

# AP<sup>®</sup> Physics C Electricity and Magnetism Syllabus

## 1 Prerequisites and Purposes of AP<sup>®</sup> C E & M

AP<sup>®</sup> Physics C Electricity and Magnetism is the second course in a two-course sequence. It is offered in the second semester to students who have completed AP<sup>®</sup> C Mechanics and who have completed or are enrolled concurrently in an AP<sup>®</sup> Calculus course. AP<sup>®</sup> Physics C Electricity and Magnetism assumes students have understood the content of Physics 163 or Physics 173. Differential and integral calculus are freely used throughout AP<sup>®</sup> Physics C Electricity and Magnetism. AP<sup>®</sup> Physics C Electricity and Magnetism completes a sequence beginning with AP<sup>®</sup> Physics C Mechanics, which is offered in the first semester. Together, AP<sup>®</sup> Physics C Mechanics and AP<sup>®</sup> Physics C Electricity and Magnetism correspond roughly to a year of University Physics.

AP<sup>®</sup> Physics C Electricity and Magnetism affords students an opportunity to increase their ability to use fundamental models in classical electricity and magnetism to describe and explain nature and also to earn university credit. In practice, many prospective science and engineering students use AP<sup>®</sup> Physics C to gain excellent preparation for their required introductory physics courses in university while students who aspire to non-science majors often apply any credit earned toward fulfillment of the science requirement of their undergraduate degree.

## 2 Textbook

*Fundamentals of Physics*, 7<sup>th</sup> edition, by Halliday, Resnick, and Walker (Wiley, 2005), is the textbook for both AP<sup>®</sup> C Mechanics and AP<sup>®</sup> C Electricity and Magnetism. It is a standard textbook for University Physics courses for science and engineering majors and meets all requirements for AP<sup>®</sup> Physics C Electricity and Magnetism.

## 3 Course Design

The goal of AP<sup>®</sup> Physics C is to provide students with an outstanding education in introductory physics at the university level. The content of the course is defined by a small set of core models, some of which were developed and used in Physics 163 and 173. The method of instruction is described by a modeling cycle. In general, a modeling cycle begins with the introduction of a model basic to the course, by way of experiment when possible. Subsequently, students refine their understanding of this model as they use it to solve problems and to conduct experiments in which they use the model to describe, explain, predict, and design various phenomena and apparatus. AP<sup>®</sup> Physics C Electricity and Magnetism meets every school day with class meetings alternating between 90 minutes and 45 minutes. Quizzes are used routinely for formative assessment.

### 3.1 Experiments

Laboratory experiments are essential to physics and to learning physics. They are therefore components of AP<sup>®</sup> Physics C Electricity and Magnetism. Out of the 84 class periods in a semester, we will spend about 20 of them doing experimental work. Each student will keep a laboratory journal including a neat record of actions, equipment, and observations during experiments as well as final, formal lab reports. In this course there are three basic kinds of experiments. First, there are experiments in which a model fundamental to the phenomena targeted by this course is developed. Second, there are experiments in which a familiar model is used to make a prediction or to calculate some desired value. Third, there are experiments in which important laboratory equipment or skills are introduced.

Typically the goal of an experiment will be framed through class discussion focused on some phenomenon presented to them. Students will identify the salient variables that characterize the phenomenon from which related variables are selected for experimental investigation. Then they will be introduced to equipment that is available that may be of use in determining the relationships of interest. Following student discussion about experimental methods that may be considered, students will be assigned to groups of two or three to design and conduct their experiments. Upon completion of their experimental work and preliminary analysis, students will reconvene for whiteboard presentations and discussion of their findings. Once difficulties and questions are addressed and a valid consensus is reached, students will generally write a formal report.

### 3.2 Using Models in Problem-Solving and in Activities

Questions to answer and problems to solve will be provided by the instructor and assigned from the textbook. These are intended to refine and deepen students' understanding of their models, of how these models account for a wide variety of phenomena, and of the classical theory governing the models. These questions and problems also develop students' mathematical skill. On the day assigned problems are due, they will be checked in by the instructor and returned to students. Students will be assigned to groups of two or three to present their solutions to the class on whiteboards. Students may make comments and corrections on their assignments as needed during presentations. After presentations are completed for an assignment, students will turn in the final version of their solutions for grading.

