SCIENCE

VISION STATEMENT: SENIOR HIGH SCIENCE PROGRAMS

The senior high science programs will help all students attain the scientific awareness needed to function as effective members of society. Students will be able to pursue further studies and careers in science, and come to a better understanding of themselves and the world around them. The same framework was used for the development of all the senior high science programs, including Science 10, Biology 20–30, Chemistry 20–30, Physics 20–30 and Science 20–30. The expected student knowledge, skills and attitudes are approached from a common philosophical position in each science course.

In the senior high science programs, students focus on learning the big interconnecting ideas and principles. These ideas, or major themes, originate from science knowledge that transcends and unifies the natural science disciplines. These themes include change, diversity, energy, equilibrium, matter and systems; the process by which scientific knowledge is developed, including the role of experimental evidence; and the connections among science, technology and society. In addition to forming a framework for the curriculum, these ideas provide continuity with the junior high program and build on students' previous learning.

The senior high science programs place an increased emphasis on developing methods of inquiry that characterize the study of science. For example, students will further their ability to ask questions, investigate and experiment; gather, analyze and assess scientific information; and test scientific principles and their applications. They will develop their problem-solving ability and use technology. By providing students with opportunities to develop and apply these skills, they will better understand the knowledge they have acquired.

Students will be expected to show an appreciation for the roles of science and technology in understanding nature. They will possess enthusiasm and positive attitudes toward science and maintain a lifelong interest in science.

The learning context is an integral part of the senior high science programs. It will foster the expected attitudes in students, further the development of students' skills and increase students' understanding of science knowledge, science process, and the connections among science, technology and society. The context for learning will be relevant so students will experience science as interesting and dynamic. Learning opportunities will be made meaningful by providing concrete experiences that students can relate to their world.

The senior high science programs place students at the centre. Students are active learners and will assume increased responsibility for their learning. They will appreciate the value of teamwork and make a positive contribution when working with others to solve problems and complete tasks.

PHYSICS 20–30

A. PROGRAM OVERVIEW

RATIONALE AND PHILOSOPHY

Physics is the study of matter and energy and their interactions. Through the study of physics, learners are given an opportunity to explore and understand the natural world and to become aware of the profound influence of physics in their lives. Learning is facilitated by relating the study of physics to what the learners already know, deem personally useful and consider relevant. Learning proceeds best when it originates from a base of concrete experiences presenting an authentic view of science in the context of physics. In Physics 20–30, students learn physics in relevant contexts and engage in meaningful activities. This facilitates the transfer of knowledge to new contexts. Students are encouraged to participate in lifelong learning about physics and to appreciate it as a scientific endeavour with practical impact on their own lives and on society as a whole.

Physics, as with all sciences, is an experimental discipline requiring creativity and imagination. Methods of inquiry characterize its study. In Physics 20–30, students further develop their ability to ask questions, investigate and experiment; to gather, analyze and assess scientific information; and to test scientific laws and principles and their applications. In the process, students exercise their creativity and develop their critical thinking skills. Through experimentation, and problem-solving activities that include the integration of technology and independent study, students develop an understanding of the processes by which scientific knowledge evolves.

The Physics 20–30 program places students at the centre. Students are active learners and will assume increased responsibility for their learning as they work through the program. A thorough study of physics is required to give students an understanding that encourages them to make appropriate applications of scientific concepts to their daily lives and prepares them for future studies in physics. Students are expected to participate actively in their own learning. An emphasis on the key concepts and principles of physics provides students with a more unified view of the sciences and a greater awareness of the connections among them.

These science learnings will take varying amounts of time to acquire, depending on the individual learning styles and abilities of students. While each course is designed for approximately 125 hours, instructional time can be modified to meet the individual needs of students. Some students will require more than 125 hours, while others will require less.

GOALS

The major goals of the Physics 20–30 program are:

- to develop in students an understanding of the interconnecting ideas and principles that transcend and unify the natural science disciplines

- to provide students with an enhanced understanding of the scientific world view, inquiry and enterprise

- to help students attain the level of scientific awareness essential for all citizens in a scientifically literate society

- to help students make informed decisions about further studies and careers in science

- to provide students with opportunities for acquiring knowledge, skills and attitudes that contribute to personal development.

Physics 20–30 is an academic program that helps students better understand and apply fundamental concepts and skills. The focus is on helping students understand the physics principles behind the natural events they experience and the technology they use in their daily lives. The program encourages enthusiasm for the scientific enterprise and develops positive attitudes about physics as an interesting human activity with personal meaning. It develops in students the knowledge, skills and attitudes to help them become capable of, and committed to, setting goals, making informed choices and acting in ways that will improve their own lives and life in their communities.

B. LEARNER EXPECTATIONS

GENERAL LEARNER EXPECTATIONS

The general learner expectations outline the many facets of scientific awareness and serve as the foundation for the specific learner expectations covered in section C. The general learner expectations are developed in two categories: *program* expectations and *course* expectations.

PROGRAM GENERAL LEARNER EXPECTATIONS

The *program* general learner expectations are broad statements of science attitudes, knowledge, skills and science, technology and society (STS) connections that students are expected to achieve in all of the senior high school science programs. These *program* general learner expectations are further refined through the *course* general learner expectations and then developed in specific detail through the study of individual units in each of Physics 20 and Physics 30. All expectations follow a progression from Science 10 through to Physics 30, and though listed separately, are meant to be developed in conjunction with one another, within a context.

ATTITUDES

Students will be encouraged to develop:

- enthusiasm for, and a continuing interest in, science
- affective attributes of scientists at work; such as, respect for evidence, tolerance of uncertainty, intellectual honesty, creativity, perseverance, cooperation, curiosity and a desire to understand
- positive attitudes toward scientific and technological skills involving process skills, mathematics, and problem solving
- open-mindedness and respect for the points of view of others
- sensitivity to the living and nonliving environment
- appreciation of the roles of science and technology in our understanding of the natural world.

KNOWLEDGE

Science Themes

Students will be expected to demonstrate an understanding of themes that transcend the discipline boundaries, and show the unity among the natural sciences, including:

- Change: how all natural entities are modified over time, how the direction of change might be predicted and, in some instances, how change can be controlled
- Diversity: the array of living and nonliving forms of matter and the procedures used to understand, classify and distinguish those forms on the basis of recurring patterns
- Energy: the capacity for doing work that drives much of what takes place in the Universe through its variety of interconvertible forms
- Equilibrium: the state in which opposing forces or processes balance in a static or dynamic way
- Matter: the constituent parts, and the variety of states of the material in the physical world
- Systems: the interrelated groups of things or events that can be defined by their boundaries and, in some instances, by their inputs and outputs.

SKILLS

Students will be expected to develop an ability to use thinking processes associated with the practice of science for understanding and exploring natural phenomena, problem solving and decision making. Students will also be expected to use teamwork, respect the points of view of others, make reasonable compromises, contribute ideas and effort, and lead when appropriate to achieve the best results. These processes involve many skills that are to be developed within the context of the program content.

Students will also be expected to be aware of the various technologies, including information technology, computer software and interfaces that can be used for collecting, organizing, analyzing and communicating data and information.

The skills framework presented here assumes that thinking processes often begin with an unresolved problem or issue, or an unanswered question. The problem, issue or question is usually defined and hypotheses formulated before information gathering can begin. At certain points in the process, the information needs to be organized and analyzed. Additional ideas may be generated—for example, by prediction or inference—and these new ideas, when incorporated into previous learning, can create a new knowledge structure. Eventually, an outcome, such as a solution, an answer or a decision is reached. Finally, criteria are established to judge ideas and information in order to assess both the problem-solving process and its outcomes.

The following skills are not intended to be developed sequentially or separately. Effective thinking is nonlinear and recursive. Students should be able to access skills and strategies flexibly; select and use skills, processes or technologies that are appropriate to the tasks; and monitor, modify or replace them with more effective strategies.

- Initiating and Planning
  - identify and clearly state the problem or issue to be investigated
  - differentiate between relevant and irrelevant data or information
  - assemble and record background information
  - identify all variables and controls
  - identify materials and apparatus required
  - formulate questions, hypotheses and/or predictions to guide research
  - design and/or describe a plan for research, or to solve a problem
  - prepare required observation charts or diagrams, and carry out preliminary calculations

- Collecting and Recording
  - carry out the procedure and modify, if necessary
  - organize and correctly use apparatus and materials to collect reliable data
  - observe, gather and record data or information accurately according to safety regulations; e.g., Workplace Hazardous Materials Information System (WHMIS), and environmental considerations

- Organizing and Communicating
  - organize and present data (themes, groups, tables, graphs, flow charts and Venn diagrams) in a concise and effective form
  - communicate data effectively, using mathematical and statistical calculations, where necessary
  - express measured and calculated quantities to the appropriate number of significant digits, using SI notation for all quantities
  - communicate findings of investigations in a clearly written report

- Analyzing
  - analyze data or information for trends, patterns, relationships, reliability and accuracy
  - identify and discuss sources of error and their affect on results

- identify assumptions, attributes, biases, claims or reasons
- identify main ideas

- Connecting, Synthesizing and Integrating

  - predict from data or information, and determine whether or not these data verify or falsify the hypothesis and/or prediction
  - formulate further, testable hypotheses supported by the knowledge and understanding generated
  - identify further problems or issues to be investigated
  - identify alternative courses of action, experimental designs, and solutions to problems for consideration
  - propose and explain interpretations or conclusions
  - develop theoretical explanations
  - relate the data or information to laws, principles, models or theories identified in background information
  - propose solutions to a problem being investigated
  - summarize and communicate findings
  - decide on a course of action

- Evaluating the Process or Outcomes

  - establish criteria to judge data or information
  - consider consequences and biases, assumptions and perspectives
  - identify limitations of the data or information, and interpretations or conclusions, as a result of the experimental/research/project/design process or method used
  - evaluate and suggest alternatives and consider improvements to the experimental technique and design, the decision-making or the problem-solving process
  - evaluate and assess ideas, information and alternatives

CONNECTIONS AMONG SCIENCE, TECHNOLOGY AND SOCIETY

Science, Technology and Society (STS)

Students will be expected to demonstrate an understanding of the processes by which scientific knowledge is developed, and of the interrelationships among science, technology and society, including:

- the central role of evidence in the accumulation of knowledge, and the ways proposed theories may be supported, modified or refuted
- the inability of science to provide complete answers to all questions
- the functioning of processes or products based on scientific principles
- the ways in which science advances technology and technology advances science
- the use of technology to solve practical problems
- the limitations of scientific knowledge and technology
- the influence of the needs, interests and financial support of society on scientific and technological research
- the ability and responsibility of society, through science and technology, to protect the environment and use natural resources judiciously to ensure quality of life for future generations.

