Waves, Optics and Modern Physics

Objectives:	00UT	**Discipline:**	Physics
Ponderation:	3-2-3	**Course Code:**	203-NYC-05
Prerequisite:	00UR (*Mechanics*), 00UN (*Calculus I*)	**Course Credit:**	2 2/3
Corequisite:	00UP (*Calculus II*)	**Semester:**	2 (Pure & Applied Profile); 3 (Health Science Profile)

Introduction

Waves, Optics and Modern Physics is the second physics course in the Science Program at Dawson College. The course begins with a study of oscillations of mechanical systems, moves on to the study of a number of the key experiments that led to the establishment of quantum mechanics. Each of these topics is a fascinating branch of physics worthy of study in its own right, and each topic also has links to other branches of science including Chemistry and Biology. Techniques learned in *Calculus I* and *Calculus II* are employed throughout the course to derive relations and to solve problems. Finally, the course invites the use of many interesting examples that speak to everyday experience such as corrective lenses, optical instruments, polarization of light, medical imaging, and so on.

The general framework of the course is the attainment of objective 00UT ("To analyze various situations or phenomena associated with waves, optics and modern physics using basic principles.").

1. The attainment of this objective requires an understanding of the characteristics of various oscillatory and wave phenomena, geometrical optics, physical optics and some aspects of modern physics.
2. The presentation of the course should contribute to the integration of objectives from the preceding physics course (*Mechanics*) and mathematics course (*Calculus I*). The major stages in the development of different models will be placed in historical context. Examples and problems drawn from technology and from everyday life will be presented where appropriate. In particular, care will be taken to make explicit the many links between topics in this course and other courses in the program.
3. Students will be required to use calculators and computers in their work. Computers will be used for data collection and analysis in some laboratory exercises, and a spreadsheets will be used to solve certain problems.
4. In the laboratory, students will use appropriate scientific instruments to carry out experiments verifying some of the laws and principles studied in the course.

Some of the learning activities in *Waves and Modern Physics* will contribute to the attainment of the integrative Objective 00UU and are marked **[00UU]**.

The student will use some of the knowledge and skills mastered in attaining the objectives of *Waves, Optics and Modern Physics* to:

- attain objective 00US (*Electricity and Magnetism*)
- attain objective 00UU, as topics in this course have direct applications in Chemistry, Biology, Astrophysics and Geology.

In the Science Program, *Waves, Optics and Modern Physics* contributes to the following program goals described in the *Exit Profile*:

	Goals of the Science Program	Performance Criteria
1.	To master the knowledge and skills of a basic scientific education	00UT, 00UU
2.	To master the knowledge and skills of a basic general education	
3.	To apply the experimental method	3.1, 3.2, 3.4, 3.5
4.	To take a systematic approach to problem solving	4.1 – 4.6
5.	To use the appropriate data-processing technology	5.1 ,5.2, 5.4
6.	To reason logically	6.1 – 6.3
7.	To communicate effectively	7.1, 7.3 – 7.6
8.	To learn in an autonomous manner	8.1 – 8.3
9.	To work as members of a team	9.1 – 9.3
10.	To recognize the links between science, technology and the evolution of society	10.1 – 10.3
11.	To construct a personal system of values	11.1 – 11.3
12.	To identify the context in which scientific ideas originated and evolved	12.1
13.	To display attitudes and behaviour compatible with the scientific spirit and method	13.1 – 13.5
14.	To apply acquired knowledge and skills to new situations	14.1

Objectives and Standards for Waves, Optics and Modern Physics

In the following chart, italicized items marked with (*) are optional enrichment items which will not be evaluated in the final exam (these are not the only possible enrichment items — they are the most commonly used ones).