When appropriate, students will also solve and present solutions to released Free Response problems from previous AP<sup>®</sup> exams. Furthermore, when the opportunity presents itself, students will work with laboratory equipment to answer a question or meet a challenge.

## 4 Assessment

Grades will be determined from an assortment of assignments including homework problems, quizzes, lab notebook, formal lab reports, projects, and exams. Daily quizzes based on reading assignments will be given. These quizzes are intended to determine if you have read the text with

understanding. Grades are calculated as the percentage of points earned out of the total possible. Typically about 30% of points are from exams, 15% from quizzes, 35% from homework, and 20% from lab reports and projects.

## 5 Course Outline

### 1. The roles of electric fields (Week 1)

- (a) Reading: Fields, Forces, Energy, and Potentials in Physics
- (b) Exerting forces:  $\mathbf{F} = q\mathbf{E}$
- (c) Storing energy:  $U = qV$
- (d) **Experiment:** Mapping electric potentials in two dimensions for various configurations (2 days, hands on)
- (e) The relationship between field and potential:  $\mathbf{E} = -\left(\frac{\partial V}{\partial x}\hat{\mathbf{i}} + \frac{\partial V}{\partial y}\hat{\mathbf{j}} + \frac{\partial V}{\partial z}\hat{\mathbf{k}}\right)$

### 2. Metallic bond model for metals; covalent bond model for dielectrics (Week 1)

- (a) Reading: Atomic-scale models for materials: metals and covalently bonded materials
- (b) Electroscopes
- (c) Electrophorus
- (d) Triboelectric series
- (e) **Experiment:** Explaining the positioning of static electric charge in metals and dielectrics with electric forces and potential (1 day, hands on)
- (f) **Project:** Selection of wave or light phenomenon to study for end-of-semester project

### 3. Modeling electric fields using Coulomb's Law (Weeks 2 & 3)

- (a) Chapter 22 Assignments
  - i. 22a pp. 598-604: 1, 3, 6, 7, 12, 13
  - ii. 22b pp. 598-604: 32, 39, 17, 19
- (b) Field created by an electrically charged particle
  - i. Field line representation
  - ii. Equipotential line representation
  - iii. Vector field representation
  - iv. Mathematical representation: Coulomb's Law
- (c) Field created by two electrically charged particles
  - i. The field created by identically charged particles in various representations
  - ii. The field created by oppositely charged particles: the electric dipole in various representations
- (d) The field created by extended distributions of charge
  - i. Field of linear segment of uniformly charged material
  - ii. Field at center of circular arc of uniformly charged material

- iii. Axial field of charged ring
- iv. Axial field of charged disk
- (e) Electric dipole in a uniform electric field
  - i. Describing an electric dipole: Dipole moment
  - ii. Explaining the motion of a dipole moment
    - A. Forces and torques
    - B. Energy

#### 4. Modeling electric fields using Gauss' Law (Weeks 4 and 5)

- (a) Chapter 23 Assignments  
(Charged particles as projectiles in a uniform  $\mathbf{E}$  field were dealt with in Mechanics.)
  - i. 23b pp. 620-621: 3, 4, 5, 7, 10
  - ii. 23c pp. 621-627: 2, 4, 18, 25, 26
  - iii. 23d pp. 621-627: 29, 43, 44, 45
- (b) Electric flux
- (c) Gauss' Law
- (d) Fields produced by a charged conductor
  - i. inside
    - A.  $\mathbf{E} = 0$
    - B.  $V = \text{constant}$
  - ii. outside
    - A.  $\mathbf{E}$  is normal to surface
    - B. Surface is an equipotential in static state
- (e) Field produced by charged metal plate
  - i. Isolated metal plate
  - ii. Pair of oppositely charged metal plates
- (f) Field produced by uniformly charged dielectric sheet
- (g) Field produced by linear charged distribution
  - i. Wire
  - ii. Cylinder
- (h) Field produced by a spherically symmetric charge distribution
  - i. Particle
  - ii. Sphere