FURTHER READING

For a more detailed discussion on how to integrate thinking and research skills into the science classroom, refer to the publications: *Teaching Thinking: Enhancing Learning*, 1990 and *Focus on Research: A Guide to Developing Students' Research Skills*, 1990.

For further reading on integrating science, technology and society into the classroom, refer to the publication: *STS Science Education: Unifying the Goals of Science Education*, 1990.

COURSE GENERAL LEARNER EXPECTATIONS

The *course* general learner expectations are specific to each of Physics 20 and Physics 30 providing a bridge between the *program* general learner expectations and the specific learner expectations for each unit of study.

The attitudes expectations refer to those predispositions that are to be fostered in students. These expectations encompass attitudes toward science, the role of science and technology, and the contributions of science and technology toward society. The knowledge expectations are the major physics concepts in each course. The skills expectations refer to the thinking processes and abilities associated with the practice of science, including understanding and exploring natural phenomena, and problem solving. The connections among science, technology and society expectations focus on: the processes by which scientific knowledge is developed; the interrelationships among science, technology and society; and links each course to careers, everyday life and subsequent studies of physics.

Although itemized separately, the attitudes, knowledge, skills and STS connections are meant to be developed together within one or more contexts.

Physics 20–30

Attitudes

Students will be encouraged to:

- appreciate the role of empirical evidence and models in science, and accept the uncertainty in explanations and interpretations of observed phenomena
- value the curiosity, openness to new ideas, creativity, perseverance and cooperative hard work required of scientists, and strive to develop these same personal characteristics
- appreciate the role of science and technology in advancing our understanding of the natural world, be open-minded and respectful of other points of view when evaluating scientific information and its applications, and appreciate that the application of science and technology by humankind can have beneficial as well as harmful effects and can cause ethical dilemmas
- show a continuing interest in science, appreciate the need for computational competence, problem-solving and process skills when doing science, and value accuracy and honesty when communicating the results of problems and investigations
- appreciate the simplicity of, and similarity among, scientific explanations for complex, physical phenomena.

Physics 20

Students will be able to:

Knowledge

- compare and contrast scalar and vector quantities; and apply the concept of field to quantitatively explain, in terms of its source, direction and intensity, the gravitational effects of objects and systems
- describe, quantitatively, analyze and predict mechanical energy transformations, using the concepts of conservation of energy, work and power
- describe, quantitatively, analyze and predict motion with constant velocity, constant acceleration and uniform circular motion of objects and systems, using the concepts of kinematics, dynamics, Newton's laws of motion and the law of universal gravitation
- use the principles of simple harmonic motion and energy conservation to relate the concepts of uniform linear and circular motion to the behaviour and characteristics of mechanical waves

- describe, quantitatively, analyze and predict the behaviour of light, using the concepts of geometric and wave optics, and graphical and mathematical techniques

Skills

- perform investigations and tasks of their own and others' design that have a few variables and yield direct or indirect evidence; and provide explanations based upon scientific theories and concepts

- collect, verify and organize data into tables of their own design, and graphs and diagrams of others' design, using written and symbolic forms; and describe findings or relationships, using scientific vocabulary, notation, theories and models

- analyze and interpret data that yield straight- and curved-line graphs; and use appropriate SI notation, fundamental and derived units, and formulas; and determine new variables, using the slopes of, and areas under graphs, plot corresponding graphs, and derive mathematical relationships among the variables

- use mathematical language of ratio and proportion, numerical and algebraic methods, two-dimensional vector addition in one plane, and unit analysis to solve single- and multi-step problems; and to communicate scientific relationships and concepts

Connections Among Science, Technology and Society

- apply cause and effect reasoning to formulate simple relationships for a given instance in which scientific evidence shapes or refutes a theory; and describe the limitations of science and technology in answering all questions and solving all problems, using appropriate and relevant examples

- describe and explain the design and function of technological solutions to practical problems, using scientific principles; and relate the ways in which physics and technology advance one another, using appropriate and relevant examples

- explain for a given instance how science and technology are influenced and supported by society, and the responsibility of society, through physics and technology, to protect the environment and use natural resources wisely

- identify subject-related careers and apply the knowledge and skills acquired in Physics 20 to everyday life and to related and new concepts in subsequent studies of physics.

Physics 30

Students will be able to:

Knowledge

- compare and contrast scalar and vector quantities and fields; and apply the concept of field to quantitatively explain, in terms of their source, direction and intensity, electric, gravitational and magnetic effects on objects and systems

- explain, quantitatively, analyze and predict physical interactions among objects and systems, using the concepts of conservation of energy and momentum

- describe, quantitatively, analyze and predict the behaviour of electric charges in electric and/or magnetic fields, using the principles of kinematics, dynamics, conservation of energy and electric charge, electrostatics and electromagnetism

- explain, quantitatively, analyze and predict the motor and generator effect involving a single conductor; and use relevant electromagnetic principles to explain the design and function of simple electric motors, generators, meters, transformers and other simple electromagnetic devices

- illustrate, using biophysical, industrial and other examples, technological applications of electromagnetic theories and effects; and describe, quantitatively, analyze and predict the functioning of simple resistive direct current circuits, using Ohm's law and Kirchhoff's rules

- explain, quantitatively, the characteristics and behaviours of the various constituents of the electromagnetic spectrum, and algebraically solve problems, using the relationship among speed, wavelength and frequency of electromagnetic waves

- explain, citing empirical evidence, the development of an atomic theory contingent upon wave–particle duality of matter and statistical probability, and its technological application

Skills

- perform and evaluate investigations and tasks of their own and others' design that have multiple variables and yield direct or indirect evidence; and provide explanations and interpretations, using scientific theories and concepts

- collect, verify and organize data into tables, graphs and diagrams of their own design, using written and symbolic forms; and describe findings or relationships and make predictions, using scientific vocabulary, notation, theories and models

- analyze, interpret and evaluate data that yield straight- and curved-line graphs; and use appropriate SI notation, fundamental and derived units, and formulas; and determine new variables using the slopes of, and areas under graphs, plot corresponding graphs, and use curve-straightening techniques to infer mathematical relationships among variables

- use mathematical language of ratio and proportion, numerical and algebraic methods, two-dimensional vector addition in one plane, unit analysis, and derived algebraic algorithms to solve multi-step, nonroutine problems; and communicate scientific relationships and concepts

Connections Among Science, Technology and Society

- apply cause and effect reasoning to formulate relationships for a range of instances in which scientific evidence shapes or refutes a theory; and explain the limitations of science and technology in answering all questions and solving all problems, using appropriate and relevant examples

- describe and evaluate the design and function of technological solutions to practical problems, using scientific principles or theories; and relate the ways in which physics and technology advance one another, using appropriate and relevant examples

- explain and evaluate for a given instance, and from a variety of given perspectives, how science and technology are influenced and supported by society; and assess the ability and responsibility of society, through physics and technology, to protect the environment and use natural resources wisely

- identify subject-related careers and apply the knowledge and skills acquired in Physics 30 to everyday life and to related and new concepts in post-secondary studies of physics.

SPECIFIC LEARNER EXPECTATIONS

LEARNING CYCLE

The specific learner expectations consist of the knowledge, skills and attitudes that are to be addressed in Physics 20–30. The use of the learning cycle allows students to progress, from:

- an introduction framing the lesson in an STS connection relevant to the lives of the learners, and makes connections between past and present learning experiences, as well as anticipates activities to focus students' thinking on the learning outcomes of the activity

TO

- the experiential exploration of new content that provides students with a common base of experiences within which they identify and develop key concepts, processes and skills

THROUGH

- a hypothesis-building phase where concepts are developed to describe a particular aspect of their experiential exploration, and opportunities are provided to communicate their conceptual understanding, or demonstrate their skills or behaviours

TO

- an elaboration phase that extends understanding of key concepts and allows further opportunities to practise desired skills and problem-solving strategies

TO

- an application phase where the hypotheses, vocabulary and patterns previously developed are applied to new situations and related to key concepts and principles of science

TO

- a final evaluation of the significance of the new learning in an STS context to assess their understanding and abilities, and provide opportunities for evaluation of student progress toward achieving the curriculum standards.

In Physics 20–30, students examine phenomena in a variety of topics to show the relationships among all the sciences. Wherever possible, examples should be framed in the context of the learners' own experiences to enable them to make the connections between scientific knowledge and the society around them, the technology that societies have developed, and the nature of science itself.

PROGRAM OVERVIEW

The Physics 20–30 program emphasizes the science themes: *change*, *diversity*, *energy*, *equilibrium*, *matter* and *systems* as they relate to physics. These themes provide a means of showing the connections among the units of study in both courses of the program, and provide a framework for students to learn how individual sections of the program relate to the big ideas of science.

In addition to developing a solid understanding of fundamental science concepts and principles, Physics 20–30 has the goal of educating students about the nature of science and technology, and the interaction between physics and technology. Students must be aware of the tremendous impact of physics and associated technology on society, but at the same time, they must be aware of the roles and limitations of the physical sciences, science in general, and of technology in problem solving in a societal context.

PHYSICS 20

Energy is the science theme common to all units in Physics 20, with *change, diversity, equilibrium, matter* and *systems* also playing a role. *Energy* in its many forms causes *change* and determines the kind of change *matter* and *systems* undergo.

The major concepts allow connections to be drawn among the four units of the course and among all eight units in the two courses in the program.

Physics 20 consists of four units of study:

Unit 1: Kinematics and Dynamics
Unit 2: Circular Motion and Gravitation
Unit 3: Mechanical Waves
Unit 4: Light.

An examination of motion, the causes of motion and their relationship to *energy changes* in *systems* emphasizes the science theme of *change* in Unit 1. In Unit 2, the principles of *change* in and conservation of *energy* motion are extended to circular motion, and lead into an investigation of gravitation and *equilibrium* in planetary *systems*. Unit 3 considers the transfer of *energy* through *matter* by means of mechanical waves, and the characteristics of waves are studied in the context of sound. Unit 4 focuses on the nature of light, a visible form of *energy* and one of the *diverse* forms of electromagnetic radiation.

PHYSICS 30

The *diversity* of *energy* and *matter* are the predominant themes of the Physics 30 course.