OBJECTIVE	STANDARD	LEARNING OBJECTIVES
Course objective	**Achievement Context**	
To analyze various situations or phenomena associated with waves, optics and modern physics using basic principles	1. In theoretical situations, working individually to solve problems taken from a standard college-level Physics textbook 2. In experimental settings, in the lab, working individually or in a group, with the aid of a laboratory write-up, or of scientific documentation, to write lab reports	
	General Performance Criteria	
	1. Appropriate use of concepts, laws and principles 2. Adequate use of diagrams to represent physical situations 3. Appropriate use of terminology and units 4. Accurate graphical representations of situations 5. Proper justification of the steps taken in analyzing a situation 6. Rigorous application of the principles in the models used to represent phenomena 7. Critical judgment of results 8. Proper interpretation of the limits of models 9. Meticulous experimentation 10. Adequate observation of College standards for scientific essays and laboratory reports	

Elements of Competency	Specific Performance Criteria	Intermediate Learning Objectives
1. To apply the basic principles of physics to oscillations and to waves and their propagation	1.1. Precise use of concepts and terminology basic to the description of oscillatory motion	1.1.1. Define simple harmonic motion, amplitude, frequency, period, phase constant, damped oscillation, forced oscillation and resonance. 1.1.2. Distinguish between simple harmonic motion and other forms of oscillatory motion.
	1.2. Proper derivation of certain relations pertaining to oscillatory motion	1.2.1. Write an equation for the displacement of an object in simple harmonic motion as a function of time and from it derive the equations for velocity and acceleration. 1.2.2. Derive from first principles, expressions for: • the frequency of a spring-mass system; • the potential and kinetic energies in a spring-mass system or other system in simple harmonic motion; and • the period of a simple pendulum.
	1.3. Accurate representation of certain aspects of simple harmonic motion using graphs	1.3.1. Sketch and interpret graphs of displacement, velocity and acceleration as functions of time for an object in simple harmonic motion. 1.3.2. Sketch and interpret graphs of kinetic energy and potential energy versus time or displacement for an object in simple harmonic motion.
	1.4. Rigorous application of the principles of oscillatory motion to solve problems	1.4.1. Write equations of motion for an object in simple harmonic motion and solve. 1.4.2. Describe qualitatively damped simple harmonic motion and forced oscillations. 1.4.3. State the conditions for resonance. 1.4.4. Calculate the resonant frequency of a spring-mass system. 1.4.5. Sketch the graph of amplitude versus driving frequency for a system near resonance.
	1.5. Precise use of the concepts and terminology basic to the general description of waves and their propagation	1.5.1. Define wavelength, amplitude, frequency, and phase constant of a wave. 1.5.2. Define longitudinal and transverse waves. 1.5.3. Describe the phase changes of a wave at reflection.
	1.6. Proper description of certain aspects of waves	1.6.1. Write the equation of a one dimensional wave on a string. 1.6.2. Describe the reflection of pulses at barriers, including conditions for phase changes. 1.6.3. Describe the reflection and transmission of waves at an interface, including the conditions for phase changes. 1.6.4. Use the equation for the velocity of a wave on a string $v = \sqrt{F/m}$ to solve problems.
	1.7. Rigorous application of the concepts and equations set out above to solve a variety of problems	1.7.1. Define wave number and angular frequency for a sinusoidal wave. 1.7.2. Write the general equation for a one dimensional sinusoidal wave.

