years, 4851 has been co-taught with 6850. The rational is as follows: 4850 is more or less the same senior undergraduate course in quantum mechanics that a student will take in any university. Following 4850, there are many different directions in quantum mechanics that can be explored, such as path integrals, relativistic quantum mechanics, quantum information etc. The content of such courses varies greatly by university. With 4850 as a foundation, students can go anyplace and continue in masters level quantum mechanics courses. Since our 4851 builds on the material of 4850, it is also appropriate as a masters level course. However, it is not likely to be identical to master courses offered elsewhere because of the enormous variety of content taught at this level. The enrollment in 4851/6850 is a minimum of 4 - usually 2 or 3 undergrads and 2 or 3 grad students. The undergrads are almost always applied math/physics joint honours .

The goal of course is to introduce students to important ideas that are relevant to current research trends, such as entanglement and Berry's phase, and to prepare students to take courses in quantum field theory, quantum statistical mechanics, quantum information, etc. Whereas 4850 covers Hermitian operators, measurements involving pure states and time-independent Hamiltonians in depth, 4851 deals with mixed states (density operators), unitary operators, including symmetry operations and the time-evolution operator, and treats time dependence in more detail.

The recommended text book is “Quantum Mechanics” by Cohen-Tannoudji, Diu and Laloe. This book is divided into regular chapters (which form the content of 4850) and complements. P4851 is based mainly on the complements of this text.

1. Tensor product of state spaces; matrix representation of kets and operators
2. Entanglement
3. Operators: functions of operators, unitary operators, parity operator, time evolution operator
4. Density operator: Pure states and statistical mixtures of states; thermodynamic equilibrium; Examples: spin 1/2 in a magnetic field in thermodynamic equilibrium; harmonic oscillator in thermodynamic equilibrium
5. von Neumann entropy and entanglement entropy
6. Time evolution operator
7. Schrodinger, Heisenberg and Interaction pictures of quantum mechanics
8. Ehrenfest's theorem; example: spin waves in a 1D chain
9. Sudden vs adiatic approximations
10. Berry's phase
11. Gauge fields; gauge transformations; Aharanov Bohm effect
12. Angular momentum and spin; rotations; brief description of SU(2) and Yang-Mills Theory (SU(2) and SU(3) gauge theories)
13. Space and time translation operators; space inversion
14. Time reversal and unti-unitary operators; application to angular momentum; Kramers degeneracy
15. Identical particles - exchange degeneracy, permutation operators; symmetrisation postulate for bosons and fermions
16. Occupation numbers, occupation number kets
17. Fock space, creation and annihilation operators
18. Propagators (Green's functions); retarded propagators;
19. Path integrals

Physics 4900: Experimental Physics II

Preamble: This is a laboratory-based course with no text book. Students are required to complete two experiments, the details of which are recorded in a laboratory notebook, and submit written reports on each in the style of a published scientific journal article. Approximately 10 laboratory periods are allotted per experiment. Experiments are open-ended and students are strongly encouraged to extend their studies beyond what is provided in lab instruction sheets, manuals and/or instructor's suggestions. Grading: laboratory notebooks submitted after each experiment (40%), two written reports, each prepared in the format of a published scientific journal article (40%), oral presentation (20%).

Introduction (1 class): Course organization, motivation, overview of different experiments

Students are required to complete two experiments from the list below and prepare research journal-style articles for each.

Experiments Available (Note: Others may become available during the semester):

- Studies of Soap Bubble Films
- Optical Waveguiding
- Diffusion Limited Aggregation
- Optical Spectroscopy
- Nuclear Magnetic Resonance
- Fourier Transform (FTIR) Spectroscopy

Student Presentations (1 class): Near the end of the semester, students give an oral presentation on one of the two experiments completed.