The major concepts allow connections to be drawn among the four units of the course and among all eight units in the two courses in the program.

Physics 30 consists of four units of study:

Unit 1: Conservation Laws
Unit 2: Electric Forces and Fields
Unit 3: Magnetic Forces and Fields
Unit 4: Nature of Matter.

Physics 30 expands upon the concepts and skills introduced in Science 10 and Physics 20. In Unit 1, students emphasize the science theme of *equilibrium*, as exemplified by the fundamental phenomenon of conservation of *energy* and momentum in isolated *systems* in the physical universe. In Unit 2, the electrical nature of *matter* in its *diverse* forms is examined. Unit 3 investigates the *diversity* and magnetic nature of *matter*, and electromagnetic interactions and technological applications. In Unit 4, the quantum concept of *energy* and *matter* is investigated via the study of the electric nature of the atom, the photoelectric effect and the wave–particle duality of radiation; as well, the applications of nuclear energy and the radioactive nature of the atom are studied.

PHYSICS 20

UNIT 1
KINEMATICS AND DYNAMICS

OVERVIEW

Science Themes: *Change, Energy* and *Systems*

In Unit 1, students investigate *change* in position and velocity of objects and *systems* in a study of kinematics. The investigation of dynamic phenomena demonstrates that a *change* in *energy* is the manifestation of the effect of forces on the motion of objects and *systems*.

This unit extends the study of motion first introduced in Science 7, Unit 3: Force and Motion, and further developed in Science 10, Unit 4: Change and Energy, to a formal study of uniform motion, uniform accelerated motion, Newton's laws of motion, and concludes with a formal introduction to mechanical *energy*, work and power. This unit provides a foundation for further study of mechanics in subsequent units and physics courses.

The three **major concepts** developed in this unit are:

- *change* in the position and velocity of objects and *systems* can be described graphically and mathematically
- the concepts of dynamics explicitly relate forces to *change* in velocity
- work is a transfer of *energy*.

In this unit, *students will develop* an ability to use the **skills** and **thinking processes** associated with the practice of science, emphasizing:

- initiating and planning
- collecting and recording
- organizing and communicating
- analyzing data from physical interactions
- connecting, synthesizing and integrating to relate the data to the laws and principles of kinematics and dynamics
- evaluating the process or outcomes of activities investigating the concepts of kinematics and dynamics.

The **STS connections** in this unit illustrate:

- the functioning of products or processes based on scientific principles
- the ways in which science advances technology and technology advances science
- the use of technology to solve practical problems.

ATTITUDES

Students will be encouraged to:

- appreciate the need for computational competence in quantifying motion, *energy*, work and power
- accept uncertainty in the descriptions and explanations of motion in the physical world
- be open-minded in evaluating potential applications of mechanical principles to new technology
- appreciate the fundamental role the principles of mechanics play in our everyday world
- appreciate the need for accurate and honest communication of all evidence gathered in the course of an investigation related to mechanical principles
- appreciate the need for empirical evidence in interpreting observed mechanical phenomena
- appreciate the restricted nature of evidence when interpreting the results of physical interactions.

MAJOR CONCEPT	KNOWLEDGE
	Students should be able to demonstrate an understanding that:
1. *Change* in the position and velocity of objects and *systems* can be described graphically and mathematically.	• the motion of objects and systems can be described in terms of displacement, time, velocity and acceleration, by extending from Science 10, Unit 4, the principles of one-dimensional motion, and by: • defining, operationally, and comparing and contrasting scalar and vector quantities • defining velocity as a change in position during a time interval • defining acceleration as a change in velocity during a time interval • comparing motion with constant velocity and variable velocity, and motion with constant acceleration and variable acceleration, average and instantaneous velocity • explaining uniform motion and uniformly accelerated motion, using position–time, velocity–time and acceleration–time graphs • applying the concepts of slope and area under a line or curve to determine velocity, displacement and acceleration from position–time and velocity–time graphs • explaining, quantitatively, two-dimensional motion, in horizontal or vertical planes, using vector components addition • explaining the uniform motion of objects, using algebraic and graphical methods, from verbal or written descriptions and mathematical data • explaining, quantitatively, the motion of one object relative to another object, using displacement and velocity vectors • using the delta notation correctly when describing change in quantities★ • using unit analysis to check the results of mathematical solutions.★ ★ To be developed throughout the course.

SKILLS	STS CONNECTIONS
Students should be able to demonstrate the skills and thinking processes associated with the practice of science, by:	*Students should be able to demonstrate the interrelationships among science, technology and society, by:*
	• understanding the motion of objects and systems in terms of position, time, velocity and acceleration, and explaining uniform motion, using graphical, algorithmic and vector methods; and by gathering, and numerically and graphically analyzing relevant data to determine mathematical relationships among acceleration, displacement, velocity and time, within the context of:
• performing experiments to demonstrate the relationships among acceleration, displacement, velocity and time, using interval timers to gather the necessary data	• evaluating the design of structures and devices, such as roadway approaches and exit ramps, airport runways and carnival rides, in terms of kinematics principles
• inferring from a graphical analysis of empirical data the mathematical relationships among acceleration, displacement, velocity and time for uniformly accelerated motion	OR
• analyzing empirical data graphically, using line-of-best-fit to discover mathematical relationships	• analyzing the use of kinematics concepts in the synchronization of traffic lights
• performing experiments to determine the local value of the acceleration due to gravity.	OR
	• researching and reporting on the use of kinematics principles in traffic accident investigations
	OR
	• any other relevant context.

MAJOR CONCEPT	KNOWLEDGE
	Students should be able to demonstrate an understanding that:
2. The concepts of dynamics explicitly relate forces to *change* in velocity.	• changes in velocity are the result of a non-zero net force, by recalling from Science 7, Unit 3, the notions of force, inertia and friction, and by: • comparing and contrasting among mass, volume and weight • explaining how a force effects a change in motion • applying Newton's first law of motion to explain an object's state of rest or uniform motion • applying Newton's second law of motion, and using it to relate force, mass and acceleration • relating Newton's third law of motion to interaction between two objects, recognizing that the two forces, equal in magnitude and opposite in direction, act on different bodies • determining, quantitatively, the net or resultant force acting on an object, using vector components addition graphically and mathematically • applying Newton's laws of motion to solve, algebraically, linear motion problems in horizontal, vertical and inclined planes, near the surface of Earth (whenever friction is included, only the resistive effect of the force of friction is considered) • solving projectile motion problems near the surface of Earth, ignoring air resistance.

SKILLS	STS CONNECTIONS
Students should be able to demonstrate the skills and thinking processes associated with the practice of science, by:	*Students should be able to demonstrate the interrelationships among science, technology and society, by:*
	• understanding changes in velocity in terms of non-zero net forces, and applying Newton's laws of motion to explain, and quantitatively solve, linear motion problems; and by performing experiments to gather and mathematically analyze data relevant to dynamics problems, within the context of:
• performing experiments to determine the relationships among acceleration, force and mass, using interval timers to gather the necessary data • using free-body diagrams in organizing and communicating the solutions of dynamics problems.	• explaining the movement of passengers in a vehicle changing speed and/or direction, in terms of the law of inertia OR • assessing the design and use of injury prevention devices in cars and sports (business and industry) in terms of the principle of inertia and Newton's laws OR • evaluating the role of the principles of mechanics in solving practical problems and addressing societal needs when legal restrictions, such as seat belts and speed limits, are established OR • researching and reporting on the use of dynamics principles in traffic accident investigations OR • any other relevant context.

MAJOR CONCEPT	KNOWLEDGE
	Students should be able to demonstrate an understanding that:
3. Work is a transfer of *energy*.	• mechanical energy exchanges involve changes in kinetic and/or potential energy, by extending the mechanical energy concepts studied in Science 10, Unit 4, and by: • defining work as a measure of the mechanical energy transferred • defining, quantitatively, power as the rate of doing work • analyzing, quantitatively, mechanical energy transformations, using the law of conservation of mechanical energy.

SKILLS	STS CONNECTIONS
Students should be able to demonstrate the skills and thinking processes associated with the practice of science, by:	*Students should be able to demonstrate the interrelationships among science, technology and society, by:*
	• understanding and quantitatively analyzing mechanical energy transformations, using the concept of conservation of mechanical energy; and by investigating and illustrating the relationships among mechanical energy, work and power, using empirical evidence and algorithms, within the context of:
• performing experiments investigating the relationships among mechanical energy, work and power • illustrating the relationships among mechanical energy, work and power, using empirical data and algorithms.	• evaluating the design of energy transfer devices, such as simple household tools, elevators, escalators and ski lifts, in terms of the relationships among mechanical energy, work and power OR • investigating and reporting on careers, supported by societal needs and interests, that require an understanding and application of kinematics and dynamics OR • any other relevant context.

UNIT 2
CIRCULAR MOTION AND GRAVITATION

OVERVIEW

Science Themes: *Change*, *Energy*, *Equilibrium* and *Systems*

In Unit 2, students investigate *change* in motion and position of objects, and the dynamic *equilibrium* of planetary *systems*, in a study of circular motion and gravitation. Uniform circular motion is seen as an example of conservation of *energy*.

This unit extends the study of kinematics and dynamics from Unit 1 to uniform circular motion, an introduction to periodic motion. Two-dimensional vectors and Newton's laws are used to analyze and explain circular motion with uniform orbital speed. The concept of "field" is introduced to explain gravitational effects; and the role that the physical principles of circular motion had in the development of Newton's universal law of gravitation is examined. This unit provides a foundation for further study of mechanics and fields in subsequent units and physics courses.

The two **major concepts** developed in this unit are:

- Newton's laws of motion can be used to explain uniform circular motion
- gravitational effects extend throughout the Universe.

In this unit, *students will develop* an ability to use the **skills** and **thinking processes** associated with the practice of science, emphasizing:

- initiating and planning
- collecting and recording
- organizing and communicating
- analyzing data from physical interactions
- connecting, synthesizing and integrating to relate the data to the principles of uniform circular motion and gravitation
- evaluating the process or outcomes of activities investigating the concepts of circular motion and gravitation.

The **STS connections** in this unit illustrate:

- the central role of evidence in the accumulation of knowledge, and the ways proposed theories may be supported, modified or refuted
- the functioning of products or processes based on scientific principles
- the ways in which science advances technology and technology advances science
- the use of technology to solve practical problems
- the influence of the needs, interests and financial support of society on scientific and technological research.

