# New Directions for the Canadian First Year Physics Course

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**Introduction:**
The first year course is, for the majority of Canadian university students, their only exposure to university level physics, and therefore the first year course is critical both for accurately portraying the nature of modern physics, and as a vehicle for encouraging students to consider physics as a career. This document, prepared by a committee of the Division of Physics Education of the Canadian Association of Physicists, is meant as a guide to the revitalization of the first year physics course at Canadian universities and colleges. While we divide the curriculum section into two parts, one aimed at physics majors and honours (or closely allied sciences) and one for students in other areas, it is our opinion that to the degree possible the two streams should share a common core of key ideas in physics. The goal in this document is not to be prescriptive in the sense that each introductory physics course across Canada should look the same, but rather to provide suggestions based on physics education research (PER) and deliberations and discussions with Canadian physics educators.

**Physics Education Research:**
The physics curriculum, and how it is taught and learned, should reflect best practice understandings of physics education research. McDermott & Redish (1999) have recently reviewed the results of this research. Some of the approaches that seem well established from that research include:

- The importance of active student learning as opposed to passive listening is probably the most critical element in effective physics learning (whether that is accomplished through studio, experiential or other lecture minimized teaching modes, peer instruction, triad discussions as part of lecture-demonstration classes, etc.).
- Generally speaking research suggests that the curriculum should concentrate on mastery of a more limited set of important concepts, rather than the encyclopaedic approach with a lower level of student mastery.
- The importance of demonstrations, applications, and experimental work is clearly validated, and there is some suggestion that introduction of applications early in the teaching of a topic, rather than following the teaching of a concept, is particularly successful.
- Collaborative learning models in which students interact with other students and with physics ideas at the same time promote deep conceptual learning.
- Spiral based approaches, in which concepts are revisited several times at increasing levels of complexity, are effective and should be implemented where feasible.
- General education research suggests that enthusiasm, relevance and a positive classroom atmosphere are rated highly as important factors promoting effective learning.

The first year physics course has in particular received extensive consideration in physics education research in recent decades (see e.g. Van Heuvelen, 1991; Wilson, 1997; Reddish 2003; Knight 2004 and references therein). The Introductory University Physics Project (IUPP), which was jointly founded by the American Institute of Physics, the American Association of Physics Teachers and the American Physical Society, involved a large group of physicists in rethinking the first year curriculum. The main recommendations of that report clearly influence the directions we propose in this document. The IUPP propose that the first year curriculum should concentrate on fewer topics, should include strong modern physics components, and to the degree possible the different components of the physics curriculum should clearly illustrate the unity in physics topics.

**Teaching Models:**
A number of specific delivery mechanisms for effective teaching of first year physics have been developed, including studio based teaching models, peer instruction, Personal System of Instruction (PSI) and other individualized mastery based models, use of small group triads in large lectures, interactive lectures supplemented with "just in time" input models, etc. Fortunately many of these modern methods of physics teaching are now in use at Canadian universities, and so a base of physics education expertise exists in the country. In this document we do not endorse a particular physics teaching and learning method, although we do encourage each university to adopt the method which is best suited for their situation and which promotes active learning, student collaboration and mastery based conceptual learning.

**Proposed Changes:**
This is a summary of the key changes of the current program from that which is reflected in many university first year physics courses, or most traditional physics textbooks. The following sections give the actual recommendations in additional detail.

- We have *reduced somewhat the number of topics covered*, and in particular the mechanics and thermodynamics are reduced significantly, and other topics such as AC circuits, DC circuits, optics and radioactivity may be reduced or eliminated depending on the topics chosen from the technological physics section.
- We have tried to *group topics into conceptual themes* (such as conservation principles, or waves)
- We have *increased somewhat the coverage of physics from the last century* through the spacetime, quantum, technological physics and Canadian physics sections, and specific inclusion of Canadian contributions to physics.
- We propose that *collaborative learning opportunities, inquiry based learning, computational methodology including numerical methods and interdisciplinary applications find stronger roles* in the first year course.

