Physics, Grade 12

University Preparation SPH4U

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

Prerequisite: Physics, Grade 11, University Preparation

Big Ideas

Dynamics

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

Energy and Momentum

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

Gravitational, Electric, and Magnetic Fields

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

The Wave Nature of Light

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

Revolutions in Modern Physics: Quantum Mechanics and Special Relativity

- Light can show particle-like and wave-like behaviour, and particles can show wave-like behaviour.
- The behaviour of light as a particle and the behaviour of particles as waves can be described mathematically.

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

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

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

A. SCIENTIFIC INVESTIGATION SKILLS AND CAREER EXPLORATION

OVERALL EXPECTATIONS

Throughout this course, students will:

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

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

SPECIFIC EXPECTATIONS

A1. Scientific Investigation Skills

Throughout this course, students will:

Initiating and Planning [IP]*

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

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

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

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

Performing and Recording [PR]*

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

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

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

Analysing and Interpreting [AI]*

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

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

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

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

Communicating [C]*

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

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

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

A2. Career Exploration

Throughout this course, students will:

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

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

B. DYNAMICS

OVERALL EXPECTATIONS

By the end of this course, students will:

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

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

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

SPECIFIC EXPECTATIONS

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

By the end of this course, students will:

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

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

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

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

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

B2. Developing Skills of Investigation and Communication

By the end of this course, students will:

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

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

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

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

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

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

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

B3. Understanding Basic Concepts

By the end of this course, students will:

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

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

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

C. ENERGY AND MOMENTUM

OVERALL EXPECTATIONS

By the end of this course, students will:

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

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

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

SPECIFIC EXPECTATIONS

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

By the end of this course, students will:

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

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

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

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

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

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

C2. Developing Skills of Investigation and Communication

By the end of this course, students will:

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

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

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

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

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

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

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

C3. Understanding Basic Concepts

By the end of this course, students will:

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

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

C3.3 distinguish between elastic and inelastic collisions

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

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

D. GRAVITATIONAL, ELECTRIC, AND MAGNETIC FIELDS

OVERALL EXPECTATIONS

By the end of this course, students will:

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

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

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

SPECIFIC EXPECTATIONS

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

By the end of this course, students will:

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

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

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

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

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

D2. Developing Skills of Investigation and Communication

By the end of this course, students will:

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

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

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

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

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

D3. Understanding Basic Concepts

By the end of this course, students will:

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

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

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

E. THE WAVE NATURE OF LIGHT

OVERALL EXPECTATIONS

By the end of this course, students will:

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

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

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

SPECIFIC EXPECTATIONS

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

By the end of this course, students will:

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

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

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

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

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

E2. Developing Skills of Investigation and Communication

By the end of this course, students will:

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

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

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

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

E3. Understanding Basic Concepts

By the end of this course, students will:

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

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

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

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

F. REVOLUTIONS IN MODERN PHYSICS: QUANTUM MECHANICS AND SPECIAL RELATIVITY

OVERALL EXPECTATIONS

By the end of this course, students will:

F1. analyse, with reference to quantum mechanics and relativity, how the introduction of new conceptual models and theories can influence and/or change scientific thought and lead to the development of new technologies;

F2. investigate special relativity and quantum mechanics, and solve related problems;

F3. demonstrate an understanding of the evidence that supports the basic concepts of quantum mechanics and Einstein's theory of special relativity.

SPECIFIC EXPECTATIONS

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

By the end of this course, students will:

F1.1 analyse the development of the two major revolutions in modern physics (e.g., the impact of the discovery of the photoelectric effect on the development of quantum mechanics; the impact of thought experiments on the development of the theory of relativity), and assess how they changed scientific thought [AI, C]

Sample questions: Which scientists made the most important contributions to the development of quantum mechanics? What kinds of experiments did they conduct? What sorts of discoveries did they make? In what ways did later discoveries build on earlier ones? What experiments and discoveries led to the development of the theory of relativity? What impact did Einstein's theories have on later scientific thought?

F1.2 assess the importance of relativity and quantum mechanics to the development of various technologies (e.g., nuclear power; light sensors; diagnostic tools such as magnetic resonance imaging [MRI], computerized axial tomography [CAT], positron emission tomography [PET]) [AI, C]

Sample questions: How has quantum computing moved the computer age forward? What are some of the applications of the theory of relativity and/or quantum mechanics in medicine? Why were quantum mechanics and the theory of relativity necessary to the development of the atomic bomb?

F2. Developing Skills of Investigation and Communication

By the end of this course, students will:

F2.1 use appropriate terminology related to quantum mechanics and special relativity, including, but not limited to: *quantum theory*, *photoelectric effect*, *matter waves*, *time dilation*, and *mass–energy transformation* [C]

F2.2 solve problems related to the photoelectric effect, the Compton effect, and de Broglie's matter waves [PR, AI]

F2.3 solve problems related to Einstein's theory of special relativity in order to calculate the effects of relativistic motion on time, length, and mass (e.g., the half-life of cosmic ray muons, how far into the future a fast space ship would travel, the magnetic field strength necessary to keep protons in the Large Hadron Collider) [PR, AI]

F2.4 conduct a laboratory inquiry or computer simulation to analyse data (e.g., on emission spectra, the photoelectric effect, relativistic momentum in accelerators) that support a scientific theory related to relativity or quantum mechanics [PR, AI]

F3. Understanding Basic Concepts

By the end of this course, students will:

F3.1 describe the experimental evidence that supports a particle model of light (e.g., the photoelectric effect, the Compton effect, pair creation, de Broglie's matter waves)

F3.2 describe the experimental evidence that supports a wave model of matter (e.g., electron diffraction)

F3.3 identify Einstein's two postulates for the theory of special relativity, and describe the evidence supporting the theory (e.g., thought experiments, half lives of elementary particles, relativistic momentum in accelerators, the conversion of matter into energy in a nuclear power plant)

F3.4 describe the standard model of elementary particles in terms of the characteristics of quarks, hadrons, and field particles

Printed on recycled paper

08-005
ISBN 978-1-4249-8084-0 (Print)
ISBN 978-1-4249-8085-7 (PDF)
ISBN 978-1-4249-8086-4 (TXT)