Electricity and Magnetism

Objectives:	00US and 00UU	**Discipline:**	Physics
Ponderation:	3-2-3	**Course Code:**	203-NYB-05
Prerequisite:	00UR (*Mechanics*), 00UN (*Calculus I*)	**Course Credit:**	2 2/3
Corequisite:	00UP (*Calculus II*)	**Semester:**	3 (Pure & Applied Profile); 4 (Health Science Profile)

Introduction

Electricity and Magnetism is the third Physics course in the Science Program, taken by Pure and Applied students in their third semester and by Health Science students in their fourth semester. The content of the course is a survey of the fundamental laws of electricity and magnetism, leading up to their synthesis in Maxwell's Equations. As students have completed the differential and integral calculus courses by the time they enroll in this course, the level of mathematics used is quite demanding.

Electricity and magnetism were once thought to be two separate forces - that is, two different ways that objects can push or pull on each other. But in 1820, Oersted noticed that an electric current in a wire can deflect a magnetic compass. Then followed a half-century of intensive study of electric and magnetic effects. Finally in 1873, James Clerk Maxwell was able to formulate four equations that **completely** describe electric and magnetic phenomena. These equations unify electricity and magnetism into a single "electromagnetic" force; their beauty, simplicity and symmetry continue to delight every student who comes to understand them. These equations are as fundamental to electromagnetism as Newton's Laws are to mechanics.

Applications of electromagnetism are all around us. They range from electric motors and generators, through radios, television and computers, to high energy particle accelerators. Medical technology depends heavily on electromagnetism, from high tech magnetic resonance imaging to X-rays and electrocardiograms. It is hardly possible to imagine our world without the wonderful nineteenth century discoveries that were synthesized by Maxwell.

Some of the learning activities in *Electricity and Magnetism* will contribute to the attainment of objective 00UU and are marked **[00UU]**.

In the Science Program, *Electricity and Magnetism* 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	00US, 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
6.	To reason logically	6.1 – 6.4
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 – 13.4
14.	To apply acquired knowledge and skills to new situations	14.1

Objectives and Standards for *Electricity and Magnetism*

In the following chart, italicized items marked with (*) are enrichment items which may or may not be covered a given semester.
(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 different physical situations and phenomena in terms of the fundamental laws of electricity and magnetism	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 diagrams to represent physical situations	
	3. Appropriate use of terminology and units	
	4. Appropriate use of vector techniques	
	5. Competent application of differential and integral calculus to solution of problems	
	6. *Competent use of techniques of algebra and functions in problem solving*	
	7. Accurate graphical and mathematical representations of motion	
	8. Proper justification of the steps taken in analyzing a situation	
	9. Rigorous application of the laws of electricity and magnetism	
	10. Critical judgment of results	
	11. Meticulous experimentation	
	12. Proper interpretation of the limits of model	
	13. Adequate observation of College standards for scientific essays and laboratory reports	

Elements of Competency	Specific Performance Criteria	Intermediate Learning Objectives
1. To analyze physical situations involving static electric charge	1.1. Precise use of the concepts, laws and terminology basic to the understanding of electrostatic phenomena	1.1.1. State Coulomb's Law. 1.1.2. Define the electric field. 1.1.3. State the basic properties of charges, conductors and insulators and apply these concepts to concrete situations. 1.1.4. Explain qualitatively the results of various electrostatic experiments such as charging a conductor by induction.
	1.2. Rigorous application of the concepts and laws of electrostatics to solve problems involving electric fields and forces, and to answer conceptual questions in a way that shows an understanding of these concepts	1.2.1. Calculate the electric field due to several point charges using vector addition. 1.2.2. Derive expressions for the electric field of continuous charge distributions by means of mathematical integration over the charge. 1.2.3. Calculate the trajectory of a charged particle in a constant electric field of any arbitrary direction. 1.2.4. Explain qualitatively how an oscilloscope works. 1.2.5. Set up and solve mathematical problems involving electric fields and forces using appropriate mathematical techniques. 1.2.6. Answer conceptual questions in such a way as to show understanding of the concepts and laws of electrostatics.
	1.3. Proper graphical representation of the electric field by means of electric field lines	1.3.1. State the rules for drawing electric field lines. 1.3.2. Sketch the electric field lines for various charge distributions. 1.3.3. Given the electric field lines representing an electric field, sketch equipotential surfaces. Given equipotential surfaces representing an electric field, sketch electric field lines.
	1.4. Rigorous application of Gauss' Law to solve mathematical problems and to answer conceptual questions about electric fields and electric flux	1.4.1. State Gauss' Law. 1.4.2. Define electric flux through a surface. 1.4.3. Evaluate electric flux through surfaces given the electric field. 1.4.4. Make the symmetry arguments necessary to simplify the Gauss' Law integral. 1.4.5. Derive equations using Gauss' Law for the electric field due to certain symmetrical charge distributions (spherical, cylindrical or planar) 1.4.6. Use Gauss' Law to calculate the charges on the inside and outside surfaces of conductors. 1.4.7. Explain the charge distribution on and electric fields about a conductor in static equilibrium. 1.4.8. Solve mathematical problems involving Gauss' Law and electric flux. 1.4.9. Answer conceptual questions in such a way as to show an understanding of the meaning of Gauss' Law.

