2008

REVISED

The Ontario Curriculum
Grades 11 and 12

Science

reach every student

Ontario

CONTENTS

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INTRODUCTION

This document replaces *The Ontario Curriculum, Grades 11 and 12: Science, 2000*. Beginning in September 2009, all science programs for Grades 11 and 12 will be based on the expectations outlined in this document.

SECONDARY SCHOOLS FOR THE TWENTY-FIRST CENTURY

The goal of Ontario secondary schools is to support high-quality learning while giving individual students the opportunity to choose programs that suit their skills and interests. The updated Ontario curriculum, in combination with a broader range of learning options outside traditional classroom instruction, will enable students to better customize their high school education and improve their prospects for success in school and in life.

THE PLACE OF SCIENCE IN THE CURRICULUM

During the twentieth century, science played an increasingly important role in the lives of all Canadians. It underpins much of what we now take for granted, from life-saving pharmaceuticals to clean water, the places we live and work in, computers and other information technologies, and how we communicate with others. The impact of science on our lives will continue to grow as the twenty-first century unfolds. Consequently, scientific literacy for all has become a goal of science education throughout the world and has been given expression in Canada in the *Common Framework of Science Learning Outcomes, K to 12: Pan-Canadian Protocol for Collaboration on School Curriculum* (Council of Ministers of Education, Canada, 1997). Scientific literacy can be defined as possession of the scientific knowledge, skills, and habits of mind required to thrive in the science-based world of the twenty-first century.

> *A scientifically and technologically literate person is one who can read and understand common media reports about science and technology, critically evaluate the information presented, and confidently engage in discussions and decision-making activities regarding issues that involve science and technology.*
>
> Science Co-ordinators' and Consultants' Association of Ontario (SCCAO)
> and Science Teachers' Association of Ontario (STAO/APSO),
> "Position Paper: The Nature of Science" (2006), p. 1

Achieving a high level of scientific literacy is not the same as becoming a scientist. The notion of thriving in a science-based world applies as much to a small-business person, a lawyer, a construction worker, a car mechanic, or a travel agent as it does to a doctor, an engineer, or a research scientist. While the specific knowledge and skills required for each of these occupations vary, the basic goal of thriving in a science-based world remains the same. Science courses have been designed for a wide variety of students, taking into account their interests and possible postsecondary destinations. Some courses have been designed to serve as preparation for specialist studies in science-related fields; others have been designed for students intending to go on to postsecondary education but not to study science; yet others have been designed with the needs of the workplace in mind. The overall intention is that all graduates of Ontario secondary schools will achieve excellence and a high degree of scientific literacy while maintaining a sense of wonder about the world around them. Accordingly, the curriculum reflects new developments on the international science scene and is intended to position science education in Ontario at the forefront of science education around the world.

THE GOALS OF THE SCIENCE PROGRAM

Achievement of both excellence and equity underlies the three major goals of the secondary science program. *The Ontario Curriculum, Grades 11 and 12: Science, 2008* therefore outlines not only the skills and knowledge that students are expected to develop but also the attitudes that they will need to develop in order to use their knowledge and skills responsibly. The three goals of the science program are as follows:

1. to relate science to technology, society, and the environment
2. to develop the skills, strategies, and habits of mind required for scientific inquiry
3. to understand the basic concepts of science

Every course in the secondary science program focuses on these three goals. The goals are reflected within each strand of every course in the three overall expectations, which in turn are developed in corresponding sets of related specific expectations. The same three goals also underlie assessment of student achievement in science.

THE NATURE OF SCIENCE

> *The primary goal of science is to understand the natural and human-designed worlds. Science refers to certain processes used by humans for obtaining knowledge about nature, and to an organized body of knowledge about nature obtained by these processes. Science is a dynamic and creative activity with a long and interesting history. Many societies have contributed to the development of scientific knowledge and understanding. . . . Scientists continuously assess and judge the soundness of scientific knowledge claims by testing laws and theories, and modifying them in light of compelling new evidence or a re-conceptualization of existing evidence.*
>
> SCCAO and STAO/APSO, "Position Paper: The Nature of Science" (2006), pp. 1–2

Science is a way of knowing that seeks to describe and explain the natural and physical world. An important part of scientific literacy is an understanding of the nature of science, which includes an understanding of the following:

- what scientists, engineers, and technologists do as individuals and as a community
- how scientific knowledge is generated and validated, and what benefits, costs, and risks are involved in using this knowledge
- how science interacts with technology, society, and the environment

Occasionally, theories and concepts undergo change, but for the most part, the fundamental concepts of science – to do with phenomena such as the cellular basis of life, the laws of energy, the particle theory of matter – have proved stable.

Fundamental Concepts

> *Change the focus of the curriculum and instruction from teaching topics to "using" topics to teach and assess deeper, conceptual understanding.*
>
> Lynn Erickson, *Concept-Based Curriculum and Instruction* (2006), p. 7

Fundamental concepts are concepts about phenomena that have not changed fundamentally over time and that are common for all cultures. The fundamental concepts in science provide a framework for the deeper understanding of all scientific knowledge – a structure that facilitates integrated thinking as students draw from the knowledge base of science and see patterns and connections within the subdisciplines of science, and between science and other disciplines. The fundamental concepts addressed in the curricula for science and technology in Grades 1 to 8 and for science in Grades 9 to 12 are similar to concepts found in science curricula around the world.

As students progress through the curriculum from Grades 1 to 12, they extend and deepen their understanding of these fundamental concepts and learn to apply their understanding with increasing sophistication. The fundamental concepts are listed and described in the following chart.

FUNDAMENTAL CONCEPTS	
Matter	Matter is anything that has mass and occupies space. Matter has particular structural and behavioural characteristics.
Energy	Energy comes in many forms, and can change forms. It is required to make things happen (to do work). Work is done when a force causes movement.
Systems and Interactions	A system is a collection of living and/or non-living things and processes that interact to perform some function. A system includes inputs, outputs, and relationships among system components. Natural and human systems develop in response to, and are limited by, a variety of environmental factors.
Structure and Function	This concept focuses on the interrelationship between the function or use of a natural or human-made object and the form that the object takes.
Sustainability and Stewardship	Sustainability is the concept of meeting the needs of the present without compromising the ability of future generations to meet their needs. Stewardship involves understanding that we need to use and care for the natural environment in a responsible way and making the effort to pass on to future generations no less than what we have access to ourselves. Values that are central to responsible stewardship are: using non-renewable resources with care; reusing and recycling what we can; switching to renewable resources where possible.
Change and Continuity	Change is the process of becoming different over time, and can be quantified. Continuity represents consistency and connectedness within and among systems over time. Interactions within and among systems result in change and variations in consistency.

“Big Ideas”

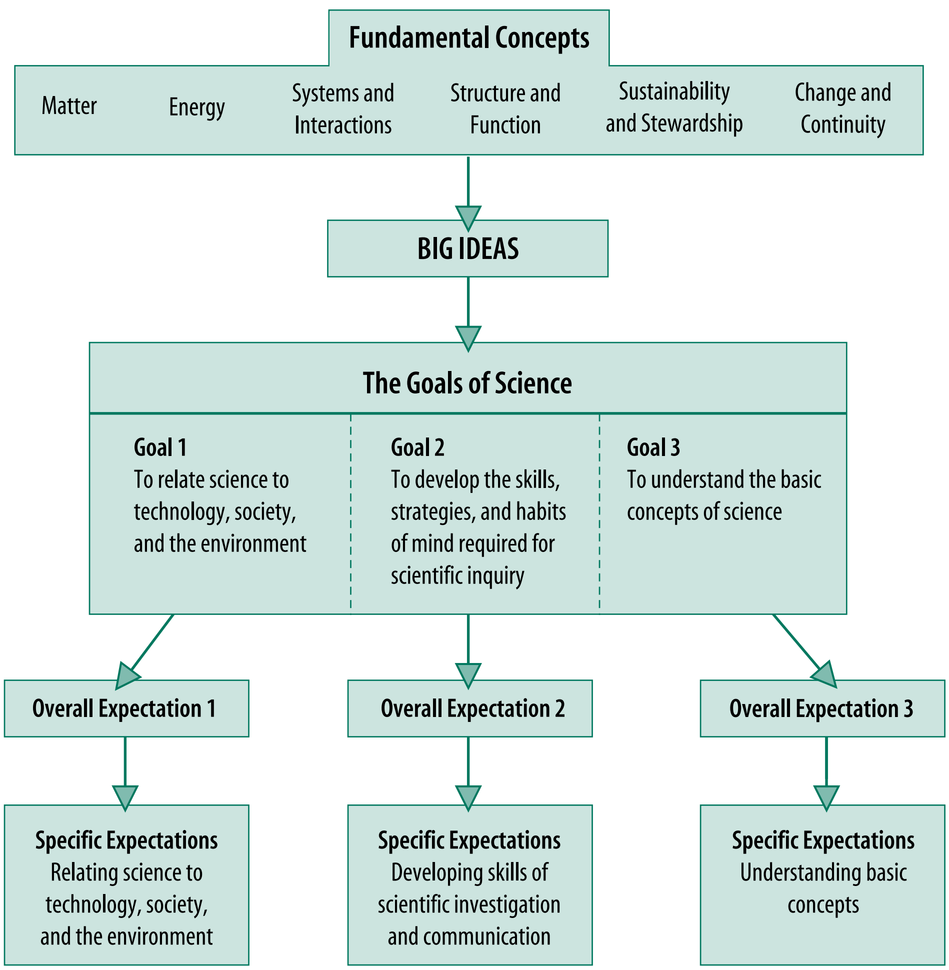
Big ideas “go beyond discrete facts or skills to focus on larger concepts, principles, or processes.”

Grant Wiggins and Jay McTighe, *Understanding by Design* (1998), p. 10

“Big ideas” are the broad, important understandings that students should retain long after they have forgotten many of the details of what they have studied in the classroom. They are the understandings that contribute to scientific literacy. The big ideas that students can take away from each course in this curriculum relate to some aspect of the fundamental concepts described in the preceding section. A list of the big ideas students need to understand appears at the start of every course in this document.

Developing a deeper understanding of the big ideas requires students to understand basic concepts, develop inquiry and problem-solving skills, and connect these concepts and skills to the world beyond the classroom. Teachers can help students gain such understanding by connecting learning based on the overall and specific expectations and the criteria in the achievement chart to the big ideas that relate to each course.

The relationship between the fundamental concepts, big ideas, the goals of the science program, and the overall and specific expectations is outlined in the chart that follows.



ROLES AND RESPONSIBILITIES IN THE SCIENCE PROGRAM

Students

Students have many responsibilities with regard to their learning, and these increase as they advance through secondary school. Students who are willing to make the effort required and who are able to monitor their thinking and learning strategies and apply themselves will soon discover that there is a direct relationship between this effort and their achievement, and will therefore be more motivated to work. Students who develop mental attitudes and ways of behaving that contribute to success in life will benefit as learners.

Successful mastery of scientific concepts and investigation skills requires students to have a sincere commitment to work and to the development of appropriate learning skills. Furthermore, students should actively pursue opportunities outside the classroom to extend and enrich their scientific understanding and skills. For example, students can make an effort to keep up with current events related to local, national, and international scientific discoveries and innovations.

Parents

Studies show that students perform better in school if their parents[1] are involved in their education. Parents who are familiar with the curriculum expectations know what is being taught in the courses their children are taking and what their children are expected to learn. This awareness enhances parents' ability to discuss school work with their children, to communicate with teachers, and to ask relevant questions about their children's progress. Knowledge of the expectations in the various courses also helps parents to interpret teachers' comments on student progress and to work with teachers to improve their children's learning.

Effective ways in which parents can support their children's learning include the following: attending parent-teacher interviews, participating in parent workshops and school council activities (including becoming a school council member), and encouraging their children to complete their assignments at home.