Elements of Competency	Specific Performance Criteria	Intermediate Learning Objectives
	concerning one dimensional waves such as a wave travelling on a string	1.7.3. From the wave equation find the amplitude, frequency, wavelength, phase constant and speed of the wave. 1.7.4. Manipulate the power equation for a sinusoidal wave.
	1.8. Precise description of sound waves	1.8.1. Define rarefaction and condensation. 1.8.2. Write expressions for pressure and displacement waves that describe a sound wave. 1.8.3. Derive an expression for the intensity of a periodic sound wave. 1.8.4. Define the decibel as a measure of sound level. 1.8.5. Derive the inverse square relation between intensity and distance from the source for a spherical sound source. 1.8.6. Describe a spherical wave. 1.8.7. Write the expression for the Doppler effect, taking into account motion of both source and receiver. 1.8.8. Explain the formation of a shock wave and derive an expression for the angle of a shock wave cone.
	1.9. Rigorous application of the concepts and equations of section 1.8 to solve mathematical problems and answer qualitative questions concerning sound waves	1.9.1. Solve problems involving relations between sound intensity, sound level (dB), and power for isotropic sources.
	1.10. Rigorous application of the superposition principle and knowledge of waves to solve mathematical problems and answer qualitative questions involving interference phenomena, standing waves and beats	1.10.1. State the superposition principle for waves. 1.10.2. Sketch the resulting pulse shape as two pulses pass each other on a string. 1.10.3. Calculate the positions of maxima and minima in the interference pattern of sound waves from multiple speakers. 1.10.4. Derive an expression for the frequencies that will produce standing waves on a string fixed at both ends. 1.10.5. Derive an expression for the frequencies of sound waves that will produce standing waves in an air column in a pipe that is: • open at both ends; • closed at one end 1.10.6. Explain the basic principles of wind and string instruments. **[00UU]** 1.10.7. Derive an expression for the wave that results when two waves of different frequencies interfere (beats). Sketch the form of the resulting wave. Calculate the beat frequency.
2. To apply the laws of geometrical optics	2.1. Precise use of the concepts, laws and terminology appropriate to the description of the reflection and refraction of light	2.1.1. State the laws of reflection, the laws of refraction (Snell's Law), Huygens' Principle and Fermat's Principle. 2.1.2. Derive the laws of reflection and refraction from Huygens' Principle. 2.1.3. *(*) Derive the laws of reflection and refraction from Fermat's Principle*

Elements of Competency	Specific Performance Criteria	Intermediate Learning Objectives
		2.1.4. State the conditions for total internal reflection. 2.1.5. Define the index of refraction of a medium in terms of the speed of light in it. 2.1.6. Explain what is meant by dispersion, or a dispersive medium. 2.1.7. Describe how a prism spreads light into a spectrum.
	2.2. Rigorous application of the laws of reflection and refraction to solve mathematical problems and answer qualitative questions	2.2.1. Calculate the angles of reflection and refraction of light rays at the interface between two media or given information about angle of refraction, calculate index of refraction. 2.2.2. Using Snell's Law, calculate the path of a light ray through a parallel-sided glass block and through a prism. 2.2.3. Explain how light is transmitted along fibre optics cables. Discuss examples of the application of fibre optics to medicine and telecommunications. **[00UU]** 2.2.4. Using the formula derived from Snell's Law and appropriate sign conventions, calculate the characteristics of an image formed by a single plane refracting surface; *a single spherical refracting surface (small angle approximation) ** 2.2.5. Describe the image formed by a plane mirror and explain it using the laws of reflection.
	2.3. Rigorous application of the equations for image formation by spherical mirrors and thin lenses to solve a variety of problems in geometrical optics	2.3.1. Describe the properties of an image: position, magnification, size, orientation, and type (real or virtual). 2.3.2. Define focal length of a spherical mirror and relate it to the radius of curvature of the mirror. 2.3.3. Define the focal length of a thin lens. 2.3.4. Calculate the focal length of a thin lens using the lens makers' equation. 2.3.5. *(*) Derive the lens makers' equation.* 2.3.6. Sketch ray diagrams to locate images formed by spherical mirrors and thin lenses. 2.3.7. Use the equation relating object distance, image distance and focal length for spherical mirrors and thin lenses and appropriate sign conventions to solve problems involving image formation by a single lens or mirror or by a combination of two or more lenses and mirrors.
	2.4. Rigorous application of the equations of image formation in spherical mirrors and thin lenses to explain in principle the operation of certain optical devices and instruments	2.4.1. Explain the function of the (mammalian) eye in terms of geometrical optics: sketch the eye showing the main structures and describe the function of each structure; define near point and far point of an eye; define hyperopia, myopia and astigmatism and explain their causes; calculate the focal length of lenses needed to correct hyperopia or myopia given the sufferer's near and or far points; define the power of