Elements of Competency	Specific Performance Criteria	Intermediate Learning Objectives
	1.5. Precise use of the concepts, laws and terminology basic to the understanding of electric potential	1.5.1. State the definition of electric potential difference and of electric potential.
	1.6. Rigorous application of the concepts of electric potential and potential difference to solve mathematical problems and to answer conceptual questions in such a way as to show understanding of these concepts	1.6.1. Calculate potential differences between points in a uniform electric field. 1.6.2. Calculate the electric potential at a point due to several point charges. 1.6.3. Calculate the potential energy of a system of point charges or of a single point charge. 1.6.4. Derive expressions for the electric potential by mathematically integrating over the electric field. Problems may require finding the electric field using Coulomb's or Gauss' Law. 1.6.5. Derive expressions for the electric potential at a point due to a continuous charge distribution by integrating over the charge. 1.6.6. Derive an expression for the electric field given the electric potential as a function of position. 1.6.7. Find potential and potential differences in the presence of conductors. 1.6.8. Set up and solve mathematical problems involving electric fields and electric potentials using appropriate mathematical techniques. 1.6.9. Answer conceptual questions in such a way as to show understanding of the concept of electric potential and its relation to the electric field.
	1.7. Precise use of the concepts, laws and terminology basic to the understanding of capacitance and dielectrics	1.7.1. State the definition of capacitance. 1.7.2. State the definition of dielectric constant.
	1.8. Rigorous application of the concepts of capacitance and dielectrics to solve mathematical problems and to answer conceptual questions	1.8.1. Derive expressions for the capacitance of various geometries — parallel plates, sphere, concentric cylinders. 1.8.2. Find the equivalent capacitance for capacitors in parallel, in series, or in various combinations of parallel and series. 1.8.3. Calculate the charge on, potential difference across, and energy stored on each capacitor in circuits involving various combinations of capacitors. 1.8.4. Solve capacitor problems involving dielectrics. 1.8.5. Set up and solve mathematical problems involving capacitors and dielectrics using appropriate mathematical techniques. 1.8.6. Answer conceptual questions in a way that shows understanding of capacitance, dielectrics, electric fields in capacitors and potential difference.
2. To analyze direct current circuits	2.1. Precise use of the concepts and terminology basic to the understanding of current, resistance and power	2.1.1. State the definition of electric current, current density, resistance and resistivity. 2.1.2. State Ohm's Law.