#### 5. Describing electric fields using electric potential (Week 6)

- (a) Chapter 24 Assignments
  - i. 24a pp. 646-647: 2, 4, 6, 7, 8
  - ii. 24b pp. 647-655: 3, 4, 7, 9, 33, 37
- (b) Calculating  $V$  from  $\mathbf{E}$ :  $V_{a,b} = -\int_a^b \mathbf{E} \cdot d\mathbf{l}$ 
  - i. Potential due to a charged particle

- ii. Potential due to an electric dipole
- iii. Potential due to a linear segment of charge
- iv. Axial potential due to a ring of charge
- v. Axial potential due to a charged disk
- vi. Potential due to a spherical distribution of charge
  - A. Metal sphere
  - B. Dielectric sphere
- (c) Electric potential energy in a system of charged particles
  - i. General charged particles
  - ii. **Experiment:** Determining  $\alpha$  particle KE in cloud chamber, given data leading to ionization energy (w-value) for air molecules, Hans Geiger's 1909 ionization data for  $\alpha$  particles in air, and  ${}^{210}_{84}\text{Po}$  sample in cloud chamber. Goal is to provide evidence for tunneling ( $\alpha$ 's  $r_0 \approx 6r_{\text{nucleus}}$ ) and a limit to the validity of classical concepts. (2 days + postlab, hands on, some data provided for analysis)

## 6. Modeling capacitors (Week 7)

- (a) Chapter 25 Assignments
  - i. 25a pp. 674-675: 2, 3, 4, 5, 7, 8, 9
  - ii. 25b pp. 675-681: 5, 8, 10, 12, 22, 36
- (b) Capacitor models
  - i. Parallel-plate capacitor
  - ii. Cylindrical capacitor
  - iii. Spherical capacitor
- (c) Capacitors in a DC circuit
  - i. Series
  - ii. Parallel
- (d) Energy stored in electric fields
- (e) Capacitors containing dielectrics

## 7. Electric fields in metals (Week 8)

- (a) Chapter 26 Assignments
  - i. 26a pp. 700-704: 4, 12, 15, 17, 20
  - ii. 26b pp. 700-704: 31, 32, 33, 34, 35, 36, 9, 26
- (b) Metallic bond model for metals
- (c) Conventional current
- (d) Model for metals elaborated
  - i. Current density
  - ii. Drift velocity
  - iii. Resistivity
- (e) **Experiment:**  $i - V$  curves for nichrome, diodes, and light bulbs (2 days, hands on)

- (f) **Experiment:** How the current through the filament of a lamp, the resistance of the filament, its temperature, and the power supplied to it vary with the potential difference across it. (2 days + 1 day postlab discussion, hands on)
- (g) Drude model for metals
- (h) Energy transfers in electric circuits
  - i. Energy transfer in power supply
  - ii. Potential energy associated with electrons “falling” through circuit
    - A. In wire
    - B. In resistor

## 8. Electric Circuits: Systems of models (Week 9)

- (a) Chapter 27 Assignments
  - i. 27a pp. 724-725: Questions 1, 2, 3; Problems 2, 4, 5, 10, 18
  - ii. 27b pp. 725-734: 17, 21, 23, 31, 32, 33, 51, 55
- (b) Ideal power supply
- (c) Real battery
  - i. Chemical energy lost
  - ii. Thermal energy gained (internal resistance)
  - iii. Electrical energy gained
- (d) Tracking conserved quantities in circuits
  - i. Energy: Kirchoff’s Loop Rule
  - ii. Charge: Kirchoff’s Junction Rule
- (e) Single and Multiloop Circuit Analysis
- (f)  $RC$  Circuits
  - i. Kirchoff’s Loop Rule: a differential equation
  - ii. Solving for  $q(t)$ 
    - A. Charging
    - B. Discharging
- (g) **Experiment:** Determining  $C$  by measuring  $RC$  (1 day, hands on)
- (h) **Experiment:** How flash rate depends on  $R$  and  $C$  in a simple relaxation oscillator (1 day, hands on)

## 9. Forces caused by magnetic fields (Week 10)

- (a) Chapter 28 Assignment
 

(Note that  $\mathbf{F} = q\mathbf{v} \times \mathbf{B}$  was introduced and used in Mechanics along with other instances in which there was a central net force. Crossed  $\mathbf{E}$  and  $\mathbf{B}$  fields were also dealt with in Mechanics along with other zero-net-force situations.)