**First Year Program for Physics Majors/Honours:**
We propose the following elements form the core of a first year program for students intending to major in physics or a closely related discipline. Process skills to be developed within the first year course include the following:

1. Physics should be presented as an inquiry-based science, with students required to inductively or deductively develop models to fit a set of physical observations.
2. Students should experience scientific collaboration through (to the degree possible) working in groups towards common lab-based or project-based goals.
3. The breadth of modern physics, including interdisciplinary applications of physics, should be presented including some mention of current research in the local or regional setting.
4. Where feasible students should have the opportunity to develop communication skills (written and oral).
5. Strong computational models should be explored as a way of understanding physics concepts, using tools such as spreadsheets or simulation software to probe the effects of modifying different variables.

In terms of curriculum topics we propose the following as core units in a first year curriculum. These would not necessarily be taught in the order shown as complete units. An alternative approach would be to revisit the themes several times in a spiral learning format. Note that most of these units are strongly interrelated and those unifying concepts should be stressed. It is critical that physics be portrayed as a constantly evolving discipline, with current discoveries integrated into the units as feasible. The program below is intended to be covered in two academic terms (6 cr), with the expectation that the class meets for roughly 6 contact hours (lecture+lab+tutorial combined) per week. Since our goal is not to prescribe an exact curriculum, we did not feel it appropriate to attach numbers of hours to each of the topics.

1. **Background Skills for Physicists**
   SI units, unit conversion, elementary statistics, handling of errors, scientific writing, scientific literature, computerized data acquisition and analysis systems, review of mathematical skills including calculus, trigonometry and algebra.
2. **Developing Models**
   We see traditional mechanics being taught within an inquiry based approach whereby students use tools such as regression and spreadsheet analysis along with computerized data acquisition to develop kinematic relationships, and then to extend them, using spreadsheets and simulation tools, to more complex situations such as those where forces such as air drag are considered. One change from many conventional courses here is to extend the examples to more interesting real-world situations.
3. **Conservation Principles**
   The key role of conservation principles in physics should appear numerous places in the course - conservation of linear momentum, angular momentum, charge, mass-energy, and the additional conservation principles in particle physics.
4. **Thermodynamics**
   The first and second laws of thermodynamics, entropy, heat flow, radiation from surfaces.
5. **Gravity**
   For centuries an understanding of the nature and consequences of gravitation have played key roles in physics. The first year course should move from acceleration in gravitational fields to looking more deeply at gravitational potential and forces and how they are related, developing escape speed relationships and local g values for different objects, orbital ideas for open and closed orbits, and a consideration of the conceptual basis for general relativity through the spacetime unit.
6. **Spacetime**
   The key concepts of special relativity including premises, derivation of Lorentz transformation, spacetime concepts and diagrams, issues of simultaneity, a qualitative view of general relativistic ideas, application to black holes and other astrophysical situations including cosmology.
7. **Oscillating Systems**
   From the mass and spring to atomic and molecular systems, the world is full of oscillating systems. The math of such systems should be developed, and this unit should show how a common physics background can be applied to a wide array of different situations. Differential equations, including numerical solution methods in simple form, are introduced in this unit. Applications of oscillating systems in everyday life and in industrially important situations should be stressed.
8. **Waves**
   Starting with physical waves and then being applied in sound and light systems, ideas of wavelength, wave speed, frequency, wave interference effects, amplitude and intensity measures.
9. **Electromagnetism**
   The unity of electromagnetic phenomena has been one of the great triumphs of modern physics, and this unit is a good place to provide a historical overview of the steps in the development which ultimately lead to Maxwell’s equations. The math background of the students may dictate what is reasonable to do in first year in this regard. Ideally students should start with the forces on charged objects in electromagnetic fields, then explore electric potentials and electric fields followed by consideration of Gauss’s Law and Ampere’s Law and Faraday’s Law of Electromagnetic Induction, and then unify these ideas into Maxwell’s equations and see how plane electromagnetic waves are predicted. Note that circuit electricity and electrical devices such as capacitors are considered in Technological Physics.
10. **Quantum Physics**
   Starting with the quantum and wave nature of light, this unit will then develop the wave properties of matter and de Broglie wavelength, the uncertainty principle, observers and causality, the Schrodinger equation applied to simple situations such as the harmonic oscillator.