The science curriculum has the potential to stimulate interest in lifelong learning not only for students but also for their parents and all those with an interest in education. In addition to supporting regular school activities, parents may want to take an active interest in current events and issues in the field of science, and to provide their children with opportunities to question and reflect on the impact of these developments on their immediate lives, the environment, and society. Parents can also provide valuable support by encouraging children to take part in activities that develop responsible citizenship (such as participating in an environmental clean-up program in their neighbourhood) or that further their interest in science (such as volunteering at local science centres or children's museums).

Throughout the secondary science program, students will have opportunities to interact with living things and to work with a variety of equipment and materials. To help ensure students' safety, parents should inform teachers of any allergies that their children may have. Parents should also encourage their children to arrive at school prepared to participate safely in activities. Simple precautions such as wearing closed-toe shoes, tying back long hair, and removing loose jewellery (or taping it down in the case of Medic Alert bracelets) contribute to a safe environment when working within science classrooms.

1. In this document, *parent(s)* is used to refer to parents and guardians.

Teachers

Teachers are responsible for developing appropriate instructional strategies to help students achieve the curriculum expectations, as well as appropriate methods for assessing and evaluating student learning. Teachers bring enthusiasm and varied teaching and assessment approaches to the classroom, addressing individual students' needs and ensuring sound learning opportunities for every student.

Using a variety of instructional, assessment, and evaluation strategies, teachers provide numerous hands-on opportunities for students to develop and refine their investigation skills, including their problem-solving skills, critical and creative thinking skills, and communication skills, while discovering fundamental concepts through inquiry, exploration, observation, and research. The activities offered should enable students to relate and apply these concepts to the social, environmental, and economic conditions and concerns of the world in which they live. Opportunities to relate knowledge and skills to these wider contexts will motivate students to learn in a meaningful way and to become lifelong learners.

Teachers need to help students understand that problem solving of any kind often requires a considerable expenditure of time and energy and a good deal of perseverance. Teachers also need to encourage students to investigate, to reason, to explore alternative solutions, and to take the risks necessary to become successful problem solvers.

Science can play a key role in shaping students' views about life and learning. Science exists in a broader social and economic context. It is affected by the values and choices of individuals, businesses, and governments and, in turn, has a significant impact on society and the environment. Teachers must provide opportunities for students to develop habits of mind appropriate for meaningful work in science, including a commitment to accuracy, precision, and integrity in observation; respect for evidence; adherence to safety procedures; and respect for living things and the environment.

Teachers are also responsible for ensuring the safety of students during classroom activities and for encouraging and motivating students to assume responsibility for their own safety and the safety of others. They must also ensure that students acquire the knowledge and skills needed for safe participation in science activities.

Principals

The principal works in partnership with teachers and parents to ensure that each student has access to the best possible educational experience. The principal is also a community builder who creates an environment that is welcoming to all, and who ensures that all members of the school community are kept well informed.

To support student learning, principals ensure that the Ontario curriculum is being properly implemented in all classrooms through the use of a variety of instructional approaches and that appropriate resources are made available for teachers and students. To enhance teaching and student learning in all subjects, including science, principals promote learning teams and work with teachers to facilitate teacher participation in professional development activities. Principals are responsible for ensuring that every student who has an Individual Education Plan (IEP) is receiving the modifications and/or accommodations described in his or her plan – in other words, that the IEP is properly developed, implemented, and monitored.

Community Partners

Community partners in areas related to science can be an important resource for schools and students. They can provide support for students in the classroom and can be models of how the knowledge and skills acquired through the study of the curriculum relate to life beyond school. As mentors, they can enrich not only the educational experience of students but also the life of the community. For example, schools can make use of community groups that recruit practising scientists (e.g., engineers, optometrists, veterinarians, geologists, lab technicians) to provide in-class workshops for students that are based on topics, concepts, and skills from the curriculum.

Schools and school boards can play a role by coordinating efforts with community partners. They can involve community volunteers in supporting science instruction and in promoting a focus on scientific literacy in and outside the school. Community partners can be included in events held in the school (such as parent education nights and science fairs), and school boards can collaborate with leaders of existing community science programs for students, including programs offered in community centres, libraries, and local museums and science centres.

THE PROGRAM IN SCIENCE

OVERVIEW OF THE PROGRAM

The overall aim of the secondary science program is to ensure scientific literacy for every secondary school graduate. To better achieve this aim, all courses in the program are designed to focus on science not only as an intellectual pursuit but also as an activity-based enterprise within a social context.

The senior science courses build on the Grade 9 and 10 science program, incorporating the same goals of science and fundamental concepts on which that program was based. Both programs are founded on the premise that students learn science most effectively when they are active participants in their own learning. Such participation is achieved when science concepts and procedures are introduced through an investigative approach and are connected to students' prior knowledge in meaningful ways. The Grade 11 and 12 science curriculum is designed to help students prepare for university, college, or the workplace by building a solid conceptual and procedural foundation in science that enables them to apply their knowledge and skills in a variety of ways and successfully further their learning.

An important component of every course in the science program is the development of students' ability to relate science to technology, society, and the environment. Students are encouraged to apply their understanding of science to real-world situations in these areas and to develop knowledge, skills, and attitudes that they will take with them beyond the science classroom.

The Grade 11 and 12 science program is designed to help students become scientifically literate. One aspect of scientific literacy is the ability to recognize, interpret, and produce representations of scientific information in forms ranging from written and oral reports, drawings and diagrams, and graphs and tables of values to equations, physical models, and computer simulations. As students' scientific knowledge and skills develop through the grades, they will become conversant with increasingly sophisticated forms and representations of scientific information.

The senior science curriculum also builds on students' experience with a variety of the sophisticated yet easy-to-use computer applications and simulations that are so prevalent in today's world. The curriculum integrates these technologies into the learning and doing of science in ways that help students develop investigation skills, extend their understanding of scientific concepts, enable them to solve meaningful problems, and familiarize them with technologies that can be applied in various other areas of endeavour. In this curriculum, technology does not replace skills acquisition; rather, it is treated as a learning tool that helps students explore concepts and hone skills.

A balanced science program must include varied opportunities for students to practise and enhance their scientific investigations skills. Like the Grade 9 and 10 science courses, the senior secondary curriculum focuses on refining specific skills that best enable students to develop their understanding of scientific concepts and acquire related knowledge.

Courses in Grades 11 and 12

Four types of courses are offered in the Grade 11 and 12 science program: university preparation, university/college preparation, college preparation, and workplace preparation courses. Students choose between course types on the basis of their interests, achievement, and postsecondary goals.

The course types offered in Grades 11 and 12 are defined as follows:

University preparation courses are designed to equip students with the knowledge and skills they need to meet the entrance requirements for university programs.

University/college preparation courses are designed to equip students with the knowledge and skills they need to meet the entrance requirements for specific programs offered at universities and colleges.

College preparation courses are designed to equip students with the knowledge and skills they need to meet the requirements for entrance to most college programs or for admission to specific apprenticeship or other training programs.

Workplace preparation courses are designed to equip students with the knowledge and skills they need to meet the expectations of employers, if they plan to enter the workplace directly after graduation, or the requirements for admission to many apprenticeship or other training programs.

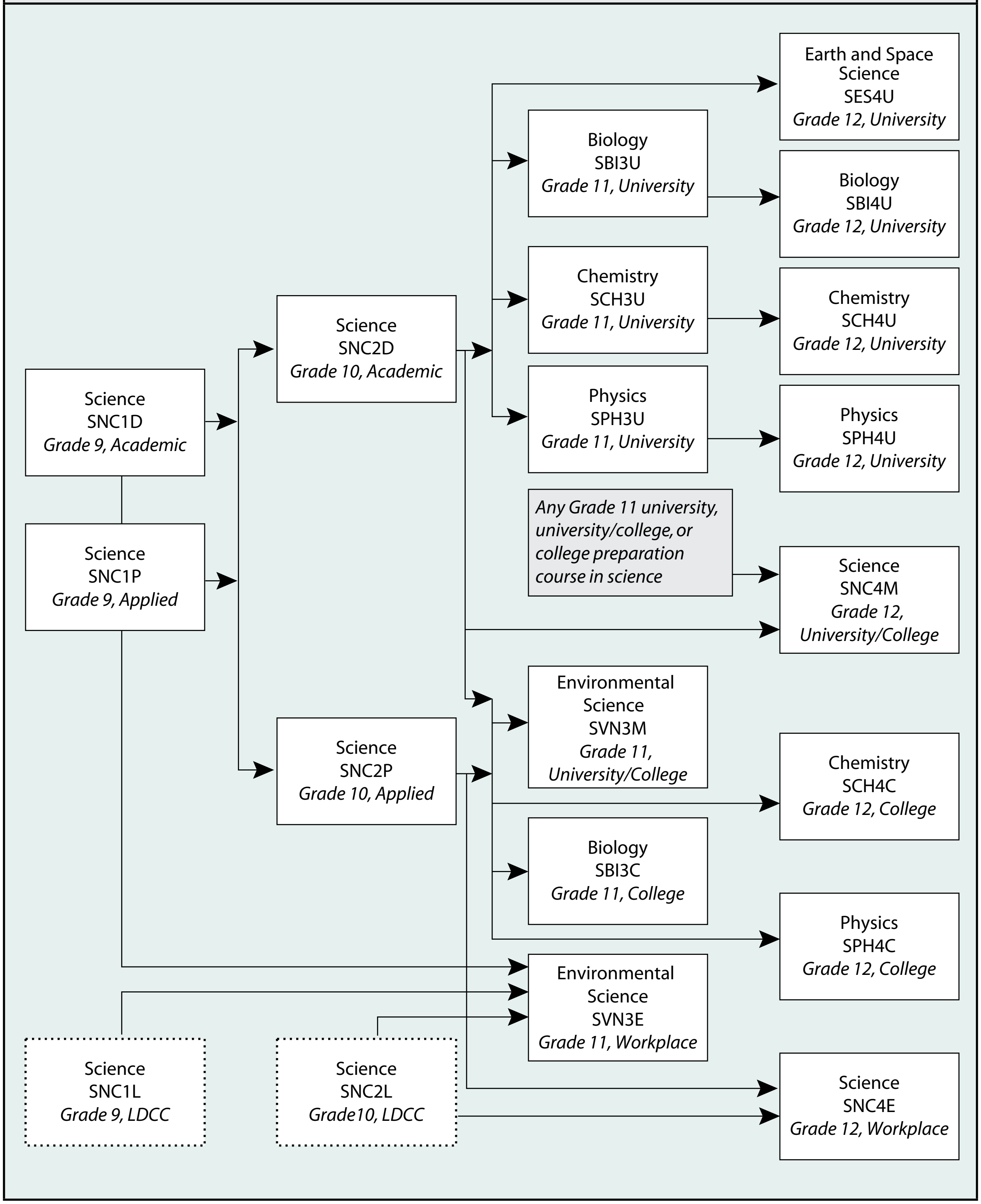
A table showing all Grade 11 and 12 science courses is given on page 12, and the prerequisite chart for all Grade 9–12 science courses appears on page 13.