  - i. 28d pp. 758-763: 16, 34, 35, 39, 48, 37, 47
- (b) Describing a magnetic field
  - i. Source
  - ii. Strength

- iii. Direction
- (c) Newtonian interaction laws
  - i. Forces on individual, moving charged particles:  $\mathbf{F} = q\mathbf{v} \times \mathbf{B}$
  - ii. Forces on currents:  $\mathbf{F} = i\mathbf{l} \times \mathbf{B}$ 
    - A. Forces on straight wires
    - B. Forces on loops of current
    - C. Potential energy in loop-field system
- (d) **Experiment:** Building a simple electric motor (2 days, hands on)
- (e) Hall effect

## 10. Models of magnetic fields created by currents (Week 10)

- (a) Chapter 29 Assignments
  - i. 29a pp. 781-782: Questions 1, 2, 3; Problems 1, 2, 4, 6, 8, 9, 10
  - ii. 29b pp. 782-790: 23, 30, 31, 40, 43
  - iii. 29c pp. 782-790: 29, 32, 50
- (b) Modeling magnetic fields using the Law of Biot-Savart
  - i. Fields due to straight currents
  - ii. Fields due to circular currents
- (c) **Experiment:** Measuring the magnetic field in and around a solenoid (2 days, hands on)
- (d) Modeling magnetic fields using Ampère's Law
  - i. Fields created by straight currents
    - A. Outside of wire
    - B. Within wire
  - ii. Fields created by solenoids
  - iii. Fields created by toroids

## 11. Faraday's Law: Modeling electric fields created by changing magnetic fields (Weeks 11 & 12)

- (a) Chapter 30 Assignments
  - i. 30a pp. 816-817: Questions 3, 4, 7, 8, 9
  - ii. 30b pp. 817-825: Problems 1, 2, 4, 7, 27, 32,
  - iii. 30c pp. 817-825: 40, 41, 42, 46, 47, 49
  - iv. 30d pp. 817-825: 8, 17, 18, 24, 28, 53, 54
- (b) Faraday's Law described
  - i. Magnetic flux
  - ii. Induced emf
  - iii. Lenz's rule
- (c) Energy transfers due to electromagnetic induction
- (d) Faraday's Law explained: Induced electric fields

- i. Closed loops
- ii. Solenoids
- iii. Toroids
- (e) Faraday's Law explained: Motional emf
- (f)  $RL$  circuits
  - i. Kirchoff's loop rule: A differential equation
  - ii. Solving for  $i(t)$
- (g) Energy stored in magnetic fields

## 12. LC Circuits (Week 12)

- (a) Chapter 31 Assignment
  - i. 31a pp. 853-854: Questions 3, 5, 6
  - ii. 31b pp. 853-854: Problems 1, 2, 3, 4, 8, 11, 13
- (b) Kirchoff's loop rule: A differential equation
- (c) Solving for  $q(t)$  for capacitors in  $LC$  circuits: An SHO analog
- (d) **Experiment:** Electromagnetic oscillations in an  $RLC$  circuit (2 days + 1 day postlab discussion, hands on)

## 13. Maxwell's Equations: Core theory for electric and magnetic systems (Week 13)

Chapter 32 Assignment

32a pp. 884-885: 3, 16

Gauss's law (E)	$\oiint \mathbf{E} \cdot d\mathbf{A} = \frac{q_{encl}}{\epsilon_0}$
Gauss's law (B)	$\oiint \mathbf{B} \cdot d\mathbf{A} = 0$
Faraday's law	$\oint \mathbf{E} \cdot d\mathbf{l} = \frac{d\phi_B}{dt}$
Ampere-Maxwell law	$\oint \mathbf{B} \cdot d\mathbf{l} = \mu_0 \epsilon_0 \frac{d\phi_E}{dt} + \mu_0 i_{encl}$

## 14. AP Exam (Week 15)

## 15. Wave and Light Projects (Weeks 16 & 17)

Students demonstrate phenomenon and findings to class and turn in a report resulting from their investigation of a wave or light phenomenon.