ATTITUDES

Students will be encouraged to:

- appreciate the need for computational competence in quantifying motion and gravitational effects
- accept uncertainty in the descriptions and explanations of circular motion and gravitation in the physical world
- be open-minded in evaluating potential applications of the principles of circular motion and gravitation to new technology
- appreciate the fundamental role the principles of circular motion have in explaining observed artificial and natural phenomena
- appreciate the fundamental role the principles of circular motion and gravitation play in our everyday world
- appreciate the contribution made by Kepler, Newton and Cavendish to the development of Newton's universal law of gravitation.

MAJOR CONCEPT	KNOWLEDGE
	Students should be able to demonstrate an understanding that:
1. Newton's laws of motion can be used to explain uniform circular motion.	• uniform circular motion requires a non-zero net force of constant magnitude, by: • describing uniform circular motion as a special case of two-dimensional motion • describing forces in circular motion as gravitational, frictional, electrostatic • explaining, quantitatively, that the acceleration in circular motion is centripetal • explaining, quantitatively, circular motion in terms of Newton's laws of motion • solving, quantitatively, circular motion problems, using algebraic and/or graphical vector analysis • explaining, quantitatively, the relationships among speed, frequency, period and circular motion • analyzing, quantitatively, the motion of objects moving with constant speed in horizontal or vertical circles near the surface of Earth.

SKILLS	STS CONNECTIONS
Students should be able to demonstrate the skills and thinking processes associated with the practice of science, by:	*Students should be able to demonstrate the interrelationships among science, technology and society, by:*
	• understanding uniform circular motion and its relationship to Newton's laws of motion, and explaining and solving, quantitatively, circular motion problems, using algebraic and/or graphical vector analysis; and by determining, empirically, the relationships among net force acting on an object moving in uniform circular motion, frequency, mass, speed and path radius, within the context of:
• performing experiments to determine the relationships among the net force, acting on an object in uniform circular motion, frequency, mass, speed and path radius.	• analyzing the principles of a centrifuge and its applications to solve problems in industry and research OR • analyzing the motion of a car, moving through a curve with constant speed, in terms of Newton's laws as applied to uniform circular motion, friction and road banking OR • analyzing, in terms of Newton's laws as applied to uniform circular motion, the motion of carnival rides and playground equipment moving in horizontal or vertical circles OR • analyzing, qualitatively, the function of a potter's wheel, in terms of Newton's laws as applied to uniform circular motion OR • any other relevant context.

MAJOR CONCEPT	KNOWLEDGE
	Students should be able to demonstrate an understanding that:
2. Gravitational effects extend throughout the Universe.	• gravity is a universal force of nature, by: • explaining, qualitatively, how mechanical understanding of circular motion and Kepler's laws were used in the development of Newton's universal law of gravitation • explaining, qualitatively, the principles pertinent to the Cavendish experiment used to determine the gravitational constant, *G* • relating the universal gravitational constant to the local value of the acceleration due to gravity • predicting, quantitatively, changes in weight that objects experience on different planets • defining "field" as a concept explaining action at a distance, and applying it to describing gravitational effects • applying, quantitatively, Newton's second law, combined with the universal law of gravitation, to explain planetary and satellite motion, using the circular motion approximation • predicting the mass of a planet from the orbital data of a satellite in uniform circular motion • explaining, qualitatively, the shape of our solar system, and that of galaxies, in terms of Newton's laws of motion and Newton's law of gravitation.

SKILLS	STS CONNECTIONS
Students should be able to demonstrate the skills and thinking processes associated with the practice of science, by:	*Students should be able to demonstrate the interrelationships among science, technology and society, by:*
	• understanding that gravity is a universal force of nature, and defining “field” as a concept explaining action at a distance and applying it to describing gravitational effects, and explaining, quantitatively, planetary and satellite motion, using Newton’s second law combined with Newton’s universal law of gravitation and the circular motion approximation, within the context of:
• relating the gravitational force, using Newton’s second law, to planetary and satellite motion problems.	• discussing and evaluating the potential applications of “microgravity” conditions in research and manufacturing to advance scientific and technological knowledge, and the influence of the needs, interests and financial support of society on scientific and technological research OR • examining the functioning and applications of geosynchronous satellites to advance scientific and technological knowledge, and the influence of the needs, interests and financial support of society on scientific and technological research OR • explaining the mass distribution in our solar system and/or the Universe in terms of the chaos theory and gravitational attraction OR • assessing objectively, in terms of scientific principles and/or the needs, interests and financial support of society, the desirability of designing and building a space station, and evaluating the impact that living on a space station has on quality of life OR • any other relevant context.

UNIT 3
MECHANICAL WAVES

OVERVIEW

Science Themes: *Energy* and *Matter*

In Unit 3, students investigate the transmission of *energy* through *matter* by means of mechanical waves.

This unit uses a brief introduction to simple harmonic motion as a bridge from circular periodic motion to linear oscillation. The concepts of motion and *energy* are extended to the study of mechanical wave characteristics and behaviour. Sound is used as an example of a mechanical wave and to enhance understanding of wave behaviour and characteristics. This unit serves as a link between Unit 1: Kinematics and Dynamics, and Unit 4: Light.

The two **major concepts** developed in this unit are:

- many vibrations are simple harmonic
- waves are a means of transmitting *energy*.

In this unit, *students will develop* an ability to use the **skills** and **thinking processes** associated with the practice of science, emphasizing:

- initiating and planning
- collecting and recording
- organizing and communicating
- analyzing data from observations of mechanical wave phenomena
- connecting, synthesizing and integrating to predict mechanical wave behaviour, from data or information
- evaluating the process or outcomes of activities investigating the concepts of mechanical waves.

The **STS connections** in this unit illustrate:

- the functioning of products or processes based on scientific principles
- the use of technology to solve practical problems
- the influence of the needs, interests and financial support of society on scientific and technological research
- the ability and responsibility of society, through science and technology, to protect the environment and use natural resources judiciously to ensure quality of life for future generations.

ATTITUDES

Students will be encouraged to:

- appreciate the need for computational competence in quantifying wave behaviour and characteristics
- accept uncertainty in the descriptions and explanations of wave phenomena in the physical world
- be open-minded in evaluating potential applications of mechanical wave principles to new technology
- appreciate the fundamental role the principles of mechanical waves have in explaining observed artificial and natural phenomena
- appreciate the fundamental role the principles of mechanical waves play in our everyday world.

MAJOR CONCEPT	KNOWLEDGE
	Students should be able to demonstrate an understanding that:
1. Many vibrations are simple harmonic.	• simple harmonic motion is used to describe mechanical wave motion, by: • defining simple harmonic motion as motion toward a fixed point, with an acceleration, due to a restoring force, that is proportional to the displacement from the equilibrium position • explaining, qualitatively, the relationships among displacement, acceleration, velocity and time, for simple harmonic motion, in terms of uniform circular motion • explaining, quantitatively, the relationships among kinetic, potential and total mechanical energies of a mass executing simple harmonic motion • defining resonance, and giving examples of mechanical and/or acoustical resonance • describing wave motion in terms of the simple harmonic motion of particles.

SKILLS	STS CONNECTIONS
Students should be able to demonstrate the skills and thinking processes associated with the practice of science, by:	*Students should be able to demonstrate the interrelationships among science, technology and society, by:*
	• understanding that simple harmonic motion links uniform circular motion to the characteristics of mechanical waves, and explaining and solving, using mathematical methods, simple harmonic motion problems; and by relating, from empirical evidence, frequency and period of a simple harmonic motion to the physical characteristics of a system, within the context of:
• designing and performing an experiment to demonstrate that simple harmonic motion can be observed in objects within certain limits, and relate the frequency and period of the motion to physical characteristics of the system; e.g., a mass on a light, vertical spring or a simple pendulum	• analyzing, qualitatively, in terms of scientific principles, dampening forces in real-life examples of simple harmonic motion; e.g., springs in vehicle suspensions, pendulum clocks, metronomes OR
• observing the phenomenon of mechanical and acoustical resonance	• analyzing seismic waves and their impact on structures on Earth's surface OR
• predicting and verifying the conditions required for mechanical resonance to occur.	• assessing the implications of resonance in the design of structures and devices with moving parts; e.g., cars, bridges, buildings OR
	• any other relevant context.

MAJOR CONCEPT	KNOWLEDGE
	Students should be able to demonstrate an understanding that:
2. Waves are a means of transmitting *energy*.	• energy from simple harmonic motion can be transmitted as a wave through a medium, by: • describing medium particle vibrations as the source of mechanical waves • comparing and contrasting energy transmission by matter that moves and by waves that move • explaining the characteristics of waves in terms of the direction of vibration of the medium particles in relation to the direction of propagation of the disturbance • defining and using the terms wavelength, amplitude, transverse and longitudinal, in describing waves • explaining how a wave travels with a speed determined by the characteristics of the medium • relating the frequency of a wave to the period of the source, and the speed of propagation to the frequency and wavelength • predicting, quantitatively, and verifying, the effects of changing one, or a combination, of the variables in the relationship $v = f\lambda$ • explaining the behaviour of waves at the boundaries between mediums; e.g., reflection and refraction at “open” and “closed” ends • predicting the resultant displacement when two waves interfere • explaining the Doppler effect on a stationary observer with a moving source, and a moving observer with a stationary source.

SKILLS

Students should be able to demonstrate the skills and thinking processes associated with the practice of science, by:

- determining the speed of a water wave in a ripple tank or a wave pulse travelling along a stretched spring, flexible coil or rope
- observing the phenomena of reflection, refraction, diffraction and interference of mechanical waves
- drawing a diagram of the resultant wave, when two waves interfere, using the principle of superposition
- designing and performing experiments to measure the speed of sound in air, using resonance in an air column that is closed at one end
- identifying the differences between sounds, such as loudness, pitch and quality.

STS CONNECTIONS

Students should be able to demonstrate the interrelationships among science, technology and society, by:

- understanding that mechanical waves are a means of transmitting energy through a medium, and describing and explaining wave characteristics and behaviour, such as reflection, refraction, interference, resonance and the Doppler effect, using appropriate terms; and by gathering and analyzing empirical evidence describing the characteristics and behaviour of mechanical waves, within the context of:
  - investigating the application of acoustical phenomena, and other wave characteristics and behaviour, to solve practical problems in recreational, medical, industrial and research technology, and the influence of the needs, interests and financial support of society on scientific and technological research; e.g., sonar, ultrasound, sonography, radar, pipe organs, wind and brass instruments

  OR

  - assessing the impact of noise and sound in daily life, and evaluating the design and functioning of noise reduction devices and their impact on the quality of life

  OR

  - investigating the requirements and potential of careers, supported by societal needs and interests, involving sound

  OR

  - any other relevant context.