Courses in Science, Grades 11 and 12				
Grade	**Course Name**	**Course Type**	**Course Code**	**Prerequisite**
Biology				
11	Biology	University	SBI3U	Grade 10 Science, Academic
11	Biology	College	SBI3C	Grade 10 Science, Academic or Applied
12	Biology	University	SBI4U	Grade 11 Biology, University
Chemistry				
11	Chemistry	University	SCH3U	Grade 10 Science, Academic
12	Chemistry	University	SCH4U	Grade 11 Chemistry, University
12	Chemistry	College	SCH4C	Grade 10 Science, Academic or Applied
Earth and Space Science				
12	Earth and Space Science	University	SES4U	Grade 10 Science, Academic
Environmental Science				
11	Environmental Science	University/ College	SVN3M	Grade 10 Science, Academic or Applied
11	Environmental Science	Workplace	SVN3E	Grade 9 Science, Academic or Applied, or a Grade 9 or Grade 10 LDCC*
Physics				
11	Physics	University	SPH3U	Grade 10 Science, Academic
12	Physics	University	SPH4U	Grade 11 Physics, University
12	Physics	College	SPH4C	Grade 10 Science, Academic or Applied
Science				
12	Science	University/ College	SNC4M	Grade 10 Science, Academic, or any Grade 11 university, university/college, or college preparation course in the science curriculum
12	Science	Workplace	SNC4E	Grade 10 Science, Applied, or a Grade 10 LDCC*

Note: Each of the courses listed above is worth one credit.
*LDCC – locally developed compulsory credit course

Prerequisite Chart for Science, Grades 9–12

This chart maps out all the courses in the discipline and shows the links between courses and the prerequisites for them. It does not attempt to depict all possible movements from course to course.



Note: Dotted lines represent locally developed compulsory credit courses (LDCCs), which are not outlined in this curriculum document.

Half-Credit Courses

The courses outlined in the Grade 9 and 10 and Grade 11 and 12 science curriculum documents are designed as full-credit courses. However, *with the exception of the Grade 12 university preparation and university/college preparation courses*, they may also be delivered as half-credit courses.

Half-credit courses, which require a minimum of fifty-five hours of scheduled instructional time, adhere to the following conditions:

- The two half-credit courses created from a full course must together contain all of the expectations of the full course. The expectations for each half-credit course must be drawn from all strands of the full course and must be divided in a manner that best enables students to achieve the required knowledge and skills in the allotted time.
- A course that is a prerequisite for another course in the secondary curriculum may be offered as two half-credit courses, but students must successfully complete both parts of the course to fulfil the prerequisite. (Students are not required to complete both parts unless the course is a prerequisite for another course they may wish to take.)
- The title of each half-credit course must include the designation *Part 1* or *Part 2*. A half credit (0.5) will be recorded in the credit-value column of both the report card and the Ontario Student Transcript.

Boards will ensure that all half-credit courses comply with the conditions described above, and will report all half-credit courses to the ministry annually in the School October Report.

CURRICULUM EXPECTATIONS

The Ontario Curriculum, Grades 11 and 12: Science, 2008 identifies the curriculum expectations for each course. The expectations describe the knowledge and skills that students are expected to develop and demonstrate in their class work and investigations, on tests, and in various other activities on which their achievement is assessed and evaluated.

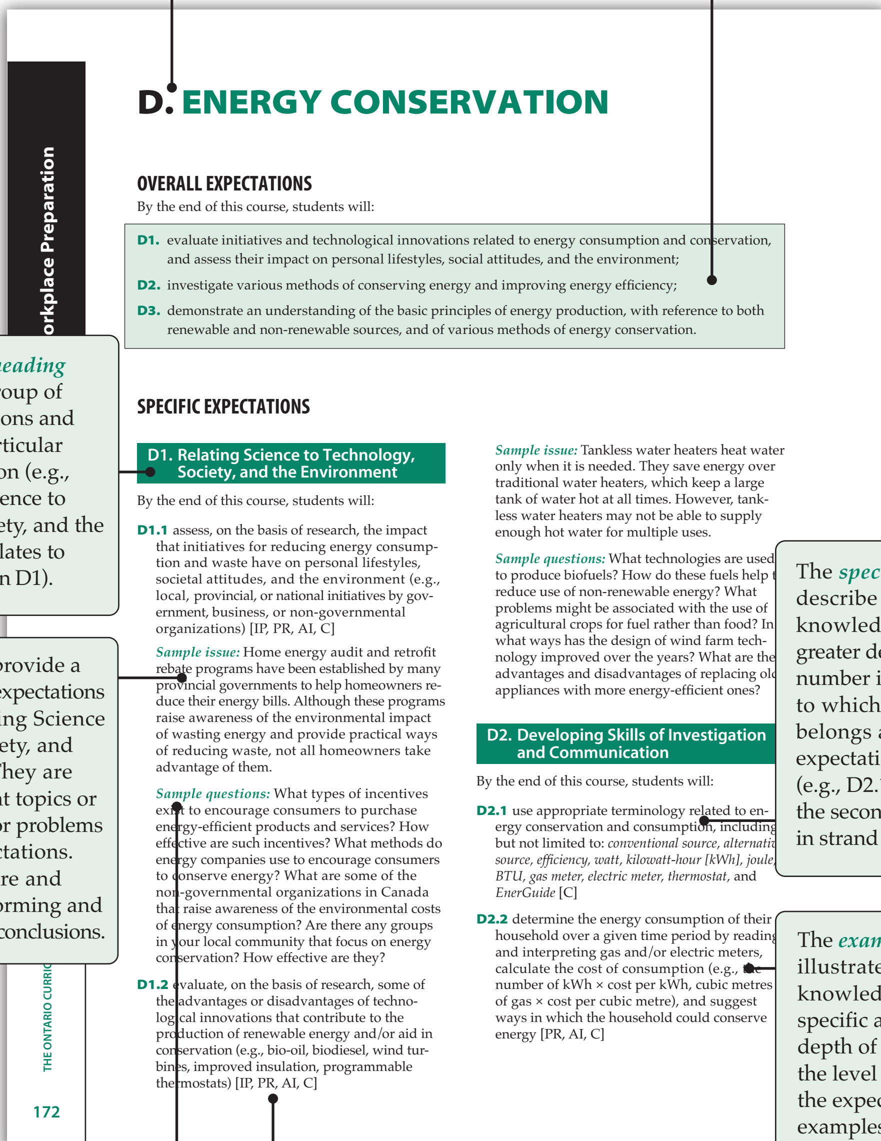
Two sets of expectations – overall expectations and specific expectations – are listed for each *strand*, or broad area of the curriculum. (The strands are numbered A, B, C, D, E, and F.) Taken together, the overall expectations and specific expectations represent the mandated curriculum.

The *overall expectations* describe in general terms the knowledge and skills that students are expected to demonstrate by the end of each course. There are three overall expectations for each content strand in each course in science.

The *specific expectations* describe the expected knowledge and skills in greater detail. The specific expectations are grouped under numbered subheadings, each of which indicates the strand and the overall expectation to which the group of specific expectations corresponds (e.g., "B2" indicates that the group relates to overall expectation 2 in strand B). The organization of expectations into groups is not meant to imply that the expectations in any one group are achieved independently of the expectations in the other groups. The subheadings are used merely to help teachers focus on particular aspects of knowledge and skills as they develop and present various lessons and learning activities for their students.

Each of the Grade 11 and 12 science courses is organized into six ***strands***, numbered A, B, C, D, E, and F.

The ***overall expectations*** describe in general terms the knowledge and skills students are expected to demonstrate by the end of each course. Two or three overall expectations are provided for each strand in every course. The numbering of overall expectations indicates the strand to which they belong (e.g., D1 through D3 are the overall expectations for strand D).



orkplace Preparation

D. ENERGY CONSERVATION

OVERALL EXPECTATIONS

By the end of this course, students will:

D1. evaluate initiatives and technological innovations related to energy consumption and conservation, and assess their impact on personal lifestyles, social attitudes, and the environment;

D2. investigate various methods of conserving energy and improving energy efficiency;

D3. demonstrate an understanding of the basic principles of energy production, with reference to both renewable and non-renewable sources, and of various methods of energy conservation.

SPECIFIC EXPECTATIONS

D1. Relating Science to Technology, Society, and the Environment

By the end of this course, students will:

D1.1 assess, on the basis of research, the impact that initiatives for reducing energy consumption and waste have on personal lifestyles, societal attitudes, and the environment (e.g., local, provincial, or national initiatives by government, business, or non-governmental organizations) [IP, PR, AI, C]

Sample issue: Home energy audit and retrofit rebate programs have been established by many provincial governments to help homeowners reduce their energy bills. Although these programs raise awareness of the environmental impact of wasting energy and provide practical ways of reducing waste, not all homeowners take advantage of them.

Sample questions: What types of incentives exist to encourage consumers to purchase energy-efficient products and services? How effective are such incentives? What methods do energy companies use to encourage consumers to conserve energy? What are some of the non-governmental organizations in Canada that raise awareness of the environmental costs of energy consumption? Are there any groups in your local community that focus on energy conservation? How effective are they?

D1.2 evaluate, on the basis of research, some of the advantages or disadvantages of technological innovations that contribute to the production of renewable energy and/or aid in conservation (e.g., bio-oil, biodiesel, wind turbines, improved insulation, programmable thermostats) [IP, PR, AI, C]

Sample issue: Tankless water heaters heat water only when it is needed. They save energy over traditional water heaters, which keep a large tank of water hot at all times. However, tankless water heaters may not be able to supply enough hot water for multiple uses.

Sample questions: What technologies are used to produce biofuels? How do these fuels help reduce use of non-renewable energy? What problems might be associated with the use of agricultural crops for fuel rather than food? In what ways has the design of wind farm technology improved over the years? What are the advantages and disadvantages of replacing old appliances with more energy-efficient ones?

D2. Developing Skills of Investigation and Communication

By the end of this course, students will:

D2.1 use appropriate terminology related to energy conservation and consumption, including but not limited to: *conventional source, alternati[ve] source, efficiency, watt, kilowatt-hour [kWh], joule, BTU, gas meter, electric meter, thermostat*, and *EnerGuide* [C]

D2.2 determine the energy consumption of their household over a given time period by reading and interpreting gas and/or electric meters, calculate the cost of consumption (e.g., the number of kWh × cost per kWh, cubic metres of gas × cost per cubic metre), and suggest ways in which the household could conserve energy [PR, AI, C]

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A ***numbered subheading*** identifies each group of specific expectations and relates to one particular overall expectation (e.g., "D1. Relating Science to Technology, Society, and the Environment" relates to overall expectation D1).

The ***sample issues*** provide a broader context for expectations in the strand Relating Science to Technology, Society, and the Environment. They are examples of relevant topics or open-ended issues or problems related to the expectations. Students can explore and debate the issues, forming and justifying their own conclusions.

The ***specific expectations*** describe the expected knowledge and skills in greater detail. The expectation number identifies the strand to which the expectation belongs and the overall expectation to which it relates (e.g., D2.1 and D2.2 relate to the second overall expectation in strand D).

The ***examples*** are meant to illustrate the kind of knowledge or skills, the specific area of learning, the depth of learning, and/or the level of complexity that the expectation entails. The examples are illustrations only, not requirements. They appear in parentheses within specific expectations.

The ***sample questions*** are intended to help teachers initiate open discussions on a range of current issues related to the topic of the expectation. They can also provide students with a focus for inquiry and/or research.

The ***abbreviations in square brackets*** following many specific expectations link the expectation to one or more of the *four broad areas of scientific investigation skills* (see p. 20). In achieving the expectation, students are expected to apply skills from the area(s) specified by the abbreviation(s).

Many of the specific expectations are accompanied by examples, given in parentheses, as well as "sample issues" and "sample questions". The examples, sample issues, and sample questions are meant to illustrate the kind of knowledge or skill, the specific area of learning, the depth of learning, and/or the level of complexity that the expectation entails. They have been developed to model appropriate practice for the grade and are meant to serve as a guide for teachers rather than an exhaustive or mandatory list. Teachers can choose to use the examples and sample issues and questions that are appropriate for their classrooms, or they may develop their own approaches that reflect a similar level of complexity. Whatever the specific ways in which the requirements outlined in the expectations are implemented in the classroom, they must, wherever possible, be inclusive and reflect the diversity of the student population and the population of the province.