Elements of Competency	Specific Performance Criteria	Intermediate Learning Objectives
		a lens in diopters. **[00UU]** 2.4.2. Explain the operation of a compound microscope. **[00UU]** 2.4.3. Explain the operation of a camera. **[00UU]**
3. To apply the characteristics of waves to light phenomena (physical optics)	3.1. Proper characterization of light as a wave	3.1.1. List the parts of the electromagnetic spectrum in order of wavelength. 3.1.2. State the range of wavelengths in the visible spectrum.
	3.2. Rigorous application of the concepts of waves and superposition and the technique of phasors to solving problems and answering qualitative questions involving interference of light	3.2.1. State the necessary conditions for the observation of interference in light waves. 3.2.2. Describe Young's double slit experiment and derive an expression for the locations of minima and maxima in the interference pattern. 3.2.3. Derive an expression for the intensity distribution of the interference pattern in a double slit experiment. Plot the function. 3.2.4. Define phasor. Use phasors to calculate intensity in interference patterns. 3.2.5. Explain how interference occurs in thin films. Work out the conditions for constructive and destructive interference.
	3.3. Rigorous application of the concepts of waves and superposition and the technique of phasors to solving problems and answering qualitative questions involving diffraction of light	3.3.1. Define diffraction. 3.3.2. Derive an expression for the positions of destructive interference in a single slit Fraunhofer diffraction pattern. 3.3.3. Derive an expression for the intensity of light in a single slit diffraction pattern as a function of slit width, angle, and wavelength. 3.3.4. Define resolution. State Rayleigh's criterion. for a rectangular slit and for a circular aperture. 3.3.5. Describe a diffraction grating. 3.3.6. Use the formula for the angle at which maxima occur in each order of the diffraction pattern as a function of the wavelength of the light and the slit spacing of the grating.
	3.4. Rigorous application of the concept of polarization and certain laws to solve mathematical problems and answer qualitative questions concerning phenomena involving polarization and polarized light	3.4.1. Define linearly (or plane) polarized light and circularly polarized light. 3.4.2. Describe how light becomes polarized by selective absorption. 3.4.3. State Malus's Law and use it to calculate transmitted intensity when light passes through two or more polarizers. 3.4.4. Explain how light becomes polarized due to reflection. 3.4.5. State Brewster's Law, and use it to calculate the polarizing angle for various substances.
4. To analyze a number of situations using concepts from modern physics: the develop-	4.1. Statement of Planck's hypotheses concerning black body radiation and description of the historical significance of his work	4.1.1. Describe the spectrum of black body radiation. Sketch a graph of it. **[00UU]** 4.1.2. Explain briefly the classical theory of black body radiation and the

Elements of Competency	Specific Performance Criteria	Intermediate Learning Objectives
ment of quantum mechanics		ultraviolet catastrophe. **[00UU]** 4.1.3. State Planck's two assumptions which allowed him to correctly derive the spectral shape of black body radiation and which led to the realization of the "quantization" of energy. **[00UU]** 4.1.4. State Stefan's Law and Wein's Law.
	4.2. Coherent explanation of Einstein's theory of the photoelectric effect and brief description of the historical significance of this work	4.2.1. Define the photoelectric effect. **[00UU]** 4.2.2. List the major observations in this experiment that could not be explained by classical theory. **[00UU]** 4.2.3. State Einstein's theory of the photoelectric effect and show how it can account for each of the previously unexplained observations. 4.2.4. Solve problems involving the wavelength of photons, the work function, maximum kinetic energy of photoelectrons, and cut-off wavelength.
	4.3. Coherent explanation of the Bohr theory of the atom and brief description of its historical significance	4.3.1. Describe atomic emission and absorption spectra. **[00UU]** 4.3.2. Calculate the wavelengths in atomic spectra from the energy level diagrams of hydrogen and other atoms. **[00UU]** 4.3.3. State the basic assumptions of the Bohr theory as it applies to the hydrogen atom. **[00UU]** 4.3.4. *(*) Using these assumptions and concepts from classical physics , derive expressions for the energies of the allowed levels in the hydrogen atom, the ionization energy of the hydrogen atom, and the equation for the wavelengths of the lines in the hydrogen spectrum.* **[00UU]**
	4.4. Correct interpretation of the concept of wave-particle duality	4.4.1. State de Broglie's postulate and describe its historical significance. **[00UU]** 4.4.2. Calculate the wavelength associated with a particle of momentum p or energy E. 4.4.3. Describe the two slit interference pattern for electrons and discuss its interpretation in terms of the interference of two matter waves. 4.4.4. Explain the advantages of an electron microscope over a light microscope. **[00UU]** 4.4.5. State the Heisenberg Uncertainty Principle in terms of position and momentum and in terms of time and energy. **[00UU]**
	4.5. Rigorous application of the concepts, theories and mathematical laws from sections 4.1 through 4.4 to solve mathematical problems and to answer qualitative questions	
	4.6. Basic understanding of the major developments of modern physics presented in the course.	4.6.1. List the major developments of modern physics presented in this course in historical order.

