The DPE/CAP Undergraduate Physics Curriculum Project
Preliminary Report

Members:
Bob Hawkes, Mount Allison University (rhawkes@mta.ca)
Joanne O'Meara, University of Guelph (omeara@physics.uoguelph.ca)
Tom Steele, University of Saskatchewan (tom.steele@usask.ca)
Tom Tiedje, University of British Columbia (tiedje@physics.ubc.ca)

Introduction

There is a need for continuing revitalization of undergraduate physics education in order to track the changes in the world in which university students find themselves. More specifically, there is often too little connection between the undergraduate physics program and the latest developments in the field. There also tends to be a general lack of appreciation among students for the connections between physics and societal needs, societal impact, and daily life. Furthermore, the job market emphasizes the need for a broader training in science and mathematics, expects versatility, and requires enhanced communication and teamwork skills. Therefore, our committee was asked to develop a recommended undergraduate physics curriculum for Canadian universities, one in which these concerns begin to be addressed and thereby work toward the nation-wide goal of increasing enrollment in undergraduate physics programs. In addition, this recommended curriculum may assist the CAP in assessing undergraduate degrees of applicants to the professional certification program (for P.Phys. designation).

As our first report to the Physics community, we have drafted the following model for discussion, which focuses on the core material recommended for an honours major in Physics. Although this is difficult to reflect in such a listing, the committee would like to emphasize that many seemingly peripheral elements are key to the success of revitalizing undergraduate physics education – a successful program is not simply one in which a prescribed list of topics is covered. A successful program is one in which the students:

- gain a solid understanding of the fundamental laws and principles of physics
- have a strong feeling of community and common purpose with all members of the department
- have a clear sense of the relevance of physics to daily life
- are exposed to cutting edge physics research
- have the flexibility (in terms of choice of electives) to pursue a broad training in science, if so desired by the student
- are encouraged to take non-science electives
- are actively engaged in the learning process
- develop communication and team-work skills
- are provided with hands-on workplace experience through internships or co-op placements
- have exposure to many possible career paths, through guest speakers from industry or organized events such as an annual (or bi-annual) Careers Night

Please contact any of the members of the committee with your comments on this initiative.

The proposed curricular content

1. FIRST YEAR CORE MATERIAL

The first year of an undergraduate physics degree tends to be similar (or even common) to the first year of other science programs. First-year science students are typically required to take two semesters each of Physics, Biology, Calculus, and Chemistry, possibly with one semester each of Algebra and Computer Science. The two semesters of Physics are the only courses over which Physics departments have curricular control at this level. These courses are tremendously important, as it is typically in 1st year that students decide whether or not they will pursue a degree in Physics. Given the fundamental role that these courses play in future enrollment, the committee's recommendations for the core physics material in first year courses are addressed in the separate document, see attached.

2. PHYSICS CORE MATERIAL

Beyond the first year of the undergraduate physics degree, there should be advanced treatment of topics in Electricity and Magnetism, Mechanics, Thermodynamics and Statistical Mechanics, Optics, and Quantum Mechanics. The curriculum should include a significant amount of Intermediate Mathematics as well as Experimental Physics, either as separate courses or integrated into the upper level physics courses. Students should be encouraged to develop their oral communication skills during the program as well, through presentations of their work to their peers. A communication course in the final year of the program would be useful in honing both oral and written skills before graduation. This committee also advocates the offering of a capstone course in their final semester, designed to integrate knowledge from the previous years, emphasize the multi-disciplinary aspect of physics, and expose students to a variety of exciting topics that point towards a number of future career paths.

Electricity and Magnetism

Coulomb's Law; electrostatic fields and potential; Laplace & Poisson equations; electric dipoles; multipole expansions of potentials; electrostatic force and energy; capacitance; polarization; dielectrics; electric displacement field; current; Ohm's Law; continuity equation; circuits; magnetic fields; Biot-Savart Law; Ampere's Law; magnetic force, energy and torque; electromagnetic potentials; magnetization; Faraday's Law, Maxwell's equations, free-space propagating waves and waveguides, and electromagnetic radiation.