The Expectations and the Goals of the Science Program

The three overall expectations in the content strands of every course, and their corresponding groups of specific expectations, are closely connected with the three goals of the science program (see page 4). The relationship between the goals and the expectations is briefly described below:

Goal 1. ***To relate science to technology, society, and the environment***

The first overall expectation in each content strand focuses on relating science to technology, society, and the environment (STSE). These expectations and their related clusters of specific expectations are positioned at the beginning of the strands to better align the curriculum with the optimal approach to teaching and learning science, and to emphasize the importance of scientific, technological, and environmental literacy for all students. The STSE expectations provide the context for developing the related skills and conceptual knowledge necessary for making connections between scientific, technological, social, and environmental issues. The STSE expectations often focus on aspects of environmental education.

Goal 2. ***To develop the skills, strategies, and habits of mind required for scientific investigation***

The skills needed for developing scientific literacy are described in the second overall expectation in each strand and elaborated in its corresponding group of specific expectations, found under the heading "Developing Skills of Investigation and Communication".

Goal 3. ***To understand the basic concepts of science***

The conceptual knowledge that students are expected to acquire in the strand is described in the third overall expectation and elaborated in its corresponding group of specific expectations, found under the heading "Understanding Basic Concepts".

The incorporation of the three goals and their interrelationships in the curriculum expectations reinforces the idea that learning in science cannot be viewed as merely the learning of facts. Rather, it involves students' making connections and acquiring, in age-appropriate ways, the knowledge and skills that will help them to understand and consider critically the role of science in their daily lives, and the impact of scientific developments on society and the environment.

STRANDS IN THE GRADE 11 AND 12 SCIENCE COURSES

The expectations for the Grade 11 and 12 science courses are organized in six distinct but related strands. The first strand (strand A) focuses on scientific investigation skills, which are similar for all courses; the remaining five strands (strands B through F) represent the major content areas for each course.

Strand A: Scientific Investigation Skills

The first strand outlines required learning related to scientific investigation skills (SIS). The expectations in this strand describe the skills that are considered to be essential for all types of scientific investigation (see page 20). These skills apply to all areas of course content and must be developed in conjunction with learning in all five content strands of the course. (Scientific investigation skills were also a focus of the elementary science and technology curriculum, but they were embedded in expectations within the content strands.)

The scientific investigation skills are organized under subheadings related to the four broad areas of investigation – initiating and planning; performing and recording; analysing and interpreting; and communicating. To highlight the connection between skills in these broad areas of investigation and the expectations in the other five strands of a course, abbreviations in square brackets are given after each specific expectation in the first two groups of specifics in every strand (under the headings "Relating Science to Technology, Society, and the Environment" and "Developing Skills of Investigation and Communication"). These abbreviations link a specific expectation to the applicable area(s) of investigation skills. For example, "[IP]" indicates that, with achievement of the specific expectation, a student will have developed skills relating to initiating and planning. Teachers should ensure that students develop the scientific investigation skills in appropriate ways as they work to achieve the curriculum expectations in the content strands. Students' mastery of these skills must be assessed and evaluated as part of students' achievement of the overall expectations for the course.

Strands B through F: Content Areas

Stands B through F in the Grade 11 and 12 courses focus on major topics in the scientific discipline under study. The content for each course includes, where possible, topics set out in the pan-Canadian *Commom Framework of Science Learning Outcomes* (CMEC, 1997). The strands for all of the Grade 11 and 12 courses, as well as the topics in the strands of the Grade 9 and 10 courses, are outlined in the chart on pages 18–19.

Grades 9 and 10 – Strands and Topics

Course	***Strand B: Biology***	***Strand C: Chemistry***	***Strand D: Earth and Space Science***	***Strand E: Physics***
Gr. 9, Academic (SNC1D)	Sustainable Ecosystems	Atoms, Elements, and Compounds	The Study of the Universe	The Characteristics of Electricity
Gr. 9, Applied (SNC1P)	Sustainable Ecosystems and Human Activity	Exploring Matter	Space Exploration	Electrical Applications
Gr. 10, Academic (SNC2D)	Tissues, Organs, and Systems of Living Things	Chemical Reactions	Climate Change	Light and Geometric Optics
Gr. 10, Applied (SNC2P)	Tissues, Organs, and Systems	Chemical Reactions and Their Practical Application	Earth's Dynamic Climate	Light and Applications of Optics

Grades 11 and 12 – Strands

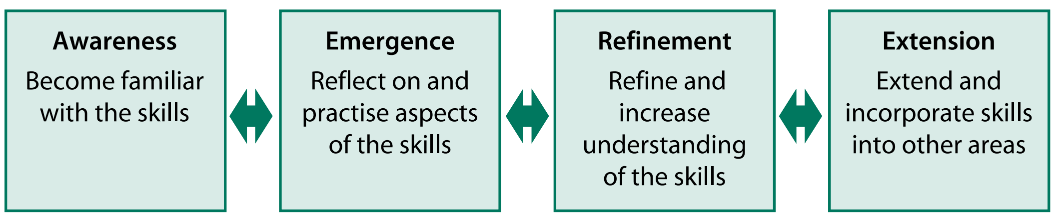
Course	***Strand B***	***Strand C***	***Strand D***	***Strand E***	***Strand F***
Biology, Gr. 11, University (SBI3U)	Diversity of Living Things	Evolution	Genetic Processes	Animals: Structure and Function	Plants: Anatomy, Growth, and Function
Biology, Gr. 11, College (SBI3C)	Cellular Biology	Microbiology	Genetics	Anatomy of Mammals	Plants in the Natural Environment
Biology, Gr. 12, University (SBI4U)	Biochemistry	Metabolic Processes	Molecular Genetics	Homeostasis	Population Dynamics
Chemistry, Gr. 11, University (SCH3U)	Matter, Chemical Trends, and Chemical Bonding	Chemical Reactions	Quantities in Chemical Reactions	Solutions and Solubility	Gases and Atmospheric Chemistry
Chemistry, Gr. 12, University (SCH4U)	Organic Chemistry	Structure and Properties of Matter	Energy Changes and Rates of Reaction	Chemical Systems and Equilibrium	Electrochemistry
Chemistry, Gr. 12, College (SCH4C)	Matter and Qualitative Analysis	Organic Chemistry	Electrochemistry	Chemical Calculations	Chemistry in the Environment

Grades 11 and 12 – Strands (*continued*)					
Course	***Strand B***	***Strand C***	***Strand D***	***Strand E***	***Strand F***
Earth and Space Science, Gr. 12, University (SES4U)	Astronomy (Science of the Universe)	Planetary Science (Science of the Solar System)	Recording Earth's Geological History	Earth Materials	Geological Processes
Environmental Science, Gr. 11, University/College (SVN3M)	Scientific Solutions to Contemporary Environmental Challenges	Human Health and the Environment	Sustainable Agriculture and Forestry	Reducing and Managing Waste	Conservation of Energy
Environmental Science, Gr. 11, Workplace (SVN3E)	Human Impact on the Environment	Human Health and the Environment	Energy Conservation	Natural Resource Science and Management	The Safe and Environmentally Responsible Workplace
Physics, Gr. 11, University (SPH3U)	Kinematics	Forces	Energy and Society	Waves and Sound	Electricity and Magnetism
Physics, Gr. 12, University (SPH4U)	Dynamics	Energy and Momentum	Gravitational, Electric, and Magnetic Fields	The Wave Nature of Light	Revolutions in Modern Physics: Quantum Mechanics and Special Relativity
Physics, Gr. 12, College (SPH4C)	Motion and Its Applications	Mechanical Systems	Electricity and Magnetism	Energy Transformations	Hydraulic and Pneumatic Systems
Science, Gr. 12, University/College (SNC4M)	Medical Technologies	Pathogens and Diseases	Nutritional Science	Science and Public Health Issues	Biotechnology
Science, Gr. 12, Workplace (SNC4E)	Hazards in the Workplace	Chemicals in Consumer Products	Disease and Its Prevention	Electricity at Home and Work	Nutritional Science

SKILLS OF SCIENTIFIC INVESTIGATION (INQUIRY AND RESEARCH)

The goal of science education is more than just providing students with a knowledge of facts. Mastery of the subject can no longer be evaluated solely in terms of students' ability to recall specialized terminology, memorize isolated facts, or repeat a theory. Rather, students must be given opportunities to learn through investigation. In doing so, they can practise and become proficient in various scientific investigation skills. These skills not only develop critical thinking and allow students to extend their understanding of science; they are also useful in students' everyday lives and will help them in pursuing their post-secondary goals, whether in science or some other area of endeavour.

As students advance from grade to grade, they practise these skills more fully and independently and in increasingly demanding contexts. Initially, students become aware of and familiar with each new skill. With emerging understanding, students reflect on and practise aspects of these skills when conducting investigations. As their knowledge and confidence grow, students begin to implement the skill more fully. Through repeated use, they are able to increase and refine their understanding of and proficiency in each skill. Finally, once they become proficient, they can extend skills, incorporating them into other areas of study as well as everyday activities.



Four Broad Areas of Scientific Investigation

Students learn to apply scientific investigation skills in four broad areas: *initiating and planning; performing and recording; analysing and interpreting;* and *communicating*.

- *Initiating and planning* skills include formulating questions or hypotheses or making predictions about ideas, issues, problems, or the relationships between observable variables, and planning investigations to answer those questions or test those hypotheses.
- *Performing and recording* skills include conducting research by gathering, organizing, and recording information, and safely conducting inquiries to make observations and to collect, organize, and record data.
- *Analysing and interpreting* skills include evaluating the adequacy of the data from inquiries or the information from research sources, and analysing the data or information in order to draw and justify conclusions.
- *Communication* skills include using appropriate linguistic, numeric, symbolic, and graphic modes of representation, and a variety of forms, to communicate ideas, procedures, and results.

Skills in these four areas are not necessarily performed sequentially. As the figure on page 21 illustrates, investigation may begin in any one of the areas, and students will tend to move back and forth among the areas as they practise and refine their skills. Students should

PHYSICS

Physics, Grade 11

University Preparation SPH3U

This course develops students' understanding of the basic concepts of physics. Students will explore kinematics, with an emphasis on linear motion; different kinds of forces; energy transformations; the properties of mechanical waves and sound; and electricity and magnetism. They will enhance their scientific investigation skills as they test laws of physics. In addition, they will analyse the interrelationships between physics and technology, and consider the impact of technological applications of physics on society and the environment.

Prerequisite: Science, Grade 10, Academic

Big Ideas

Kinematics

- Motion involves a change in the position of an object over time.
- Motion can be described using mathematical relationships.
- Many technologies that apply concepts related to kinematics have societal and environmental implications.

Forces

- Forces can change the motion of an object.
- Applications of Newton's laws of motion have led to technological developments that affect society and the environment.

Energy and Society

- Energy can be transformed from one type to another.
- Energy transformation systems often involve thermal energy losses and are never 100% efficient.
- Although technological applications that involve energy transformations can affect society and the environment in positive ways, they can also have negative effects, and therefore must be used responsibly.

Waves and Sound

- Mechanical waves have specific characteristics and predictable properties.
- Sound is a mechanical wave.
- Mechanical waves can affect structures, society, and the environment in positive and negative ways.

Electricity and Magnetism

- Relationships between electricity and magnetism are predictable.
- Electricity and magnetism have many technological applications.
- Technological applications that involve electromagnetism and energy transformations can affect society and the environment in positive and negative ways.

Fundamental Concepts Covered in This Course (see also page 5)

Fundamental Concepts	Kinematics	Forces	Energy and Society	Waves and Sound	Electricity and Magnetism
Matter		✓	✓	✓	✓
Energy	✓	✓	✓	✓	✓
Systems and Interactions	✓	✓	✓	✓	✓
Structure and Function	✓	✓		✓	✓
Sustainability and Stewardship			✓	✓	✓
Change and Continuity			✓		

A. SCIENTIFIC INVESTIGATION SKILLS AND CAREER EXPLORATION

OVERALL EXPECTATIONS

Throughout this course, students will:

A1. demonstrate scientific investigation skills (related to both inquiry and research) in the four areas of skills (initiating and planning, performing and recording, analysing and interpreting, and communicating);

A2. identify and describe careers related to the fields of science under study, and describe the contributions of scientists, including Canadians, to those fields.