UNIT 4
LIGHT

OVERVIEW

Science Themes: *Diversity* and *Energy*

In Unit 4, students investigate *diversity* and *energy*, in a study of the nature and behaviour of light.

This unit applies prior knowledge from Unit 3 about the characteristics and behaviour of waves, in addition to the principles and methods of ray optics, to the phenomenon of light. The nature of science is particularly emphasized by the attention paid to the use of models in the development of a theory of light. This unit provides a foundation for the study of electromagnetic radiation and the photon model of light in Physics 30.

The two **major concepts** developed in this unit are:

- geometric optics is one model used to explain the nature and behaviour of light
- the wave model of light improves our understanding of the behaviour of light.

In this unit, *students will develop* an ability to use the **skills** and **thinking processes** associated with the practice of science, emphasizing:

- initiating and planning
- collecting and recording
- organizing and communicating
- analyzing data from observations of light phenomena, and identifying the limits of the data or information obtained
- connecting, synthesizing and integrating to relate the data to the behaviour and characteristics of light
- evaluating the process or outcomes of activities investigating the characteristics and behaviour of light.

The **STS connections** in this unit illustrate:

- the central role of evidence in the accumulation of knowledge, and the ways proposed theories may be supported, modified or refuted
- the functioning of products or processes based on scientific principles
- the ways in which science advances technology and technology advances science
- the use of technology to solve practical problems
- the limitations of scientific knowledge and technology
- the influence of the needs, interests and financial support of society on scientific and technological research.

ATTITUDES

Students will be encouraged to:

- appreciate that models are modified, as new and/or conflicting evidence is presented
- appreciate the need for computational competence in quantifying the behaviour of light
- accept uncertainty in the descriptions and explanations of the behaviour and nature of light
- be open-minded in evaluating potential applications of the principles of the nature of light to new technology
- appreciate the fundamental role of models in explaining observed natural phenomena
- appreciate the fundamental role the principles of the nature and behaviour of light play in our everyday world.

MAJOR CONCEPT	KNOWLEDGE
	Students should be able to demonstrate an understanding that:
1. Geometric optics is one model used to explain the nature and behaviour of light.	• geometric optics can be used to explain observed phenomena of light, by: • citing evidence for the linear propagation of light • explaining a method of measuring the speed of light • calculating *c*, given experimental data of various methods employed to measure the speed of light • defining a ray as a straight line representing the rectilinear propagation of light • explaining, using ray diagrams, the phenomena of dispersion, reflection and refraction at plane and uniformly curved surfaces • stating and using Snell's law in the form of $n_1 \sin \theta_1 = n_2 \sin \theta_2$ • deriving the curved mirror equation from empirical data • solving reflection and refraction problems, using algebraic, trigonometric and graphical methods • analyzing simple optical systems, consisting of no more than two lenses or one mirror and one lens, using algebraic and/or graphical methods.

SKILLS	STS CONNECTIONS
Students should be able to demonstrate the skills and thinking processes associated with the practice of science, by:	*Students should be able to demonstrate the interrelationships among science, technology and society, by:*
	• understanding and explaining observed light phenomena, reflection, refraction and dispersion in terms of geometric optics, and solving reflection and refraction problems, using algebraic, trigonometric and graphical means; and by gathering and mathematically analyzing relevant data describing the characteristics and behaviour of light, within the context of:
• designing and performing an experiment demonstrating that light travels in a straight line when in a uniform medium • performing experiments demonstrating reflection and refraction at plane and uniformly curved surfaces • deriving the mathematical representations of the laws of reflection and refraction, from the data obtained from these experiments • performing an experiment to determine the index of refraction of several different substances, and predicting the conditions required for total internal reflection to occur.	• assessing the influence of available technology on the experimental designs used by Galileo, Römer, Huygens, Fizeau, Foucault, Michelson and contemporary experimenters, to measure the speed of light OR • assessing the processes in which light affects living organisms, and the use of light technology to solve practical problems; e.g., growth, vision OR • evaluating and explaining technological and biological applications of linear propagation, reflection, refraction and total internal reflection of light to solve practical problems, and how these applications reflect the needs, interests and financial support of society; e.g., binoculars, eyeglasses, design of greenhouses, solar collectors, fibre optics OR • investigating the requirements and potential of careers, supported by societal needs and interests, involving optics OR • any other relevant context.

MAJOR CONCEPT	KNOWLEDGE
	Students should be able to demonstrate an understanding that:
2. The wave model of light improves our understanding of the behaviour of light.	• wave optics can explain light phenomena that geometric optics cannot, by recalling from Unit 3, the behaviour of waves during reflection, refraction and interference, and by: • comparing the explanations of reflection and refraction by the particle theory and by the wave theory of light • explaining, using the wave theory of light, the phenomena of reflection and refraction • explaining why geometric optics fail to adequately account for the phenomena of diffraction, interference and polarization • explaining, qualitatively, diffraction and interference, using the wave model of light • explaining how the results of Young's double-slit experiment support the wave theory of light • solving double-slit problems, using $\lambda = \frac{xd}{nl}$, and diffraction grating problems, using $\lambda = \frac{d \sin\theta}{n}$ • explaining, qualitatively, polarization in terms of the wave model of light • demonstrating how Snell's law in the form $\frac{\sin\theta_1}{\sin\theta_2} = \frac{n_2}{n_1} = \frac{v_1}{v_2} = \frac{\lambda_1}{\lambda_2}$ offers support for the wave model of light.

SKILLS	STS CONNECTIONS
Students should be able to demonstrate the skills and thinking processes associated with the practice of science, by:	*Students should be able to demonstrate the interrelationships among science, technology and society, by:*

SKILLS

- predicting the conditions required for diffraction to be observed
- performing an experiment to determine the wavelength of a light source in air or a liquid, using a Young's double-slit apparatus or a diffraction grating
- predicting and performing an experiment to verify the effects on an interference pattern due to changes in any one or more of the following variables: wavelength, slit separation or screen distance.

STS CONNECTIONS

- understanding how the wave model explains the behaviour of light in the phenomena of interference, double-slit diffraction and polarization; and by empirically investigating and mathematically analyzing the phenomena of diffraction and interference, within the context of:
  - investigating and reporting on Newton's influence, and the role of experimental evidence, in the development of a model for the theory of light

    OR

  - identifying and explaining, qualitatively, Poisson's spot as an example of the role of experimental evidence in the accumulation of knowledge, and the way in which proposed theories may be supported, modified or refuted where a model predicted new light phenomena

    OR

  - analyzing, qualitatively, the structure and function of polarizing filters in everyday life and nature, in terms of scientific principles; e.g., sunglasses, photography, bees, calculator liquid crystal diodes (LCDs)

    OR

  - any other relevant context.

PHYSICS 30

UNIT 1
CONSERVATION LAWS

OVERVIEW

Science Themes: *Energy, Equilibrium* and *Systems*

In Unit 1, students investigate *energy* and *equilibrium* in the physical world, in a study of the conservation of *energy* and momentum.

In this unit, the *energy* concepts from Science 10, Unit 4: Change and Energy; and Physics 20, Unit 1: Kinematics and Dynamics, are recalled and extended. The vector nature of momentum is explored through the algebraic and graphical solution of conservation of linear momentum problems. The principles learned are reinforced by analyzing common and practical physical interactions in isolated *systems*. This unit provides a foundation for further study of mechanics in subsequent units and for post-secondary studies in physics.

The two **major concepts** developed in this unit are:

- conservation of *energy* in an isolated *system* is a fundamental physical concept
- momentum is conserved when objects interact in an isolated *system*.

In this unit, *students will develop* an ability to use the **skills** and **thinking processes** associated with the practice of science, emphasizing:

- initiating and planning
- collecting and recording
- organizing and communicating
- analyzing data from physical interactions
- connecting, synthesizing and integrating to relate the data to the laws and principles of conservation of energy and momentum
- evaluating the process or outcomes of activities investigating the concepts of conservation of energy and momentum.

The **STS connections** in this unit illustrate:

- the functioning of products or processes based on scientific principles
- the use of technology to solve practical problems
- the influence of the needs, interests and financial support of society on scientific and technological research.

ATTITUDES

Students will be encouraged to:

- appreciate the need for computational competence in quantifying conservation of energy and momentum
- accept uncertainty in the descriptions and explanations of conservation in the physical world
- be open-minded in evaluating potential applications of conservation principles to new technology
- appreciate the fundamental role the principles of conservation play in our everyday world
- appreciate the need for simplicity in scientific explanations of complex physical interactions and the role conservation laws play in many of these explanations
- appreciate the need for accurate and honest communication of all evidence gathered in the course of an investigation related to conservation principles
- appreciate the need for empirical evidence in interpreting observed conservation phenomena
- appreciate the restricted nature of evidence when interpreting the results of physical interactions.

MAJOR CONCEPT	KNOWLEDGE
	Students should be able to demonstrate an understanding that:
1. Conservation of *energy* in an isolated *system* is a fundamental physical concept.	• mechanical energy interactions involve changes in kinetic and potential energy, by extending energy concepts from Science 10, Unit 4, and the mechanical energy concepts and problem-solving methods studied in Physics 20, Unit 1, and by: • describing energy and mass as scalar quantities • relating the conservation of mass and energy in a qualitative analysis of Einstein's concept of mass–energy equivalence • defining mechanical energy as the sum of kinetic and potential energy • solving conservation problems, using algebraic and/or graphical analysis • analyzing and solving, quantitatively, kinematics and dynamics problems, using mechanical energy conservation concepts by extending previous problem-solving methods.

SKILLS	STS CONNECTIONS
Students should be able to demonstrate the skills and thinking processes associated with the practice of science, by:	*Students should be able to demonstrate the interrelationships among science, technology and society, by:*
	• understanding that changes in kinetic and potential energy occur in mechanical energy interactions; and analyzing and solving, quantitatively, kinematic and dynamics problems, using mechanical energy concepts, and algebraic and/or graphical analyses; and by gathering, and graphically analyzing, relevant data inferring mathematical relationships, within the context of:
• designing and performing experiments demonstrating the law of conservation of energy, and the relationship between kinetic and mechanical potential energy • using free-body diagrams (force diagrams) in organizing and communicating the solutions of conservation problems • analyzing data graphically, using curve-straightening techniques, to infer mathematical relationships.	• investigating and reporting the application of conservation principles in research and design OR • any other relevant context.