Elements of Competency	Specific Performance Criteria	Intermediate Learning Objectives
	2.2. Rigorous application of the concepts of current, resistance and power to solve various problems	2.2.1. Calculate the resistance of conductors of various geometries and of different materials, and at different temperatures. 2.2.2. Solve problems involving the interrelation of resistance, voltage, power, current and time. 2.2.3. Answer conceptual questions about these interrelations in a way that shows understanding of the concepts.
	2.3. Rigorous application of Kirchhoff's Rules to the solution of problems involving direct current circuits	2.3.1. State Kirchhoff's Rules. 2.3.2. Calculate terminal voltage and power output for circuits with a source of emf that has an internal resistance. 2.3.3. Solve for current through, voltage across and power dissipated in each resistor in a direct current circuit containing series and parallel combinations of resistors. 2.3.4. Using Kirchhoff's Rules, solve for current through, voltage across and power dissipated in individual elements of a multi-loop circuit with several sources of emf. 2.3.5. Calculate instantaneous voltages across, currents through, charge stored on and energy content of circuit elements in dc circuits with capacitors charging and discharging through a resistance. The circuits may contain series and parallel combinations of resistances and capacitors. 2.3.6. Apply Ohm's Law and circuit theory to explain the workings of the Wheatstone bridge and the potentiometer. 2.3.7. Apply Ohm's Law and circuit theory to calculate the effects of ammeters and voltmeters on the circuits in which they are used. 2.3.8. Answer conceptual questions involving electric current, voltage, resistance, power and the behaviour of series and parallel circuits.
3. To analyze physical situations involving magnetic fields and magnetic induction	3.1. Precise use of the concepts, laws and terminology basic to the understanding of magnetic forces	3.1.1. Define the magnetic field vector $\mathbf{B}$ (also called magnetic flux density or magnetic induction). 3.1.2. State the laws that determine the force on a charged particle in a magnetic field. 3.1.3. Determine the direction of any of the following three vectors in three dimensions (angular or $\hat{i}$, $\hat{j}$ and $\hat{k}$ notation) given the directions of the other two: magnetic force, velocity of a charged particle or current direction in a conductor, and magnetic field.
	3.2. Rigorous application of the laws of magnetic force	3.2.1. Solve problems concerning the motion of charged particles in constant magnetic fields, or in a combination constant magnetic field and constant electric field. 3.2.2. Explain the operation of the mass spectrometer. Perform various calculations concerning the operation of this instrument given

Elements of Competency	Specific Performance Criteria	Intermediate Learning Objectives
		appropriate data. **[00UU]**
		3.2.3. Explain the operation of particle accelerators, particularly the cyclotron and synchrocyclotron. Perform various calculations concerning the operation of this instrument given appropriate data. **[00UU]**
		3.2.4. Explain the operation of an electric motor - AC or DC. Perform various calculations concerning electric motors given appropriate data. **[00UU]**
		3.2.5. Explain qualitatively the Hall effect and its use in the Hall-effect probes used to measure magnetic fields in the laboratory.
		3.2.6. Calculate the force and the torque on current loops and segments in the presence of a magnetic field using vector algebra.
		3.2.7. Set up and solve mathematical problems involving magnetic fields and forces using appropriate mathematical techniques.
		3.2.8. Answer conceptual questions in a way that shows understanding of the concepts of magnetic fields and forces.
	3.3. Precise use of concepts, laws and terminology basic to the understanding of the production of magnetic fields	3.3.1. State the Biot-Savart Law for the determination of magnetic fields. 3.3.2. State Ampère's Law for the determination of magnetic fields. 3.3.3. Define magnetic flux. 3.3.4. State Gauss' Law for magnetism.
	3.4. Rigorous application of the laws (Biot-Savart, Ampère's and Gauss) to solve mathematical problems and answer conceptual questions involving magnetic fields and magnetic forces	3.4.1. Derive expressions for the magnetic fields due to straight or curved current carrying wires using the Biot-Savart Law and integral calculus.
		3.4.2. Derive expressions for the magnetic field due to certain symmetrical current configurations using Ampère's Law, making the necessary symmetry arguments to simplify the integral.
		3.4.3. Calculate the magnitude and direction of the magnetic fields due to combinations of currents.
		3.4.4. Calculate the magnitude and direction of magnetic fields due to current loops, solenoids and toroids.
		3.4.5. Calculate the magnetic flux for a non-uniform magnetic field through a simple area (at any angle) using the techniques of integral calculus.
		3.4.6. Set up and solve mathematical problems involving magnetic fields and forces using appropriate mathematical techniques.
		3.4.7. Answer conceptual questions concerning magnetic fields and forces in a way that shows understanding of the concepts of magnetic fields and forces.