SPECIFIC EXPECTATIONS

A1. Scientific Investigation Skills

Throughout this course, students will:

Initiating and Planning [IP]*

A1.1 formulate relevant scientific questions about observed relationships, ideas, problems, or issues, make informed predictions, and/or formulate educated hypotheses to focus inquiries or research

A1.2 select appropriate instruments (e.g., probeware, calorimeters, pendulums, solenoids) and materials (e.g., drag sleds, electric bells, balls, ramps), and identify appropriate methods, techniques, and procedures, for each inquiry

A1.3 identify and locate a variety of print and electronic sources that enable them to address research topics fully and appropriately

A1.4 apply knowledge and understanding of safe laboratory practices and procedures when planning investigations by correctly interpreting Workplace Hazardous Materials Information System (WHMIS) symbols; by using appropriate techniques for handling and storing laboratory equipment and materials and disposing of laboratory materials; and by using appropriate personal protection

Performing and Recording [PR]*

A1.5 conduct inquiries, controlling relevant variables, adapting or extending procedures as required, and using appropriate materials and equipment safely, accurately, and effectively, to collect observations and data

A1.6 compile accurate data from laboratory and other sources, and organize and record the data, using appropriate formats, including tables, flow charts, graphs, and/or diagrams

A1.7 select, organize, and record relevant information on research topics from a variety of appropriate sources, including electronic, print, and/or human sources, using suitable formats and an accepted form of academic documentation

Analysing and Interpreting [AI]*

A1.8 synthesize, analyse, interpret, and evaluate qualitative and/or quantitative data; solve problems involving quantitative data; determine whether the evidence supports or refutes the initial prediction or hypothesis and whether it is consistent with scientific theory; identify sources of bias and/or error; and suggest improvements to the inquiry to reduce the likelihood of error

A1.9 analyse the information gathered from research sources for logic, accuracy, reliability, adequacy, and bias

* The abbreviation(s) for the broad area(s) of investigation skills – IP, PR, AI, and/or C – are provided in square brackets at the end of the expectations in strands B–F to which the particular area(s) relate (see pp. 20–22 for information on scientific investigation skills).

A1.10 draw conclusions based on inquiry results and research findings, and justify their conclusions with reference to scientific knowledge

Communicating [C]*

A1.11 communicate ideas, plans, procedures, results, and conclusions orally, in writing, and/or in electronic presentations, using appropriate language and a variety of formats (e.g., data tables, laboratory reports, presentations, debates, simulations, models)

A1.12 use appropriate numeric (e.g., SI and imperial units), symbolic, and graphic modes of representation for qualitative and quantitative data (e.g., vector diagrams, free-body diagrams, algebraic equations)

A1.13 express the results of any calculations involving data accurately and precisely, to the appropriate number of decimal places or significant figures

A2. Career Exploration

Throughout this course, students will:

A2.1 identify and describe a variety of careers related to the fields of science under study (e.g., theoretical physicist; communications, networks, and control systems professional; engineer; metallurgist) and the education and training necessary for these careers

A2.2 describe the contributions of scientists, including Canadians (e.g., Richard E. Taylor, Leonard T. Bruton, Willard S. Boyle, Martha Salcudean, Harriet Brooks, Louis Slotin), to the fields under study

B. KINEMATICS

OVERALL EXPECTATIONS

By the end of this course, students will:

B1. analyse technologies that apply concepts related to kinematics, and assess the technologies' social and environmental impact;

B2. investigate, in qualitative and quantitative terms, uniform and non-uniform linear motion, and solve related problems;

B3. demonstrate an understanding of uniform and non-uniform linear motion, in one and two dimensions.

SPECIFIC EXPECTATIONS

B1. Relating Science to Technology, Society, and the Environment

By the end of this course, students will:

B1.1 analyse, on the basis of research, a technology that applies concepts related to kinematics (e.g., devices used to measure speed in sports; rocket accelerators; motion-detecting sensors for security systems; speedometers in automobiles) [IP, PR, AI, C]

Sample questions: How does a speed gun measure the motion of a ball thrown by a baseball pitcher? How are accelerometers used to study the motion of animals in wilderness settings? How are accelerometers used in video game consoles? What type of device is used to monitor false starts in a sprint? How does it work?

B1.2 assess the impact on society and the environment of a technology that applies concepts related to kinematics (e.g., photo radar helps prevent vehicular accidents and reduces fuel consumption associated with excessive speeding) [AI, C]

Sample issue: The use of the global positioning system (GPS) increases accuracy in mapping, surveying, navigation, monitoring earthquakes, and tracking the movement of oil spills and forest fires, among other benefits. However, its extensive use raises concerns about privacy and human rights.

Sample questions: How are satellites used to track animal species in remote areas? How can scientists and environmentalists use this information to help protect vulnerable species? What is the impact of the use of speed limiters and tracking devices in the trucking industry? What effect do lower truck speeds have on highway safety and vehicle emissions?

B2. Developing Skills of Investigation and Communication

By the end of this course, students will:

B2.1 use appropriate terminology related to kinematics, including, but not limited to: *time, distance, position, displacement, speed, velocity,* and *acceleration* [C]

B2.2 analyse and interpret position–time, velocity–time, and acceleration–time graphs of motion in one dimension (e.g., use tangent slopes to create velocity–time graphs from position–time graphs and acceleration–time graphs from velocity–time graphs; use the area under the curve to create position–time graphs from velocity–time graphs and velocity–time graphs from acceleration–time graphs) [AI, C]

B2.3 use a velocity–time graph for constant acceleration to derive the equation for average velocity [e.g., $v_{av} = (v_1 + v_2)/2$] and the equations for displacement [e.g., $\Delta d = ((v_1 + v_2)/2)\,\Delta t$, $\Delta d = v_1\Delta t + ½\,a\,(\Delta t^2)$], and solve simple problems in one dimension using these equations [AI]

B2.4 conduct an inquiry into the uniform and non-uniform linear motion of an object (e.g., use probeware to record the motion of a cart moving at a constant velocity or a constant acceleration; view a computer simulation of an object attaining terminal velocity; observe a video of a bouncing ball or a skydiver; observe the motion of a balloon with a small mass suspended from it) [PR]

B2.5 solve problems involving distance, position, and displacement (e.g., find total displacement using a scale vector diagram and vector components, and compare it to total distance travelled) [AI, C]

B2.6 plan and conduct an inquiry into the motion of objects in one dimension, using vector diagrams and uniform acceleration equations [IP, PR, C]

B2.7 solve problems involving uniform and non-uniform linear motion in one and two dimensions, using graphical analysis and algebraic equations [AI, C]

B2.8 use kinematic equations to solve problems related to the horizontal and vertical components of the motion of a projectile (e.g., a cannon ball shot horizontally off a cliff, a ball rolling off a table, a golf ball launched at a 45º angle to the horizontal) [AI, C]

B2.9 conduct an inquiry into the projectile motion of an object, and analyse, in qualitative and quantitative terms, the relationship between the horizontal and vertical components (e.g., airborne time, range, maximum height, horizontal velocity, vertical velocity) [PR, AI]

B3. Understanding Basic Concepts

By the end of this course, students will:

B3.1 distinguish between the terms *constant*, *instantaneous*, and *average* with reference to speed, velocity, and acceleration, and provide examples to illustrate each term

B3.2 distinguish between, and provide examples of, scalar and vector quantities as they relate to the description of uniform and non-uniform linear motion (e.g., time, distance, position, velocity, acceleration)

B3.3 describe the characteristics and give examples of a projectile's motion in vertical and horizontal planes

C. FORCES

OVERALL EXPECTATIONS

By the end of this course, students will:

C1. analyse and propose improvements to technologies that apply concepts related to dynamics and Newton's laws, and assess the technologies' social and environmental impact;

C2. investigate, in qualitative and quantitative terms, net force, acceleration, and mass, and solve related problems;

C3. demonstrate an understanding of the relationship between changes in velocity and unbalanced forces in one dimension.

SPECIFIC EXPECTATIONS

C1. Relating Science to Technology, Society, and the Environment

By the end of this course, students will:

C1.1 analyse, with reference to Newton's laws, a technology that applies these laws (e.g., extremely low friction bearings, near frictionless carbon, different types of athletic shoes, roller coasters), and propose ways to improve its performance [AI, C]

Sample questions: What factors are taken into consideration in the design of golf clubs? What element(s) could be changed to improve a club's performance? How do anti-lock brakes work, and what limitations do they have? What impact does the condition of the road (wet, dry, smooth, grooved) have on the forces acting on the braking of a skidding car? What are the benefits and limitations of electronic stability controls (ESC) on automobiles?

C1.2 evaluate the impact on society and the environment of technologies that use the principles of force (e.g., prosthetics, plastic car bodies) [AI, C]

Sample issue: Before the 1960s, when car bodies were strong and rigid, passengers tended to be severely injured during collisions. The introduction of technologies that absorb or dissipate force, such as crumple zones, seat belts, and air bags, has reduced serious automobile injuries and the social costs associated with them.

Sample questions: How do snow tires reduce the risk of traffic accidents in the winter? How does society benefit from this risk reduction? What are the advantages and disadvantages for the environment of various methods of using the natural forces from tidal currents to generate energy?

C2. Developing Skills of Investigation and Communication

By the end of this course, students will:

C2.1 use appropriate terminology related to forces, including, but not limited to: *mass*, *time*, *speed*, *velocity*, *acceleration*, *friction*, *gravity*, *normal force*, and *free-body diagrams* [C]

C2.2 conduct an inquiry that applies Newton's laws to analyse, in qualitative and quantitative terms, the forces acting on an object, and use free-body diagrams to determine the net force and the acceleration of the object [PR, AI, C]

C2.3 conduct an inquiry into the relationship between the acceleration of an object and its net force and mass (e.g., view a computer simulation of an object attaining terminal velocity; observe the motion of an object subject to friction; use electronic probes to observe the motion of an object being pulled across the floor), and analyse the resulting data [PR, AI]

C2.4 analyse the relationships between acceleration and applied forces such as the force of gravity, normal force, force of friction, coefficient of static friction, and coefficient of kinetic friction, and solve related problems involving forces in one dimension, using free-body diagrams and algebraic equations (e.g., use a drag sled to find the coefficient of friction between two surfaces) [AI, C]

C2.5 plan and conduct an inquiry to analyse the effect of forces acting on objects in one dimension, using vector diagrams, free-body diagrams, and Newton's laws [IP, PR, AI, C]

C2.6 analyse and solve problems involving the relationship between the force of gravity and acceleration for objects in free fall [AI]

C3. Understanding Basic Concepts

By the end of this course, students will:

C3.1 distinguish between, and provide examples of, different forces (e.g., friction, gravity, normal force), and describe the effect of each type of force on the velocity of an object

C3.2 explain how the theories and discoveries of Galileo and Newton advanced knowledge of the effects of forces on the motion of objects

C3.3 state Newton's laws, and apply them, in qualitative terms, to explain the effect of forces acting on objects

C3.4 describe, in qualitative and quantitative terms, the relationships between mass, gravitational field strength, and force of gravity

D. ENERGY AND SOCIETY

OVERALL EXPECTATIONS

By the end of this course, students will:

D1. analyse technologies that apply principles of and concepts related to energy transformations, and assess the technologies' social and environmental impact;

D2. investigate energy transformations and the law of conservation of energy, and solve related problems;

D3. demonstrate an understanding of work, efficiency, power, gravitational potential energy, kinetic energy, nuclear energy, and thermal energy and its transfer (heat).