11. **Technological Physics**
This unit, which would be adapted in different ways according to departmental strengths, would consider a range of applications in which physics plays a key role in technology and interdisciplinary science. Some possibilities include electrical circuits and electronics, materials science, photonics, fluid mechanics, radiation and medical treatments, imaging technologies and applications, environmental physics, energy production, physics of structures and static equilibrium, and thermodynamic applications.
12. **Canadian Physics**
According to the strengths of the instructor and the department, the course should expose students to some of the major triumphs Canadians have made in physics; including both theoretical and applied areas and include coverage both of historical and current discoveries and innovations.

**First Year Program for Students from Other Disciplines:**
We propose that the above program might be modified in the following ways in order to structure a first year experience for students from other disciplines. Clearly a fair amount of flexibility is required here to meet the needs of students from such diverse areas as engineering, biological sciences, medicine, psychology, music and others. As mentioned earlier we have kept a common core with the proposed program for physics majors, to the degree that it is feasible to do so.

Process skills to be developed within the first year course include the following:
1. Physics should be presented as an inquiry based science, with students required to inductively or deductively develop models. Current discoveries and innovations, and open problems, should be stressed.
2. Students should experience scientific collaboration by at least occasionally working in groups on labs or on projects. Project based approaches are particularly valuable for this group.
3. The breadth of modern physics, including interdisciplinary applications of physics, should be presented including some mention of current research in the local or regional setting. Controversial aspects of the application of physics concepts in our society should form a part of this course.

In terms of curriculum topics we propose the following:
1. **Background Skills**
SI units, unit conversion, elementary statistics, handling of errors, scientific writing, scientific literature, computerized data acquisition and analysis systems, review of mathematical skills – very similar to the physics major group, but less detailed mathematical background.
2. **Developing Models**
Similar to physics major group, but a bit less stress on this unit.
3. **Conservation Principles**
Same as for physics major group, but with less emphasis on particle physics aspects of conservation principles.
4. **Energy, Work and Power**
These concepts are so critical to all the sciences that extensive coverage should be given including application to the human body and to energy production, use and transfer.
5. **Thermodynamics**
The content and emphasis will vary greatly according to the discipline.
6. **Fluid Mechanics**
Concepts of pressure, buoyancy, fluid dynamics including Bernoulli's principle, viscosity, applications.
7. **Oscillating Systems**
A bit less mathematical approach, but the key concepts of this unit for the physics majors should be included.

8. **Waves–Optics**
   Starting with physical waves and then being applied in sound and light systems, ideas of wavelength, wave speed, frequency, wave interference effects, amplitude and intensity measures. Extensive applications in human and animal optical systems, optical devices such as cameras and microscopes, sound, ultrasound, *etc.*.
9. **Electricity and Magnetism**
   Students should start with the forces on charged objects in electromagnetic fields, then explore electric potentials and electric fields followed by consideration of electric currents in simple AC and DC circuits and electrical devices including capacitors, inductors, transformers, etc. In conjunction with the Waves-Optics and Quantum units the different parts of the electromagnetic spectrum should be viewed as a common phenomena but with different wavelengths and engergies resulting in different effects on living bodies.
10. **Quantum Physics**
    Starting with the quantum and wave nature of light, this unit will then develop the wave properties of matter and de Broglie wavelength, the uncertainty principle, observers and causality, the Schrodinger equation applied to simple situations such as the harmonic oscillator.
11. **Biophysics**
    Given the importance of medical physics, biophysics and biotechnology in our society, the course for nonphysics majors should include a selection of topics from these areas (which can also be found in several of the other units including waves-optics, technological physics, *etc.*).
12. **Technological Physics**
    This unit, which would be adapted in different ways according to departmental strengths and the interest of the students, would consider a range of applications in which physics plays a key role in technology and interdisciplinary science. Some possibilities include electronics, materials science, solid state physics, photonics, fluid mechanics, radiation and medical treatments, imaging technologies and applications, environmental physics, energy production, physics of structures and static equilibrium, and thermodynamic applications.
13. **Canadian Physics**
    Similar emphasis as for physics major group, but with different selection of topics.

**References:**


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