MAJOR CONCEPT	KNOWLEDGE
	Students should be able to demonstrate an understanding that:
2. Momentum is conserved when objects interact in an isolated *system*.	• conservation laws provide a simple means to explain interactions among objects, by: • describing momentum as a vector quantity • defining momentum as a quantity of motion equal to the product of the mass and the velocity of an object • relating Newton's laws of motion, quantitatively, to explain the concepts of impulse and a change in momentum • explaining, quantitatively, using vectors, that momentum appears to be conserved during one- and two-dimensional interactions in one plane among objects (the sine and cosine rules are not required) • defining, comparing and contrasting elastic and inelastic collisions, using quantitative examples • comparing scalar and vector conservation laws.

SKILLS	STS CONNECTIONS
Students should be able to demonstrate the skills and thinking processes associated with the practice of science, by:	*Students should be able to demonstrate the interrelationships among science, technology and society, by:*
	• understanding that the law of conservation of momentum provides a means to explain interactions among objects; and explaining, quantitatively, using vectors and one- and two-dimensional interactions in one plane; and by obtaining and analyzing empirical evidence to demonstrate the conservation of momentum, and estimating and predicting results of interactions, within the context of:
• performing and analyzing experiments demonstrating the conservation of momentum and the principle of impulse • approximating, estimating and predicting results of interactions, based on an understanding of the conservation laws.	• assessing the role conservation laws and the principle of impulse play in the design and use of injury prevention devices in vehicles and sports; e.g., air bags, child restraint systems, running shoes, helmets OR • analyzing how the need for decreasing momentum over a long period has influenced the design of ropes used in such activities as “bunji” jumping and mountain climbing OR • investigating and reporting on a technology developed to improve the efficiency of energy transfer in a response to reconcile the energy needs of society with its responsibility to protect the environment and to use energy judiciously OR • investigating and reporting on a safety device that results in a cost saving to consumers and society, in terms of the problem addressed and its impact on quality of life OR • any other relevant context.

UNIT 2
ELECTRIC FORCES AND FIELDS

OVERVIEW

Science Themes: *Diversity*, *Energy* and *Matter*

In Unit 2, the *diversity* of *matter* is highlighted as its electric nature is considered in the context of electrical interactions and electric energy.

This unit covers the principles of electrostatics and how to describe the interaction of electric charges mathematically from empirical data. The concepts from Physics 20, Unit 1: Kinematics and Dynamics, are extended to charged particle dynamics. The concept of field, introduced in Physics 20, Unit 2: Circular Motion and Gravitation, is applied to electrical phenomena. The unit concludes with the consideration of electric *energy* and simple direct current (DC) circuits. This unit provides a foundation for further study of electrical principles in subsequent units and for post-secondary studies in physics.

The four **major concepts** developed in this unit are:

- the laws governing electrical interactions are used to explain the behaviour of electric charges at rest
- Coulomb's law relates electric charge to electric force
- electric field theory is a model used to explain how charges interact
- electric circuits facilitate the use of electric *energy*.

In this unit, *students will develop* an ability to use the **skills** and **thinking processes** associated with the practice of science, emphasizing:

- initiating and planning
- collecting and recording
- organizing and communicating
- analyzing data from electrical interactions
- connecting, synthesizing and integrating to relate the data to the laws and principles of electric forces and fields
- evaluating the process or outcomes of activities investigating the concepts of electric forces and fields.

The **STS connections** in this unit illustrate:

- the central role of evidence in the accumulation of knowledge, and the ways proposed theories may be supported, modified or refuted
- the functioning of products or processes based on scientific principles
- the ways in which science advances technology and technology advances science
- the use of technology to solve practical problems
- the ability and responsibility of society, through science and technology, to protect the environment and use natural resources judiciously to ensure quality of life for future generations.

ATTITUDES

Students will be encouraged to:

- appreciate the need for computational competence in quantifying electrical interactions
- accept uncertainty in the descriptions and explanations of electrical phenomena in the physical world
- be open-minded in evaluating potential applications of electrical principles to new technology
- appreciate the fundamental role the principles of electricity play in our everyday world
- appreciate the need to follow safe practices when working with electricity
- foster a responsible attitude to environmental and social change as related to the use and production of electrical *energy*
- appreciate the restricted nature of evidence when interpreting the results of electrical interactions.

MAJOR CONCEPT	KNOWLEDGE
	Students should be able to demonstrate an understanding that:
1. The laws governing electrical interactions are used to explain the behaviour of electric charges at rest.	• the electrical model of matter is fundamental to the explanation of electrical interactions, by extending from Physics 20, Unit 1, and by: • describing matter as containing discrete positive and negative particles • explaining electrical interactions in terms of the law of conservation of charge • explaining electrical interactions in terms of the law of electric charge (two types of charge: like charges repel, unlike charges attract) • comparing the methods of transferring charge: conduction and induction.

SKILLS	STS CONNECTIONS
Students should be able to demonstrate the skills and thinking processes associated with the practice of science, by:	*Students should be able to demonstrate the interrelationships among science, technology and society, by:*
	• understanding that the electrical model of matter is fundamental to the explanation of electrical phenomena; and explaining electrical interactions in terms of the law of conservation of charge and the law of electric charge; and by investigating, empirically, and explaining electrostatics, using the electric nature of matter, within the context of:
• performing an activity demonstrating the electrical nature of matter, using methods of electrification, and describing observations in terms of the laws of electrostatics • using safe practices when conducting electrical experiments.	• assessing how the principles of electrostatics are used to solve problems in industry and technology, and improve upon quality of life; e.g., telephones, photocopiers, electrostatic air cleaners, precipitators OR • investigating natural and artificial electrical discharge and the need for grounding in terms of scientific principles and the inability of science to provide complete answers to all questions OR • any other relevant context.

MAJOR CONCEPT	KNOWLEDGE
	Students should be able to demonstrate an understanding that:
2. Coulomb’s law relates electric charge to electric force.	• Coulomb’s law explains the relationships among force, charge and separating distance, by: • explaining, qualitatively, the principles pertinent to Coulomb’s torsion balance experiment • explaining, quantitatively, using Coulomb’s law and vectors, the electrostatic interaction between discrete point charges • comparing the inverse square relationship as it is expressed by Coulomb’s law and Newton’s universal law of gravitation.

SKILLS	STS CONNECTIONS
Students should be able to demonstrate the skills and thinking processes associated with the practice of science, by:	*Students should be able to demonstrate the interrelationships among science, technology and society, by:*
	• understanding that the relationships among force, charge and separating distance is explained by Coulomb's law; and explaining, quantitatively, using Coulomb's law and vectors, the electrostatic interaction between discrete point charges; and by gathering and analyzing relevant data inferring the mathematical relationships among force, charge and separating distance, within the context of:
• performing an experiment demonstrating the relationships among magnitude of charge, electric force and distance • inferring the mathematical relationships among force, charge and separating distance from empirical evidence.	• comparing and contrasting the experimental designs used by Coulomb and Cavendish, in terms of the role of technology in advancing science OR • any other relevant context.

MAJOR CONCEPT	KNOWLEDGE
	Students should be able to demonstrate an understanding that:
3. Electric field theory is a model used to explain how charges interact.	• the concept of field is applied to electric interactions, by extending from Physics 20, Unit 2, the definition of field, and by: • comparing scalar and vector fields • comparing forces and fields • explaining, quantitatively, using vector addition, electric fields in terms of intensity (strength) and direction relative to the source of the field • explaining, quantitatively, using vector addition, electric fields in terms of intensity (strength) and direction relative to the effect on an electric charge • predicting, using algebraic and/or graphical methods, the path followed by a moving electric charge in a uniform electric field, using kinematics and dynamics concepts • explaining electrical interactions, quantitatively, using the conservation laws of energy and charge.

SKILLS	STS CONNECTIONS
Students should be able to demonstrate the skills and thinking processes associated with the practice of science, by:	*Students should be able to demonstrate the interrelationships among science, technology and society, by:*
	• understanding the concept of field as related to electrical interactions; and explaining, quantitatively, using vector addition electric fields in terms of intensity and direction relative to the source of the field and its effect on an electric charge; and by plotting electric fields, using field lines and linking centripetal force to the electric force, within the context of:
• plotting electric fields, using field lines, for fields induced by discrete point charges, combinations of discrete point charges (like and oppositely charged) and charged parallel plates • relating the electric force, using Newton's second law, to the motion of an electric charge following a curved path in an electric field.	• evaluating electric field theory as a model used to explain the behaviour of electric charges in terms of supporting experimental evidence OR • explaining, qualitatively, how the problem of protecting sensitive components in a computer from electric fields is solved OR • any other relevant context.

MAJOR CONCEPT	KNOWLEDGE
	Students should be able to demonstrate an understanding that:
4. Electric circuits facilitate the use of electric *energy*.	• Ohm's law and Kirchhoff's rules are fundamental to explaining simple electric circuits, by: • defining current, potential difference, resistance and power, using appropriate terminology • defining the ampere as a fundamental SI unit, and relating the coulomb and second to it • distinguishing between conventional and electron flow current • explaining Ohm's law as an empirical, rather than a theoretical, relationship • quantifying electrical energy and power dissipated in a resistor, using Ohm's law • explaining Kirchhoff's current and voltage rules as a logical consequence of the laws of conservation of energy and charge • analyzing, quantitatively, simple series and/or parallel DC circuits in terms of the variables of potential difference, current and resistance, using Kirchhoff's rules and/or Ohm's law (solutions requiring Kirchhoff's rules to be limited to networks containing two power supplies and three branch currents).