Mechanics

Particle dynamics; central field problem; many-particle systems; conservation of energy, momentum and angular momentum; rigid body motion; Lagrangian mechanics; special relativity.

Thermodynamics and Statistical Mechanics

Temperature; work; specific heat; entropy; the laws of thermodynamics; practical applications, *e.g.* engines, radiation, phase transitions, *etc.*; the kinetic theory of gases; partition functions; ensembles, Maxwell-Boltzmann, Fermi-Dirac, and Bose-Einstein statistics, Bose-Einstein condensation.

Quantum Mechanics

The historical foundations of quantum physics: blackbody radiation, Compton scattering, the Davisson-Germer experiment, and the Bohr-Sommerfeld model of the atom; applications of the Schrodinger equation to one-dimensional problems, *e.g.* the square-well potential, barrier scattering and tunneling, and the harmonic oscillator; uncertainty principle, quantization of angular momentum; Schrodinger equation for three-dimensional problems, *e.g.* the hydrogen atom with relativistic corrections; applications to major fields of physics; and perturbation theory (with emphasis on computational approaches where relevant)

Optics
Geometrical optics, polarization, interference, Fraunhofer and Fresnel diffraction, optical fibers and planar waveguides, introduction to semiconductors, spontaneous and stimulated emission, gain, lasers, photodetectors.

Experimental Physics
Experiments illustrating concepts in Electricity & Magnetism, Mechanics, Thermodynamics and Quantum Physics, Optics, Nuclear Physics, and Spectroscopy. Electronic circuits: diodes, op-amps, digital logic elements. There should be emphasis on computational methods, including computer data acquisition, throughout these experiments. Furthermore, students should be encouraged to develop their written communication skills as well as independence in experimental work, demonstrating their mastery of real-world apparatus, their ability to exercise judgment and initiative in an experimental setting, and their understanding of related concepts such as precision, accuracy, and statistics in general. The laboratory experience can also serve to foster teamwork skills, by requiring one or more reports to be submitted by a team, as well as mixing up the partnerships through the year.

3. MATHEMATICS AND COMPUTER SCIENCE

Intermediate Mathematics
Linear algebra: matrices, vector spaces, determinants, eigenvalues and eigenvectors. Advanced calculus: convergence, Taylor's series, partial differentiation, planes, gradients, line integrals, coordinate transformation; vector analysis; Gauss' theorem, Stokes theorem; ordinary differential equations: 1^{st} order, 2^{nd} and higher order linear equations, power series methods. Laplace transforms, partial differential equations, applications; eigenvalue problems; Fourier series; Legendre functions; spherical harmonics; numerical analysis and Bessel functions. Functions of complex variables, residue theorem, contour integration, Fourier transforms. Probability theory, random variables, probability distributions, probability densities. Elementary group theory.

Computer Science
Unix fundamentals; scientific programming in a computer language such as Fortran, C, C++, or JAVA; mathematical software such as Maple, MatLab and Mathematica; scientific visualization software.

4. COMMUNICATION AND SYNTHESIS

Communications Course
Oral and written communication skills developed through constructive feedback from peers and faculty through the presentation of results of individual research projects; the development of literature search skills.

Undergraduate Thesis Project/Internship
Research project, either individual or team, research could be experimental, theoretical or computational. Involving physics or applications of physics, with guidance from a professional

researcher, conducted at the university or in an industrial/national laboratory setting as part of a co-op work term or internship. Oral presentation and written report at the end.