SPECIFIC EXPECTATIONS

D1. Relating Science to Technology, Society, and the Environment

By the end of this course, students will:

D1.1 analyse, using the principles of energy transformations, a technology that involves the transfer and transformation of thermal energy (e.g., a power station, an air conditioner, a fuel cell, a laser printer) [AI, C]

Sample questions: How do vertical or rooftop gardens help insulate structures? In what ways have refrigeration technologies changed since their initial development? When they are designed efficiently, how do homes with solar-powered cells use the energy from the sun? How do ground-source heat pumps reduce the need for traditional heating and cooling systems?

D1.2 assess, on the basis of research, how technologies related to nuclear, thermal, or geothermal energy affect society and the environment (e.g., thermal regulating units, radiopharmaceuticals, dry-steam power plants, ground-source heat pumps) [IP, PR, AI, C]

Sample issue: With the rising economic and environmental costs of heating homes using conventional methods, geothermal technologies are an increasingly popular alternative. However, tapping geothermal heat sources involves placing kilometres of tubing containing antifreeze in the ground, which constitutes a potential environmental hazard.

Sample questions: How is the nuclear technology known as receptor binding assay used to monitor the toxicity of shellfish? How does this technology benefit consumers? How can nuclear technology be used to sterilize insects? If used widely, what impact would such a pest-control technique have on society and the environment? What is the benefit of using fast-freeze technologies in cold chain shipping for highly perishable goods?

D2. Developing Skills of Investigation and Communication

By the end of this course, students will:

D2.1 use appropriate terminology related to energy transformations, including, but not limited to: *mechanical energy, gravitational potential energy, kinetic energy, work, power, fission, fusion, heat, heat capacity, temperature,* and *latent heat* [C]

D2.2 solve problems relating to work, force, and displacement along the line of force [AI]

D2.3 use the law of conservation of energy to solve problems in simple situations involving work, gravitational potential energy, kinetic energy, and thermal energy and its transfer (heat) [AI]

D2.4 plan and conduct inquiries involving transformations between gravitational potential energy and kinetic energy (e.g., using a pendulum, a falling ball, an object rolling down a ramp) to test the law of conservation of energy [IP, PR]

D2.5 solve problems involving the relationship between power, energy, and time [AI]

D2.6 conduct inquiries and solve problems involving the relationship between power and work (e.g., the power of a student using different types of fitness equipment) [PR, AI]

D2.7 compare and contrast the input energy, useful output energy, and per cent efficiency of selected energy generation methods (e.g., hydroelectric, thermal, geothermal, nuclear fission, nuclear fusion, wind, solar) [AI, C]

D2.8 investigate the relationship between the concepts of conservation of mass and conservation of energy, and solve problems using the mass–energy equivalence [PR, AI]

D2.9 conduct an inquiry to determine the specific heat capacity of a single substance (e.g., aluminum, iron, brass) and of two substances when they are mixed together (e.g., the heat lost by a sample of hot water and the heat gained by a sample of cold water when the two samples are mixed together) [PR]

D2.10 solve problems involving changes in temperature and changes of state, using algebraic equations (e.g., $Q = mc\Delta T$, $Q = mL_f$, $Q = mL_v$) [AI, C]

D2.11 draw and analyse heating and cooling curves that show temperature changes and changes of state for various substances [AI, C]

D3. Understanding Basic Concepts

By the end of this course, students will:

D3.1 describe a variety of energy transfers and transformations, and explain them using the law of conservation of energy

D3.2 explain the concepts of and interrelationships between energy, work, and power, and identify and describe their related units

D3.3 explain the following concepts, giving examples of each, and identify their related units: *thermal energy, kinetic energy, gravitational potential energy, heat, specific heat capacity, specific latent heat, power,* and *efficiency*

D3.4 identify, qualitatively, the relationship between efficiency and thermal energy transfer

D3.5 describe, with reference to force and displacement along the line of force, the conditions that are required for work to be done

D3.6 describe and compare nuclear fission and nuclear fusion

D3.7 explain, using the kinetic molecular theory, the energy transfer that occurs during changes of state

D3.8 distinguish between and provide examples of conduction, convection, and radiation

D3.9 identify and describe the structure of common nuclear isotopes (e.g., hydrogen, deuterium, tritium)

D3.10 compare the characteristics of (e.g., mass, charge, speed, penetrating power, ionizing ability) and safety precautions related to alpha particles, beta particles, and gamma rays

D3.11 explain radioactive half-life for a given radioisotope, and describe its applications and their consequences

D3.12 explain the energy transformations that occur within a nuclear power plant, with reference to the laws of thermodynamics (e.g., nuclear fission results in the liberation of energy, which is converted into thermal energy; the thermal energy is converted into electrical energy and waste heat, using a steam turbine)

E. WAVES AND SOUND

OVERALL EXPECTATIONS

By the end of this course, students will:

E1. analyse how mechanical waves and sound affect technology, structures, society, and the environment, and assess ways of reducing their negative effects;

E2. investigate, in qualitative and quantitative terms, the properties of mechanical waves and sound, and solve related problems;

E3. demonstrate an understanding of the properties of mechanical waves and sound and of the principles underlying their production, transmission, interaction, and reception.

SPECIFIC EXPECTATIONS

E1. Relating Science to Technology, Society, and the Environment

By the end of this course, students will:

E1.1 analyse how properties of mechanical waves and sound influence the design of structures and technological devices (e.g., the acoustical design of a concert hall; the design of headphones, hearing aids, musical instruments, wave pools) [AI, C]

Sample issue: Waves cause vibrations when they oscillate at different frequencies. Oscillating waves caused by wind or earthquakes can threaten the structure of bridges if they are not properly designed. Engineers have developed different designs of bridges, depending on local conditions, but no single design can take all possible wave frequencies into account.

Sample questions: How do energy-conversion buoys use the properties of waves to generate electricity? Why do different musical instruments produce different sounds? What features need to be incorporated into the acoustic design of an outdoor concert venue in order for it to provide optimal sound quality for the audience but limited noise in the surrounding area?

E1.2 analyse the negative impact that mechanical waves and/or sound can have on society and the environment, and assess the effectiveness of a technology intended to reduce this impact [AI, C]

Sample issue: Noise pollution from industrial, transportation, entertainment, and other sources can increase stress, lead to hearing loss, disrupt ecosystems, and alter animal behaviour. Noise pollution can be reduced by using mufflers, sound barriers, baffles, and earplugs, and by turning down the volume on devices such as cellphones and headsets.

Sample questions: What impact can tsunamis have on coastal regions? How effective is tsunami-monitoring equipment in reducing death tolls and property destruction? How do the noise levels produced by different types of jet engines compare with each other? How effective are the sound baffles erected on the sides of highways that run through residential areas?

E2. Developing Skills of Investigation and Communication

By the end of this course, students will:

E2.1 use appropriate terminology related to mechanical waves and sound, including, but not limited to: *longitudinal wave, transverse wave, frequency, period, cycle, amplitude, phase, wavelength, velocity, superposition, constructive interference, destructive interference, standing waves*, and *resonance* [C]

E2.2 conduct laboratory inquiries or computer simulations involving mechanical waves and their interference (e.g., using a mass oscillating on a spring, a mass oscillating on a pendulum, the oscillation in a string instrument) [PR]

E2.3 plan and conduct inquiries to determine the speed of waves in a medium (e.g., a vibrating air column, an oscillating string of a musical instrument), compare theoretical and empirical values, and account for discrepancies [IP, PR, AI, C]

E2.4 investigate the relationship between the wavelength, frequency, and speed of a wave, and solve related problems [PR, AI]

E2.5 analyse the relationship between a moving source of sound and the change in frequency perceived by a stationary observer (i.e., the Doppler effect) [AI]

E2.6 predict the conditions needed to produce resonance in vibrating objects or air columns (e.g., in a wind instrument, a string instrument, a tuning fork), and test their predictions through inquiry [IP, PR, AI]

E2.7 analyse the conditions required to produce resonance in vibrating objects and/or in air columns (e.g., in a string instrument, a tuning fork, a wind instrument), and explain how resonance is used in a variety of situations (e.g., to produce different notes in musical instruments; to limit undesirable vibrations in suspension bridges; to design buildings so that they do not resonate at the frequencies produced by earthquakes) [AI, C]

E3. Understanding Basic Concepts

By the end of this course, students will:

E3.1 distinguish between longitudinal and transverse waves in different media, and provide examples of both types of waves

E3.2 explain the components of resonance, and identify the conditions required for resonance to occur in vibrating objects and in various media (e.g., with reference to a musical instrument, a child on a swing, the Tacoma Narrows Bridge)

E3.3 explain and graphically illustrate the principle of superposition with respect to standing waves and beat frequencies

E3.4 identify the properties of standing waves, and, for both mechanical and sound waves, explain the conditions required for standing waves to occur

E3.5 explain the relationship between the speed of sound in various media and the particle nature of the media (e.g., the speed of sound in solids, liquids, and gases; the speed of sound in warm and cold air)

E3.6 explain selected natural phenomena (e.g., echo location, or organisms that produce or receive infrasonic, audible, or ultrasonic sound) with reference to the characteristics and properties of waves

F. ELECTRICITY AND MAGNETISM

OVERALL EXPECTATIONS

By the end of this course, students will:

F1. analyse the social, economic, and environmental impact of electrical energy production and technologies related to electromagnetism, and propose ways to improve the sustainability of electrical energy production;

F2. investigate, in qualitative and quantitative terms, magnetic fields and electric circuits, and solve related problems;

F3. demonstrate an understanding of the properties of magnetic fields, the principles of current and electron flow, and the operation of selected technologies that use these properties and principles to produce and transmit electrical energy.

SPECIFIC EXPECTATIONS

F1. Relating Science to Technology, Society, and the Environment

By the end of this course, students will:

F1.1 analyse the social and economic impact of technologies related to electromagnetism (e.g., particle accelerators, mass spectrometers, magnetic levitation [maglev] trains, magnetic resonance imaging [MRI], electromagnetic pulses after nuclear explosions) [AI, C]

Sample issue: The use of red-light camera technology at busy intersections has decreased the number of accidents and pedestrian fatalities. However, some people view the use of this technology as an unnecessary intrusion by "Big Brother".

Sample questions: What are the benefits of electromagnetic medical technologies? What impact does the cost of acquiring these technologies, and the need for specialized technicians to operate them, have on equitable access to health care in all regions of Canada? What harmful effects do solar flares have on our atmosphere, satellites orbiting the earth, and electrical systems?

F1.2 analyse the efficiency and the environmental impact of one type of electrical energy production (e.g., from hydroelectric, fossil fuel–burning, wind, solar, geothermal, or nuclear sources), and propose ways to improve the sustainability of electrical energy production [AI, C]

Sample issue: Compared to oil, coal is relatively inexpensive and plentiful, and, globally, the number of coal-burning electrical plants is expanding. Yet, coal power is inefficient, and the mining and burning of coal produce a great deal of pollution. Although technology is available to make coal cleaner, it is costly and has been implemented to only a limited extent.

Sample questions: How efficient are the small- and large-scale solar-power systems used in individual homes and industrial settings? What is the environmental impact of the generation of solar power? What technologies are being used to improve the efficiency of energy sources such as coal and biofuel? What impact does the increasing use of biofuels have on air quality, land use, and agricultural practices?