SKILLS	STS CONNECTIONS
Students should be able to demonstrate the skills and thinking processes associated with the practice of science, by:	*Students should be able to demonstrate the interrelationships among science, technology and society, by:*
	• understanding and analyzing, quantitatively, simple series and parallel circuits in terms of Ohm's law and Kirchhoff's rules; and quantifying electrical energy and power dissipated in a resistor, using Ohm's law; and by determining, from empirical and theoretical evidence the relationships among electric energy/power, current, resistance and voltage, within the context of:
• determining, from empirical and theoretical evidence, the relationships among electric energy/power, current, resistance and voltage • performing an experiment to explain the relationships among current, voltage and resistance • designing, analyzing and solving simple resistive DC circuits • drawing diagrams of simple resistive DC circuits, using accepted symbols for circuit components • designing and performing an experiment demonstrating the heating effect of electric energy.	• analyzing common technological applications of electricity to solve practical problems in daily life; e.g., toasters, hair dryers, light fixtures OR • comparing and contrasting electrical energy with other energy sources with respect to such factors as cost, energy potential, risks and benefits to society, safety concerns and their impact on the quality of life of future generations OR • analyzing the use of series and parallel networks in household circuits in terms of the problems addressed OR • investigating the need for and the functioning of circuit breakers in household circuits OR • analyzing the risks of electric shock in terms of scientific principles OR • investigating the requirements and potential of careers, supported by societal needs and interests, involving electricity OR • any other relevant context.

UNIT 3
MAGNETIC FORCES AND FIELDS

OVERVIEW

Science Themes: *Diversity* and *Matter*

In Unit 3, the *diversity* of *matter* is highlighted as its magnetic nature is considered in the context of electric and magnetic interactions.

The concept of field, introduced in Physics 20, Unit 2: Circular Motion and Gravitation, is applied to magnetic phenomena. The concepts from Physics 20, Unit 1: Kinematics and Dynamics, are applied to charged particle dynamics in magnetic fields. The principles of electromagnetism introduced in Science 9, Unit 4: Electromagnetic Systems are further applied to an investigation of the functioning of electric motors, generators and transformers. The unit concludes with the consideration of the characteristics of the electromagnetic spectrum and alternating current (AC) circuits. This unit provides a foundation for further study of electromagnetic principles in Unit 4 and for post-secondary studies in physics.

The three **major concepts** developed in this unit are:

- magnetic field theory is a model used to describe magnetic behaviour
- electromagnetism pervades the Universe
- electromagnetic radiation is a physical manifestation of the interaction of electricity and magnetism.

In this unit, *students will develop* an ability to use the **skills** and **thinking processes** associated with the practice of science, emphasizing:

- initiating and planning
- collecting and recording
- organizing and communicating
- analyzing data from electromagnetic interactions
- connecting, synthesizing and integrating to relate the data to the laws and principles of magnetic forces and fields
- evaluating the process or outcomes of activities investigating the concepts of magnetic forces and fields.

The **STS connections** in this unit illustrate:

- the central role of evidence in the accumulation of knowledge, and the ways proposed theories may be supported, modified or refuted
- the ways in which science advances technology and technology advances science
- the use of technology to solve practical problems
- the influence of the needs, interests and financial support of society on scientific and technological research
- the ability and responsibility of society, through science and technology, to protect the environment and use natural resources judiciously to ensure quality of life for future generations.

ATTITUDES

Students will be encouraged to:

- appreciate the need for computational competence in quantifying electromagnetic phenomena
- accept uncertainty in the descriptions and explanations of electromagnetic phenomena in the physical world
- be open-minded in evaluating potential applications of electromagnetic principles to new technology
- appreciate the parallelism in the characteristics of electrical, gravitational and magnetic phenomena
- appreciate the fundamental role the principles of electricity and magnetism play in our everyday world
- appreciate the need to follow safe practices when working with electricity
- appreciate the restricted nature of evidence when interpreting the results of electromagnetic interactions.

MAJOR CONCEPT	KNOWLEDGE
	Students should be able to demonstrate an understanding that:
1. Magnetic field theory is a model used to describe magnetic behaviour.	• field theory can be used to describe magnetic interactions, by extending from Physics 20, Unit 1 and Physics 20, Unit 2, and by: • explaining the source of magnetic characteristics of matter in terms of magnetic domains • comparing the magnetic properties of Earth with those of artificial magnets • explaining magnetic interactions in terms of vector fields • comparing gravitational, electric and magnetic fields in terms of their sources and directions.

SKILLS	STS CONNECTIONS
Students should be able to demonstrate the skills and thinking processes associated with the practice of science, by:	*Students should be able to demonstrate the interrelationships among science, technology and society, by:*
	• understanding that magnetic interactions are described using field theory; and comparing and contrasting gravitational, electric and magnetic fields and interactions in terms of their source, direction and vectors; and by using field lines to show the shape and orientation of magnetic fields due to a variety of sources, within the context of:
• plotting magnetic fields, using field lines to show the shape and orientation of the magnetic fields resulting from magnetic poles or current-carrying conductors.	• evaluating magnetic field theory as a model to describe and predict observations of magnetic behaviour based on supportive evidence OR • discussing contemporary developments in the areas of electricity and magnetism, and their immediate and potential impact on daily life; e.g., superconductivity OR • investigating and reporting the affects of magnetism on the behaviour of living organisms in terms of the limitations of scientific knowledge and technology and in terms of quality of life OR • any other relevant context.

MAJOR CONCEPT	KNOWLEDGE
	Students should be able to demonstrate an understanding that:
2. Electromagnetism pervades the Universe.	• magnetic forces and fields are described in relation to electric currents, by extending electromagnetic concepts from Science 9, Unit 4, and by: • demonstrating how the discoveries of Oersted and Faraday form the foundation of the theory relating electricity to magnetism • describing a moving charge as the source of a magnetic field; and predicting the orientation of the magnetic field from the direction of motion • predicting, quantitatively, how a uniform electric and/or magnetic field affects a moving electric charge, using the relationships among charge, motion and field direction • relating and explaining, qualitatively, the interaction between a magnetic field and a moving charge as to how a magnetic field affects a current-carrying conductor • predicting, quantitatively, the effect of an external magnetic field on a current-carrying conductor • describing the effects of moving a conductor in an external magnetic field, using the analogy of a moving charge in a magnetic field • predicting, quantitatively, the effects of a magnetic field on a moving conductor • predicting, quantitatively, and verifying, the effects of changing one, or a combination, of the variables in the relationship $\frac{N_p}{N_s} = \frac{V_p}{V_s} = \frac{I_s}{I_p}$ • explaining the relationship between, and calculating, the effective and maximum values of, voltage and current in AC devices, given appropriate information • discussing, qualitatively, Lenz's law in terms of conservation of energy; describing, giving examples, situations where Lenz's law applies.

SKILLS	STS CONNECTIONS
Students should be able to demonstrate the skills and thinking processes associated with the practice of science, by:	*Students should be able to demonstrate the interrelationships among science, technology and society, by:*
	• understanding that magnetic forces and fields are related to electric currents; and predicting, quantitatively, the effect of a uniform electric and/or magnetic field on a moving electric charge, and explaining the motor and generator effects; and by analyzing empirical evidence of magnetic field–current interactions, within the context of:
• designing, performing and analyzing experiments demonstrating magnetic field–current interactions • predicting, using the LHR or RHR (hand rules), the relative directions of motion, force and field in electromagnetic devices • relating the magnetic force, using Newton's second law, to the motion of an electric charge following a curved path in a magnetic field.	• identifying and analyzing the application of electromagnetic interactions in the functioning of several types of technology OR • explaining, qualitatively, the design and function of AC and DC motors, generators, meters and other simple electromagnetic devices, using correct scientific terminology OR • assessing the impact of the transformer and alternating current on the generation, transmission and use of electrical energy, and on quality of life OR • evaluating, objectively, electromagnetic biomedical technology, in terms of solving practical problems and the influence of the needs, interests and financial support of society for its development, such as magnetic resonance imaging (MRI) or positron emission tomography (PET) OR • analyzing the parallels among gravitational, electrical and magnetic phenomena in terms of empirical evidence, and evaluating the role the conservation laws play in the accumulation of knowledge OR • any other relevant context.

MAJOR CONCEPT	KNOWLEDGE
	Students should be able to demonstrate an understanding that:
3. Electromagnetic radiation is a physical manifestation of the interaction of electricity and magnetism.	• Maxwell's theory of electromagnetism expanded on Oersted's and Faraday's generalizations, by: • stating that electromagnetic radiation is the result of accelerating electric charges, and demonstrates wavelike behaviour • comparing and contrasting the constituents of the electromagnetic spectrum on the basis of frequency, wavelength and energy • solving problems algebraically, using the relationships among speed, wavelength, frequency, period and/or distance, of electromagnetic waves • comparing and contrasting natural and technological processes by which the major constituents of the electromagnetic spectrum are produced • explaining, qualitatively, Maxwell's theory of electromagnetism • explaining the propagation of electromagnetic radiation in terms of perpendicular electric and magnetic fields, varying with time, travelling away from their source at the speed of light • explaining, qualitatively, how different types of electromagnetic radiation interact with matter, including biological effects; e.g., microwaves, ultraviolet radiation, X-rays.

SKILLS	STS CONNECTIONS
Students should be able to demonstrate the skills and thinking processes associated with the practice of science, by:	*Students should be able to demonstrate the interrelationships among science, technology and society, by:*
	• understanding that electromagnetic radiation is a physical manifestation of the interaction of electricity and magnetism; and explaining the propagation of electromagnetic radiation in terms of electric and magnetic fields; and by demonstrating the wavelike behaviour of electromagnetic radiation; and by predicting the conditions required for electromagnetic radiation emission, within the context of:
• performing experiments, and/or using simulations, demonstrating the wavelike behaviour of electromagnetic radiation • predicting the conditions required for electromagnetic radiation emission.	• evaluating the risks and benefits of using electromagnetic radiation in technological solutions to practical problems; in terms of the quality of life, the limitations of science and technology, and societal needs, interests and financial support OR • researching, reporting on and evaluating the use of electromagnetic radiation technology in such scientific fields as biology, chemistry, medicine, astronomy, in terms of societal needs, interests and financial support, and the contribution to the accumulation of scientific knowledge OR • investigating the requirements and potential of careers, supported by societal needs and interests, involving electromagnetism OR • any other relevant context.

UNIT 4
NATURE OF MATTER

OVERVIEW

Science Themes: *Energy* and *Matter*

In Unit 4, students investigate the science themes of *energy* and *matter*, as the electric nature of *matter* is considered in the context of developing and understanding of quantum concepts, atomic theory and nuclear processes.

Building on previous learning from Science 10, Unit 3: Energy and Matter in Chemical Change, the discovery of the electron and the development of the quantum model of the atom is studied. The study of the photoelectric effect and the photon model of light provides a link to Physics 20, Unit 4: Light, where the wave model of light is emphasized. The unit concludes with the study of radiation, the characteristics of fission and fusion reactions, quantization of *energy* and how *energy* levels in nature support modern atomic theory. This unit provides a foundation for post-secondary studies in related areas.