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		4.6.2. Compare and contrast the quantum viewpoint of the twentieth century with the classical view of continuously variable quantities. **[00UU]** 4.6.3. Discuss the impact of the uncertainty principle on classical determinism. **[00UU]**
5. To analyze a number of situations using concepts from modern physics: the physics of the nucleus and radioactivity	5.1. Precise use of terms and correct notation for the description of the nucleus, of radioactivity and of nuclear reactions	5.1.1. Define mass number, atomic number and neutron number for a nucleus, isotope, unified mass unit, binding energy, nuclear fusion and nuclear fission. 5.1.2. Use standard notation in the style ${}^{A}_{Z}X$ to describe nuclei. **[00UU]**
	5.2. Precise description of certain properties of nuclei	5.2.1. Represent a nucleus whose mass number and atomic number are given in standard notation and calculate the number of neutrons in it. 5.2.2. Given the standard notation for a nucleus, determine the number of protons and neutrons in it. 5.2.3. Describe the structure of an atom. 5.2.4. *Describe the phenomenon of nuclear magnetic resonance and its use in medicine* *. **[00UU]**
	5.3. Precise description of the three nuclear decay processes	5.3.1. Define half-life, alpha particle, beta particle, gamma ray, alpha decay, beta decay and gamma decay. 5.3.2. Write an equation describing the alpha, beta or gamma decay of a nucleus using the standard ${}^{A}_{Z}X$ notation. 5.3.3. Write an equation describing the beta plus or beta minus decay of a nucleus using the standard ${}^{A}_{Z}X$ notation. 5.3.4. Explain why the existence of neutrinos and anti-neutrinos was originally hypothesized and list their properties. 5.3.5. Explain the application of beta decay of carbon-14 to date historical artifacts. **[00UU]** 5.3.6. Explain the use of radio-isotopes in medicine. **[00UU]**
	5.4. Rigorous application of the concepts, theories and mathematical laws from sections 5.1 through 5.3 to solve mathematical problems and to answer qualitative questions	
6. To verify experimentally some of the laws and principles associated with oscillatory motion, waves, optics and modern physics	6.1. Careful performance of the laboratory procedures provided	6.1.1. Work cooperatively in a small group to obtain data. 6.1.2. Employ safe procedures and show concern for one's own safety and the safety of others in the lab. 6.1.3. Exercise care in carrying out measurements to obtain the best results possible.
	6.2. Logical analysis of and appropriate mathematical treatment of data	6.2.1. Choose and apply appropriate mathematical, graphical and logical tools.

Elements of Competency	Specific Performance Criteria	Intermediate Learning Objectives
	6.3. Coherent and justifiable conclusions	6.3.1. Understand and apply the principles involved in each experiment. 6.3.2. State clearly the conclusions to be drawn from your analysis and justify them.
	6.4. Proper adherence to course norms for submitting laboratory reports	
	6.5. Competent use of computers	6.5.1. Use computers in the laboratory to gather and analyze data. 6.5.2. Use a computer spreadsheet to perform: • curve-fitting and regression analysis; • modelling and changing parameters; • graphical representation of physical phenomena; and • numerical solutions to Physics problems.

Methodology

1. Lecture presentation and participation in class discussions and activities.
2. Presentation of demonstrations, films.
3. Laboratory experiments
4. Assigned practice problems
5. Use of computer spreadsheets.