F2. Developing Skills of Investigation and Communication

By the end of this course, students will:

F2.1 use appropriate terminology related to electricity and magnetism, including, but not limited to: *direct current*, *alternating current*, *conventional current*, *electron flow*, *electrical potential difference*, *electrical resistance*, *power*, *energy*, *step-up transformer*, and *step-down transformer* [C]

F2.2 analyse diagrams of series, parallel, and mixed circuits with reference to Ohm's law ($V = IR$) and Kirchhoff's laws [AI]

F2.3 design and build real or computer-simulated mixed direct current (DC) circuits, and explain the circuits with reference to direct current, potential difference, and resistance [PR, C]

F2.4 conduct an inquiry to identify the characteristics and properties of magnetic fields (e.g., using magnetic compasses, iron filings, and electric and magnetic field sensors) [PR]

F2.5 investigate, through laboratory inquiry or computer simulation, the magnetic fields produced by an electric current flowing through a long straight conductor and a solenoid (e.g., use sensors to map the magnetic field around a solenoid) [PR]

F2.6 solve problems involving energy, power, potential difference, current, and the number of turns in the primary and secondary coils of a transformer [AI]

F2.7 investigate electromagnetic induction, and, using Lenz's law, the law of conservation of energy, and the right-hand rule, explain and illustrate the direction of the electric current induced by a changing magnetic field [PR, AI, C]

F2.8 construct a prototype of a device that uses the principles of electromagnetism (e.g., an electric bell, loudspeaker, ammeter, electric motor, electric generator), and test and refine their device [PR, AI]

F3. Understanding Basic Concepts

By the end of this course, students will:

F3.1 describe the properties of magnetic fields in permanent magnets and electromagnets (e.g., the three-dimensional nature of fields, continuous field lines, fields around current-carrying conductors and coils)

F3.2 explain, by applying the right-hand rule, the direction of the magnetic field produced when electric current flows through a long straight conductor and through a solenoid

F3.3 distinguish between conventional current and electron flow in relation to the left- and right-hand rules

F3.4 explain Ohm's law, Kirchhoff's laws, Oersted's principle, the motor principle, Faraday's law, and Lenz's law in relation to electricity and magnetism

F3.5 describe the production and interaction of magnetic fields, using diagrams and the principles of electromagnetism (e.g., Oersted's principle, the motor principle, Faraday's law, Lenz's law)

F3.6 explain the operation of an electric motor and a generator, including the roles of their respective components

F3.7 distinguish between alternating current (AC) and direct current, and explain why alternating current is presently used in the transmission of electrical energy

F3.8 describe the components of step-up and step-down transformers, and, using concepts and principles related to electric current and magnetic fields, explain the operation of these transformers

F3.9 describe and explain safety precautions (e.g., "call before you dig", current-limiting outlets in bathrooms) related to electrical circuits and higher transmission voltages (e.g., with reference to transformer substations, buried cables, overhead power lines)

Physics, Grade 12

University Preparation SPH4U

This course enables students to deepen their understanding of physics concepts and theories. Students will continue their exploration of energy transformations and the forces that affect motion, and will investigate electrical, gravitational, and magnetic fields and electromagnetic radiation. Students will also explore the wave nature of light, quantum mechanics, and special relativity. They will further develop their scientific investigation skills, learning, for example, how to analyse, qualitatively and quantitatively, data related to a variety of physics concepts and principles. Students will also consider the impact of technological applications of physics on society and the environment.

Prerequisite: Physics, Grade 11, University Preparation

Big Ideas

Dynamics
- Forces affect motion in predictable and quantifiable ways.
- Forces acting on an object will determine the motion of that object.
- Many technologies that utilize the principles of dynamics have societal and environmental implications.

Energy and Momentum
- Energy and momentum are conserved in all interactions.
- Interactions involving the laws of conservation of energy and conservation of momentum can be analysed mathematically.
- Technological applications that involve energy and momentum can affect society and the environment in positive and negative ways.

Gravitational, Electric, and Magnetic Fields
- Gravitational, electric, and magnetic forces act on matter from a distance.
- Gravitational, electric, and magnetic fields share many similar properties.
- The behaviour of matter in gravitational, electric, and magnetic fields can be described mathematically.
- Technological systems that involve gravitational, electric, and magnetic fields can have an effect on society and the environment.

The Wave Nature of Light
- Light has properties that are similar to the properties of mechanical waves.
- The behaviour of light as a wave can be described mathematically.
- Technologies that use the principles of the wave nature of light can have societal and environmental implications.

Revolutions in Modern Physics: Quantum Mechanics and Special Relativity
- Light can show particle-like and wave-like behaviour, and particles can show wave-like behaviour.
- The behaviour of light as a particle and the behaviour of particles as waves can be described mathematically.

- Time is relative to a person's frame of reference.
- The effects of relativistic motion can be described mathematically.
- New theories can change scientific thought and lead to the development of new technologies.

Fundamental Concepts Covered in This Course (see also page 5)

Fundamental Concepts	Dynamics	Energy and Momentum	Gravitational, Electric, and Magnetic Fields	The Wave Nature of Light	Revolutions in Modern Physics: Quantum Mechanics and Special Relativity
Matter	✓	✓	✓	✓	✓
Energy	✓	✓	✓	✓	✓
Systems and Interactions	✓	✓	✓		
Structure and Function	✓	✓	✓	✓	
Sustainability and Stewardship		✓		✓	
Change and Continuity		✓			✓

A. SCIENTIFIC INVESTIGATION SKILLS AND CAREER EXPLORATION

OVERALL EXPECTATIONS

Throughout this course, students will:

A1. demonstrate scientific investigation skills (related to both inquiry and research) in the four areas of skills (initiating and planning, performing and recording, analysing and interpreting, and communicating);

A2. identify and describe careers related to the fields of science under study, and describe the contributions of scientists, including Canadians, to those fields.

SPECIFIC EXPECTATIONS

A1. Scientific Investigation Skills

Throughout this course, students will:

Initiating and Planning [IP]*

A1.1 formulate relevant scientific questions about observed relationships, ideas, problems, or issues, make informed predictions, and/or formulate educated hypotheses to focus inquiries or research

A1.2 select appropriate instruments (e.g., pendulums, springs, ripple tanks, lasers) and materials (e.g., sliding blocks, inclined planes), and identify appropriate methods, techniques, and procedures, for each inquiry

A1.3 identify and locate a variety of print and electronic sources that enable them to address research topics fully and appropriately

A1.4 apply knowledge and understanding of safe laboratory practices and procedures when planning investigations by correctly interpreting Workplace Hazardous Materials Information System (WHMIS) symbols; by using appropriate techniques for handling and storing laboratory equipment and materials and disposing of laboratory materials; and by using appropriate personal protection

Performing and Recording [PR]*

A1.5 conduct inquiries, controlling relevant variables, adapting or extending procedures as required, and using appropriate materials and equipment safely, accurately, and effectively, to collect observations and data

A1.6 compile accurate data from laboratory and other sources, and organize and record the data, using appropriate formats, including tables, flow charts, graphs, and/or diagrams

A1.7 select, organize, and record relevant information on research topics from a variety of appropriate sources, including electronic, print, and/or human sources, using suitable formats and an accepted form of academic documentation

Analysing and Interpreting [AI]*

A1.8 synthesize, analyse, interpret, and evaluate qualitative and quantitative data; solve problems involving quantitative data; determine whether the evidence supports or refutes the initial prediction or hypothesis and whether it is consistent with scientific theory; identify sources of bias and/or error; and suggest improvements to the inquiry to reduce the likelihood of error

A1.9 analyse the information gathered from research sources for logic, accuracy, reliability, adequacy, and bias

* The abbreviation(s) for the broad area(s) of investigation skills – IP, PR, AI, and/or C – are provided in square brackets at the end of the expectations in strands B–F to which the particular area(s) relate (see pp. 20–22 for information on scientific investigation skills).

A1.10 draw conclusions based on inquiry results and research findings, and justify their conclusions with reference to scientific knowledge

Communicating [C]*

A1.11 communicate ideas, plans, procedures, results, and conclusions orally, in writing, and/or in electronic presentations, using appropriate language and a variety of formats (e.g., data tables, laboratory reports, presentations, debates, simulations, models)

A1.12 use appropriate numeric (e.g., SI and imperial units), symbolic, and graphic modes of representation (e.g., vector diagrams, free-body diagrams, vector components, and algebraic equations)

A1.13 express the results of any calculations involving data accurately and precisely, to the appropriate number of decimal places or significant figures

A2. Career Exploration

Throughout this course, students will:

A2.1 identify and describe a variety of careers related to the fields of science under study (e.g., laser optics researcher, geoscientist, photonics researcher, aerospace engineer) and the education and training necessary for these careers

A2.2 describe the contributions of scientists, including Canadians (e.g., Elizabeth MacGill, Pierre Coulombe, Allan Carswell, Gerhard Herzberg), to the fields under study

B. DYNAMICS

OVERALL EXPECTATIONS

By the end of this course, students will:

B1. analyse technological devices that apply the principles of the dynamics of motion, and assess the technologies' social and environmental impact;

B2. investigate, in qualitative and quantitative terms, forces involved in uniform circular motion and motion in a plane, and solve related problems;

B3. demonstrate an understanding of the forces involved in uniform circular motion and motion in a plane.

SPECIFIC EXPECTATIONS

B1. Relating Science to Technology, Society, and the Environment

By the end of this course, students will:

B1.1 analyse a technological device that applies the principles of linear or circular motion (e.g., a slingshot, a rocket launcher, a race car, a trebuchet) [AI, C]

Sample questions: What aspects of the principles of motion are applied in archery? How does the equipment used by competitive skiers reduce friction and resistance? How does a "pop bottle" rocket use the principles of motion? How does the spin cycle of a washing machine use circular motion to remove water from clothes?

B1.2 assess the impact on society and the environment of technological devices that use linear or circular motion (e.g., projectile weapons, centrifuges, elevators) [AI, C]

Sample issue: Satellites, which use principles of circular motion to revolve around Earth, support communications technologies and are used by governments to gather intelligence. They also provide information on the movement of animal populations and forest fires, and on changes in weather systems or the atmosphere. But satellites use huge amounts of fuel, and old satellites often become space junk.

Sample questions: How are large-scale centrifuges used in wastewater treatment? How do windmills use the principles of dynamics to generate power? What is the environmental impact of wind power and wind farms? How are linear actuators used to make the workplace more ergonomic, reducing work days lost to strain and injury?

B2. Developing Skills of Investigation and Communication

By the end of this course, students will:

B2.1 use appropriate terminology related to dynamics, including, but not limited to: *inertial and non-inertial frames of reference, components, centripetal, period, frequency, static friction*, and *kinetic friction* [C]

B2.2 solve problems related to motion, including projectile and relative motion, by adding and subtracting two-dimensional vector quantities, using vector diagrams, vector components, and algebraic methods [PR, AI, C]

B2.3 analyse, in qualitative and quantitative terms, the relationships between the force of gravity, normal force, applied force, force of friction, coefficient of static friction, and coefficient of kinetic friction, and solve related two-dimensional problems using free-body diagrams, vector components, and algebraic equations (e.g., calculate the acceleration of a block sliding along an inclined plane or the force acting on a vehicle navigating a curve) [AI, C]

B2.4 predict, in qualitative and quantitative terms, the forces acting on systems of objects (e.g., masses in a vertical pulley system [a "dumb waiter"], a block sliding off an accelerating vehicle, masses in an inclined-plane pulley system), and plan and conduct an inquiry to test their predictions [IP, PR, AI]

B2.5 analyse, in qualitative and quantitative terms, the relationships between the motion of a system and the forces involved (e.g., a block sliding on an inclined plane, acceleration of a pulley system), and use free-body diagrams and algebraic equations to solve related problems [AI, C]

B2.6 analyse, in qualitative and quantitative terms, the forces acting on and the acceleration experienced by an object in uniform circular motion in horizontal and vertical planes, and use free-body diagrams and algebraic equations to solve related problems [AI, C]

B2.7 conduct inquiries into the uniform circular motion of an object (e.g., using video analysis of an amusement park ride, measuring the forces and period of a tether ball), and analyse, in qualitative and quantitative terms, the relationships between centripetal acceleration, centripetal force, radius of orbit, period, frequency, mass, and speed [PR, AI]

B3. Understanding Basic Concepts

By the end of this course, students will:

B3.1 distinguish between reference systems (inertial and non-inertial) with respect to the real and apparent forces acting within such systems (e.g., apparent force in a rotating frame, apparent gravitational force in a vertically accelerating frame, real force pulling on the elastic of a ball-and-paddle toy)

B3.2 explain the advantages and disadvantages of static and kinetic friction in situations involving various planes (e.g., a horizontal plane, a variety of inclined planes)

B3.3 explain the derivation of equations for uniform circular motion that involve the variables frequency, period, radius speed, and mass

C. ENERGY AND MOMENTUM

OVERALL EXPECTATIONS

By the end of this course, students will:

C1. analyse, and propose ways to improve, technologies or procedures that apply principles related to energy and momentum, and assess the social and environmental impact of these technologies or procedures;

C2. investigate, in qualitative and quantitative terms, through laboratory inquiry or computer simulation, the relationship between the laws of conservation of energy and conservation of momentum, and solve related problems;

C3. demonstrate an understanding of work, energy, momentum, and the laws of conservation of energy and conservation of momentum, in one and two dimensions.