The four **major concepts** developed in this unit are:

- the atom has an electric nature
- the photoelectric effect requires the adoption of the photon model of light
- nuclear fission and fusion are nature's most powerful *energy* sources
- *energy* levels in nature support modern atomic theory.

In this unit, *students will develop* an ability to use the **skills** and **thinking processes** associated with the practice of science, emphasizing:

- initiating and planning
- collecting and recording
- organizing and communicating
- analyzing data from experiments, empirical and theoretical evidence for the electron and quantum concepts
- connecting, synthesizing and integrating to relate the data to a theoretical model of the atom, and to the principles of the wave–particle duality of *matter*
- evaluating the process or outcomes of activities investigating quantum concepts and the wave–particle duality of matter.

The **STS connections** in this unit illustrate:

- the central role of evidence in the accumulation of knowledge, and the ways proposed theories may be supported, modified or refuted
- the inability of science to provide complete answers to all questions
- the functioning of products or processes based on scientific principles
- the ways in which science advances technology and technology advances science
- the use of technology to solve practical problems
- the limitations of scientific knowledge and technology
- the ability and responsibility of society, through science and technology, to protect the environment and use natural resources judiciously to ensure quality of life for future generations.

ATTITUDES

Students will be encouraged to:

- appreciate that models are modified as new and/or conflicting evidence is presented
- appreciate the role of mathematics in assessing the risks and benefits of radioactivity and the commercial use of nuclear *energy*.

MAJOR CONCEPT	KNOWLEDGE
	Students should be able to demonstrate an understanding that:
1. The atom has an electric nature.	• the discovery of the electron contributed to the formulation of quantum concepts and atomic models, by extending from Science 10, Unit 3, and by: • explaining how the discovery of cathode rays contributed to the development of atomic models • explaining Thomson's experiment and the significance of the results • deriving the relationship $\frac{q}{m} = \frac{v}{BR}$, using circular motion and charged particles in electric and magnetic field concepts • explaining Millikan's experiment and its significance relative to charge quantization • relating the electronvolt, as a unit of energy, to the joule.

SKILLS	STS CONNECTIONS
Students should be able to demonstrate the skills and thinking processes associated with the practice of science, by:	*Students should be able to demonstrate the interrelationships among science, technology and society, by:*
	• understanding and explaining how technological advances and experimental evidence contributed to the formulation of models of the atom; and by determining the charge to mass ratio of the electron, and the mass of an electron and/or ion, given appropriate empirical data, within the context of:
• performing an experiment, or using simulations, to determine the charge to mass ratio of the electron • determining, in quantitative terms, the mass of an electron and/or ion, given appropriate empirical data.	• analyzing how the identification of the electron and its characteristics is an example of the interaction of science and technology OR • evaluating how, in the scientific process, discoveries are often missed by investigators failing to identify and/or correctly interpret evidence; e.g., X-rays OR • any other relevant context.

MAJOR CONCEPT	KNOWLEDGE
	Students should be able to demonstrate an understanding that:
2. The photoelectric effect requires the adoption of the photon model of light.	• the quantum concept is required to explain adequately some natural phenomena, by extending from Physics 20, Unit 4, and by: • explaining the necessity for Planck to introduce the quantum of energy concept to explain blackbody radiation • defining the photon as a quantum of electromagnetic radiation • describing how Hertz discovered the photoelectric effect while investigating electromagnetic waves • explaining the photoelectric effect in terms of the intensity and wavelength of the incident light and surface material • assessing the assumptions made by Einstein in explaining the photoelectric effect • defining threshold frequency as the minimum frequency giving rise to the photoelectric effect; and work function as the energy binding an electron to a photoelectric surface • explaining the relationship between the kinetic energy of a photoelectron and stopping voltage • using Einstein's equation, quantitatively, to describe photoelectric emission • describing the photoelectric effect as a phenomenon that supports the notion of the wave–particle duality of electromagnetic radiation • explaining X-ray production as an inverse photoelectric effect, and predicting, quantitatively, the short wavelength limit of X-rays produced, given appropriate data • explaining, qualitatively, the Compton effect and the de Broglie hypothesis applying the laws of mechanics, conservation of momentum and energy, to photons, as another example of wave–particle duality.

SKILLS	STS CONNECTIONS
Students should be able to demonstrate the skills and thinking processes associated with the practice of science, by:	*Students should be able to demonstrate the interrelationships among science, technology and society, by:*
	• understanding that an adequate explanation of some natural phenomena requires the quantum concept; and describing the photoelectric effect as evidence for the notion of wave–particle duality of electromagnetic radiation; and by investigating, empirically, the photoelectric effect, within the context of:
• performing an experiment demonstrating the photoelectric effect and interpreting the data obtained • predicting and verifying the effect that changing the intensity and/or frequency of the incident radiation or the material of the photocathode has on photoelectric emission.	• analyzing, in general terms, the functioning of various technological applications of the photoelectric effect to solve practical problems; e.g., automatic door openers, burglar alarms, light meters, smoke detectors OR • discussing why the photoelectric effect could not be explained, using the wave model of electromagnetic radiation, and thus required a new hypothesis OR • identifying industrial and scientific uses of X-rays; e.g., X-ray examination of welds, crystal structure analysis OR • any other relevant context.

MAJOR CONCEPT	KNOWLEDGE
	Students should be able to demonstrate an understanding that:
3. Nuclear fission and fusion are nature's most powerful *energy* sources.	• the processes of nuclear fission and fusion are nature's most powerful energy sources, by: • using the isotope notation to describe and identify common nuclear isotopes, and determine the number of each nucleon of an atom • describing the nature and behaviour of alpha, beta and gamma radiation • writing nuclear equations for alpha and beta decay • performing simple, nonlogarithmic, half-life calculations • predicting the particles emitted by a nucleus from the examination of representative transmutation equations • explaining, qualitatively, how radiation is absorbed by matter, and compare and contrast the biological effects of different types of radiation • comparing and contrasting the characteristics of fission and fusion reactions • explaining, qualitatively, the importance of Einstein's concept of mass–energy equivalence • relating, qualitatively, the mass defect of the nucleus to the energy released in nuclear reactions.

SKILLS	STS CONNECTIONS

SKILLS

Students should be able to demonstrate the skills and thinking processes associated with the practice of science, by:

- using library resources to research and report on selected scientists who contributed to our understanding of the structure of the nucleus
- inferring radiation properties from experimental data provided
- graphing data for radioactive decay and interpolating values for half-life
- interpreting some common nuclear decay chains
- performing a qualitative risk/benefit analysis of a nuclear energy application.

STS CONNECTIONS

Students should be able to demonstrate the interrelationships among science, technology and society, by:

- understanding that the processes of nuclear fission and fusion are nature's most powerful energy sources; and describing the nature of particle radiation and nuclear decay, and explaining, qualitatively, the importance of the concept of mass–energy equivalence in nuclear reaction processes; and by analyzing empirical nuclear decay data, and performing a risk/benefit analysis of a nuclear energy application, within the context of:
  - assessing the value to society of nuclear and particle research

    OR

  - evaluating the applications of radiation phenomena and technologies in research, medicine, agriculture, industry; e.g., isotope tracing, food irradiation

    OR

  - assessing the risks and benefits of exposure to natural background radioactivity and artificially induced radioactivity; e.g., air travellers to cosmic radiation, dental X-rays

    OR

  - evaluating, qualitatively, the risks and benefits of using fission and/or fusion as commercial sources of energy, in terms of the limitations of scientific knowledge and technology, and the ability and responsibility of society to protect the environment and to use natural resources judiciously to ensure quality of life for future generations

    OR

  - investigating the requirements and potential of careers, supported by societal needs and interests, involving nuclear physics

    OR

  - any other relevant context.

MAJOR CONCEPT	KNOWLEDGE
	Students should be able to demonstrate an understanding that:
4. *Energy* levels in nature support modern atomic theory.	• the Rutherford–Bohr model of the atom represents a synthesis of classical and quantum concepts, by: • explaining, qualitatively, the significance of the results of Rutherford's scattering experiment in terms of the nature and role of the nucleons; and the size and mass of the nucleus and the atom, which lead to the proposal of a planetary model of the atom • explaining why Maxwell's theory of electromagnetism predicts the failure of a planetary model of the atom • describing why each element has a unique line spectrum, and comparing and contrasting the characteristics of continuous and line spectra • explaining, qualitatively, the conditions necessary to produce line emission and line absorption spectra • explaining the quantum implications of the line absorption and the line emission spectra, and determining any variable in the Balmer equation $\frac{1}{\lambda} = R_H\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$ • explaining Bohr's concept of "stationary states" and their relationship to line spectra of atoms; and using the frequency/wavelength of an emitted photon to determine the energy difference between states • explaining the relationship between hydrogen's absorption spectrum and its energy levels • describing how the Bohr atom can be used to predict the ionization energy of hydrogen, and to calculate the allowed radii of the hydrogen atom • describing how the Rutherford–Bohr model has been further refined, by applying quantum concepts to a purely mathematical model based on probability and waves • comparing and contrasting, qualitatively, the Rutherford, the Bohr and the quantum model of the atom.

SKILLS	STS CONNECTIONS
Students should be able to demonstrate the skills and thinking processes associated with the practice of science, by:	*Students should be able to demonstrate the interrelationships among science, technology and society, by:*
	• understanding that the Rutherford–Bohr model offers a restricted explanation of the structure of the atom, and that a mathematical model provides a fuller explanation of the empirical evidence of energy levels within the atom; and by observing line spectra and predicting potential energy transition in an atom, within the context of:
• observing representative line spectra of selected elements • predicting the conditions necessary to produce and observe line emission and line absorption spectra • predicting the potential energy transitions in the hydrogen atom, using a labelled diagram showing the energy levels.	• investigating and reporting on the use of line spectra in the study of the Universe and the identification of substances OR • describing the functioning of lasers in terms of energy level transitions and resonance OR • investigating and reporting on the application of spectra concepts in the design and functioning of lighting devices; e.g., street lights, signs OR • analyzing how quantum concepts led to technological advances that benefit society; e.g., semiconductors, electron microscopes, computers OR • investigating and reporting on the contributions made by scientists to the development of the early quantum theory; e.g., Hertz, Planck, Einstein, Bohr, Compton, Davisson, Germer OR • any other relevant context.