Capstone Course
Required course for all physics majors, this physics course is designed to be offered in the final year of the program, integrating much of the material covered in the past few years. Such a capstone physics course could, for example, focus on a central theme that makes connections between various subfields and with the history of the overall discipline, *e.g.* a course in which all of the basic physics learned in the previous courses is applied to the explication of the major developments of twentieth-century physics at the atomic, nuclear, and subnuclear levels. This course can serve to develop further the oral and written communication skills of students, and would also serve to enhance the literature search skills of the students, when conducted in an inquiry-based method of instruction.

5. Specialization and Advanced Topics

Additional Elements
In the final two years of the undergraduate curriculum, students should have a suite of courses available from which to choose based on personal interest/career goals, *e.g.*, Astrophysics, Atmospheric Science, Atomic & Molecular Physics, Biophysics, Electronics, General Relativity, Geophysics, Medical Physics, Nuclear Physics, Optics, Particle Physics, or Solid State Physics. The suite of elective physics courses will vary from university to university, as this is largely dependent on the number of faculty in the department, as well as the diversity of expertise represented. These elective physics courses could be packaged into specializations, such as Biophysics or Optics/Photonics, as just two possible examples. In addition to these elective physics courses, the program should be sufficiently flexible to allow students to gain exposure to a wide range of subjects, from the arts, humanities, business, or other fields of sciences, at all levels.

Atomic and Molecular Physics
The application of quantum theory to atomic and molecular structure, and the interaction between electromagnetic radiation and atoms and simple molecules. Atoms: central forces and angular momentum, complex atoms, electro- and magnetostatic interactions, transition probabilities; Molecules: electronic structure, vibrations and rotations of diatomic molecules.

Atmospheric and Space Science
Atmospheric dynamics, climate and climate change, numerical weather prediction, space geodynamics.

Biophysics
Introduction to the molecular biophysics of cellular membranes, structure and function of the major membrane components (lipids, protein and carbohydrates), physical techniques: patch-clamping, x-ray and neutron scattering and diffraction, NMR and ESR spectroscopy, infrared and Raman spectroscopy, electron microscopy, atomic force microscopy, absorption spectroscopy, light scattering, circular and linear dichroism, fluorescence.

Computational Physics
At least one of the following three themes: a) Continuum Systems: numerical solutions of ODE's and PDE's, applications from mechanics, field theories, *etc.*; b) Stochastic and Quantum Systems: Monte Carlo methods, molecular dynamics methods, stochastic differential equations, applications

from quantum mechanics/condensed matter; c) Data Analysis: statistical analysis, Fourier analysis and the FFT, maximum entropy methods, dealing with large data sets, data mining techniques, applications from image processing, spectroscopy

Condensed Matter Physics
Free electron model, reciprocal lattice, Bloch's theorem, nearly free electron and tight binding model, semiclassical electron transport, phonons, semiconductors, magnetism, superconductivity.

Electromagnetic Theory
Relativistic electrodynamics, electromagnetic potentials, gauge transformations, Lagrangian and Hamiltonian formalisms, multipole expansions, radiation in Maxwell's theory of electromagnetism.

General Relativity
Physical consequences of Einstein's equations, including the principle of equivalence, curved space-time, geodesics, the Schwarzchild solution, deflection of light, black holes and gravitational radiation.

Geophysics
Global Geophysics: earthquake seismology, gravity, the geoid, geomagnetism, paleomagnetism and geodynamics, heat flow, radioactivity and geochronology; Exploration Geophysics: refraction seismic, reflection seismic, direct current resistivity, induced polarization (IP), low induction number electromagnetic profiling and depth sounding, ground penetrating radar, magnetics and microgravity.

Medical Physics
Physical and chemical interactions of ionizing radiations and their biological effects; structural imaging (*e.g.* magnetic resonance imaging, ultrasound, computed tomography, and optical microscopy); nuclear medicine; therapeutic applications of radiation.

Nuclear/Particle Physics
Quark models; strong, electromagnetic and weak interactions; isospin, strangeness, conservation laws and symmetry principles; systematics of nuclear properties, nuclear radioactivity, nuclear models and reactions.