SPECIFIC EXPECTATIONS

C1. Relating Science to Technology, Society, and the Environment

By the end of this course, students will:

C1.1 analyse, with reference to the principles of energy and momentum, and propose practical ways to improve, a technology or procedure that applies these principles (e.g., fireworks, rocket propulsion, protective equipment, forensic analysis of vehicle crashes, demolition of buildings) [AI, C]

Sample issue: Sports helmets are designed to absorb energy from falls and collisions, reducing the number and severity of head injuries. Helmets must be light enough not to hamper performance while providing optimal protection.

Sample questions: How are principles of energy and momentum used in the design of amusement park rides, such as roller coasters and swing rides? How could the rides be improved, either in terms of their function or their safety? How does a child car seat help protect children riding in motor vehicles? How might the design of or materials used in standard child car seats be improved?

C1.2 assess the impact on society and the environment of technologies or procedures that apply the principles of energy and momentum (e.g., crumple zones, safety restraints, strategic building implosion) [AI, C]

Sample issue: Hydroelectricity is produced by using the potential energy of dammed water to drive turbines and generators. Although hydroelectricity is renewable and generates no greenhouse gases, the damming of waterways can create massive flooding upstream and reduce flows downstream, affecting aquatic and terrestrial ecosystems and people living near the water source.

Sample questions: Why do researchers use crash test dummies in simulated motor vehicle accidents? What impact have innovations such as seat belts and airbags had on injuries resulting from traffic accidents and on the associated health care costs? What is the environmental impact of the chemicals whose combustion produces the effects in fireworks displays?

C2. Developing Skills of Investigation and Communication

By the end of this course, students will:

C2.1 use appropriate terminology related to energy and momentum, including, but not limited to: *work, work–energy theorem, kinetic energy, gravitational potential energy, elastic potential energy, thermal energy, impulse, change in momentum–impulse theorem, elastic collision,* and *inelastic collision* [C]

C2.2 analyse, in qualitative and quantitative terms, the relationship between work and energy, using the work–energy theorem and the law of conservation of energy, and solve related problems in one and two dimensions [PR, AI]

C2.3 use an inquiry process to analyse, in qualitative and quantitative terms, situations involving work, gravitational potential energy, kinetic energy, thermal energy, and elastic potential energy, in one and two dimensions (e.g., a block sliding along an inclined plane with friction; a cart rising and falling on a roller coaster track; an object, such as a mass attached to a spring pendulum, that undergoes simple harmonic motion), and use the law of conservation of energy to solve related problems [PR, AI]

C2.4 conduct a laboratory inquiry or computer simulation to test the law of conservation of energy during energy transformations that involve gravitational potential energy, kinetic energy, thermal energy, and elastic potential energy (e.g., using a bouncing ball, a simple pendulum, a computer simulation of a bungee jump) [PR, AI]

C2.5 analyse, in qualitative and quantitative terms, the relationships between mass, velocity, kinetic energy, momentum, and impulse for a system of objects moving in one and two dimensions (e.g., an off-centre collision of two masses on an air table, two carts recoiling from opposite ends of a released spring), and solve problems involving these concepts [PR, AI]

C2.6 analyse, in qualitative and quantitative terms, elastic and inelastic collisions in one and two dimensions, using the laws of conservation of momentum and conservation of energy, and solve related problems [PR, AI]

C2.7 conduct laboratory inquiries or computer simulations involving collisions and explosions in one and two dimensions (e.g., interactions between masses on an air track, the collision of two pucks on an air table, collisions between spheres of similar and different masses) to test the laws of conservation of momentum and conservation of energy [PR, AI]

C3. Understanding Basic Concepts

By the end of this course, students will:

C3.1 describe and explain Hooke's law, and explain the relationships between that law, work, and elastic potential energy in a system of objects

C3.2 describe and explain the simple harmonic motion (SHM) of an object, and explain the relationship between SHM, Hooke's law, and uniform circular motion

C3.3 distinguish between elastic and inelastic collisions

C3.4 explain the implications of the laws of conservation of energy and conservation of momentum with reference to mechanical systems (e.g., damped harmonic motion in shock absorbers, the impossibility of developing a perpetual motion machine)

C3.5 explain how the laws of conservation of energy and conservation of momentum were used to predict the existence and properties of the neutrino

D. GRAVITATIONAL, ELECTRIC, AND MAGNETIC FIELDS

OVERALL EXPECTATIONS

By the end of this course, students will:

D1. analyse the operation of technologies that use gravitational, electric, or magnetic fields, and assess the technologies' social and environmental impact;

D2. investigate, in qualitative and quantitative terms, gravitational, electric, and magnetic fields, and solve related problems;

D3. demonstrate an understanding of the concepts, properties, principles, and laws related to gravitational, electric, and magnetic fields and their interactions with matter.

SPECIFIC EXPECTATIONS

D1. Relating Science to Technology, Society, and the Environment

By the end of this course, students will:

D1.1 analyse the operation of a technological system that uses gravitational, electric, or magnetic fields (e.g., a home entertainment system, a computer, magnetic strips on credit cards) [AI, C]

Sample questions: How are gravitational field maps used to correct errors in navigational systems used in unmanned underwater vehicles (UUVs)? How are magneto-rheological (MR) fluid dampers used in buildings to absorb the shocks from earthquakes? How can radio frequency identification (RFID) chips be used for inventory tracking in stores and warehouses?

D1.2 assess the impact on society and the environment of technologies that use gravitational, electric, or magnetic fields (e.g., satellites used in surveillance or storm tracking, particle accelerators that provide high-energy particles for medical imaging) [AI, C]

Sample issue: The radiation produced by the magnetic and electric fields of electron accelerators is used to treat tumours. In conjunction with other therapies, radiation increases the survival rate of cancer patients, but safeguards are needed to ensure that patients receive safe doses of radiation and that medical personnel and the immediate environment are not contaminated.

Sample questions: What are some of the uses of particle accelerators, and how have these benefited society? What is the effect on human health of long-term exposure to the electrical fields created by high-voltage lines? How could zero-gravity experiments on agricultural products benefit society and the environment? What are the environmental benefits of using technology involving gravitational fields to search for mineral deposits?

D2. Developing Skills of Investigation and Communication

By the end of this course, students will:

D2.1 use appropriate terminology related to fields, including, but not limited to: *forces*, *potential energies*, *potential*, and *exchange particles* [C]

D2.2 analyse, and solve problems relating to, Newton's law of universal gravitation and circular motion (e.g., with respect to satellite orbits, black holes, dark matter) [AI]

D2.3 analyse, and solve problems involving, electric force, field strength, potential energy, and potential as they apply to uniform and non-uniform electric fields (e.g., the fields produced by a parallel plate and by point charges) [AI]

D2.4 analyse, and solve problems involving, the force on charges moving in a uniform magnetic field (e.g., the force on a current-carrying conductor or a free electron) [AI]

D2.5 conduct a laboratory inquiry or computer simulation to examine the behaviour of a particle in a field (e.g., test Coulomb's law; replicate Millikan's experiment or Rutherford's scattering experiment; use a bubble or cloud chamber) [PR]

D3. Understanding Basic Concepts

By the end of this course, students will:

D3.1 identify, and compare the properties of, fundamental forces that are associated with different theories and models of physics (e.g., the theory of general relativity and the standard model of particle physics)

D3.2 compare and contrast the corresponding properties of gravitational, electric, and magnetic fields (e.g., the strength of each field; the relationship between charge in electric fields and mass in gravitational fields)

D3.3 use field diagrams to explain differences in the sources and directions of fields, including, but not limited to, differences between near-Earth and distant fields, parallel plates and point charges, straight line conductors and solenoids

E. THE WAVE NATURE OF LIGHT

OVERALL EXPECTATIONS

By the end of this course, students will:

E1. analyse technologies that use the wave nature of light, and assess their impact on society and the environment;

E2. investigate, in qualitative and quantitative terms, the properties of waves and light, and solve related problems;

E3. demonstrate an understanding of the properties of waves and light in relation to diffraction, refraction, interference, and polarization.

SPECIFIC EXPECTATIONS

E1. Relating Science to Technology, Society, and the Environment

By the end of this course, students will:

E1.1 analyse, with reference to the principles related to the wave nature of light, a technology that uses these principles (e.g., Xeon lights, spectroscopes, polarized sunglasses) [AI, C]

Sample questions: How do geologists use the wave nature of light to find mineral deposits? How do surface plasmon polaritons (SPPs) make use of the wave nature of light? What are some of the applications of SPPs? How does the global positioning system (GPS) use the wave nature of light? What are its applications? What are its shortcomings?

E1.2 assess the impact on society and the environment of technologies that use the wave nature of light (e.g., DVDs, polarized lenses, night vision goggles, wireless networks) [AI, C]

Sample issue: Fibre optical technology has revolutionized access to information. Some people argue that unrestricted access to information helps to open up societies and improve human rights and can be used as tools for pro-democracy groups. However, some totalitarian governments practise censorship by restricting citizens' access to Internet sites promoting human rights and democracy.

Sample questions: How has holographic technology made it more difficult to counterfeit Canadian currency? In what ways does the use of lasers in surgery improve surgical techniques and recovery time? In what ways can posting magazines or newsletters on the Internet, rather than printing and distributing them, benefit the environment?

E2. Developing Skills of Investigation and Communication

By the end of this course, students will:

E2.1 use appropriate terminology related to the wave nature of light, including, but not limited to: *diffraction*, *dispersion*, *wave interference*, *nodal line*, *phase*, *oscillate*, *polarization*, and *electromagnetic radiation* [C]

E2.2 conduct inquiries involving the diffraction and interference of waves, using ripple tanks or computer simulations [PR]

E2.3 conduct inquiries involving the diffraction, refraction, polarization, and interference of light waves (e.g., shine lasers through single, double, and multiple slits; observe a computer simulation of Young's double-slit experiment; measure the index of refraction of different materials; observe the effect of crossed polarizing filters on transmitted light) [PR]

E2.4 analyse diffraction and interference of water waves and light waves (e.g., with reference to two-point source interference in a ripple tank, thin-film interference, multiple-slit interference), and solve related problems [PR, AI]

E3. Understanding Basic Concepts

By the end of this course, students will:

E3.1 describe and explain the diffraction and interference of water waves in two dimensions

E3.2 describe and explain the diffraction, refraction, polarization, and interference of light waves (e.g., reduced resolution caused by diffraction, mirages caused by refraction, polarization caused by reflection and filters, thin-film interference in soap films and air wedges, interference of light on CDs)

E3.3 use the concepts of refraction, diffraction, polarization, and wave interference to explain the separation of light into colours in various situations (e.g., light travelling through a prism; light contacting thin film, soap film, stressed plastic between two polarizing filters)

E3.4 describe, in qualitative terms, the production of electromagnetic radiation by an oscillating electric dipole (e.g., a radio transmitter, a microwave emitter, an X-ray emitter, electron energy transitions in an atom)