Elements of Competency	Specific Performance Criteria	Intermediate Learning Objectives
	3.5. Precise use of the concepts, laws and terminology basic to the understanding of electromagnetic induction	3.5.1. State Faraday's Law of Inductance. 3.5.2. State Lenz's Law. 3.5.3. Define self-inductance. 3.5.4. Define mutual inductance.
	3.6. Rigorous application of the concepts and laws describing electromagnetic induction to solve mathematical problems and to answer conceptual questions in a way that shows understanding of them	3.6.1. Derive an expression for the emf induced in a loop by different time-varying magnetic fluxes. 3.6.2. Determine the emf produced in wires moving through magnetic fields, both uniform and non-uniform fields. 3.6.3. Apply Lenz's Law in three dimensions to determine the direction of induced current in a loop under various conditions of varying magnetic flux (changing magnetic field strength, changing area, or changing angle). 3.6.4. Describe the functioning of electric generators. **[00UU]** 3.6.5. Calculate back emf in an electric motor and explain its cause. 3.6.6. Set up and solve mathematical problems involving magnetic inductance using appropriate mathematical techniques. 3.6.7. Answer conceptual questions concerning induced currents in a way that shows understanding of the concepts of electromagnetic induction. 3.6.8. Determine the self-inductance of a solenoid. 3.6.9. Calculate as a function of time the instantaneous voltage across, the current through, and energy stored in the individual elements of a simple circuit consisting of inductors, resistances, a source of emf and a switch. 3.6.10. Determine circuit conditions, initially and after a long time has elapsed, for more complex circuits containing inductors, capacitors, resistances, a source of emf and a switch. 3.6.11. Set up and solve mathematical problems involving circuits containing combinations of inductors and resistances using appropriate mathematical techniques. 3.6.12. Answer conceptual questions concerning R-L circuits in a way that shows understanding of the concepts of inductance and circuit theory. 3.6.13. Explain the synthesis of the laws of electricity and magnetism into Maxwell's equations.
4. To analyze alternating current circuits	4.1. Precise use of the concepts, laws and terminology basic to the understanding of alternating current circuits	4.1.1. State the definition of ac voltage. 4.1.2. Define impedance. 4.1.3. Define reactance.
	4.2. Rigorous application of the concepts and rules governing alternating current circuits to solve	4.2.1. Calculate the impedance (reactance and resistance) of circuits containing resistors, capacitors and inductors in series.

Elements of Competency	Specific Performance Criteria	Intermediate Learning Objectives
	mathematical problems and to answer conceptual questions in a way that shows understanding of these concepts and rules	4.2.2. Calculate the current and voltage and their phase relation in an RLC circuit using phasors. 4.2.3. Calculate the power dissipated in an RLC circuit with an alternating current flowing in it. 4.2.4. Calculate voltage, current and power in a simple transformer circuit. 4.2.5. Set up and solve mathematical problems involving RLC ac circuits using appropriate mathematical techniques including phasors. 4.2.6. Answer conceptual questions about RLC ac circuits in a way that shows understanding of the concepts involved.
5. To verify experimentally some of the laws of electricity and magnetism	5.1. Proper interpretation of schematic circuit diagrams	5.1.1. Wire a circuit correctly given a schematic diagram. 5.1.2. Draw a correct schematic diagram for a circuit given a written description of the circuit.
	5.2. Proper use of measuring instruments	5.2.1. Connect analog and digital voltmeters, ammeters, and ohmmeters correctly in a circuit. 5.2.2. Use a computer with appropriate interfaces, data collection and analysis software to gather and analyze data from certain experiments.
	5.3. Proper adherence to course norms for submitting laboratory reports	5.3.1. Estimate the margin of uncertainty in experimental measurements. 5.3.2. Calculate the uncertainty in calculated results using simple equations governing the propagation of uncertainty. 5.3.3. Present data in proper tabular and graphical form. 5.3.4. Present an appropriate conclusion based on the results of experiments. 5.3.5. Write a laboratory report using a style appropriate to technical writing in English.

Methodology

Electricity and Magnetism is presented in a series of lectures, labs and demonstrations. Emphasis is placed on developing a good understanding of the principles introduced in the course and facility in the setting up and solving of problems. Differential and integral calculus and vector techniques are used extensively as a problem solving tools. Applications to instruments such as mass spectrometers and particle accelerators and devices such as generators and motors are introduced to link the theoretical material in the course to other disciplines and to "real life" situations.