

### STUDY GUIDE #4

In this part of the course we will study the following topics:

- Motion of a charged particle in a magnetic field (mass spectrometer)
- Magnetic field of a current element, and of straight wires, circular loops and solenoids (magnetic field in an MRI machine)
- Force between current carrying conductors (magnetic levitation and transportation)
- Faraday's Law of electromagnetic induction (computer read heads)

One application of each topic is mentioned in brackets after it. At the end of this course, you should be able to explain the qualitative basis of each of these applications and also carry out the simplest calculations connected with some of them. The applications of electric and magnetic fields, and the devices based on them, are almost endless: xerox machines, laser printers, van de Graaf generators, electrostatic precipitators, camera flash units, television picture tubes, magnetic credit cards, computer hard drives... . You will find the workings of many of these devices scattered throughout your text.

The main laws of electromagnetism, which are associated with the names of Coulomb, Gauss, Ampere and Faraday, can be summarized in a set of four differential equations known as Maxwell's equations. Maxwell's equations provide an explanation of all known electromagnetic phenomena, including light and all other types of electromagnetic radiation (such as radio waves, microwaves and x-rays). Along with Newton's laws of motion and Newton's law of universal gravitation, Maxwell's equations are one of the crowning achievements of classical (i.e. pre-twentieth century) physics. Those of you who take a more advanced course in electromagnetism will certainly have the opportunity to meet and learn about Maxwell's equations.

*Nature and Nature's laws lay hid in night,  
God said: "Let Newton be!", and all was light.*

*Alexander Pope (1688-1744)*

Has any poet composed a similar tribute to Maxwell?

**Please note that the objectives for this part of the course will be covered in the order indicated below. Both the numbers attached to the objectives, as well as the order in which they are covered, may differ slightly from that indicated in the Syllabus/Calendar sheet.**

#### **Objective 17: Motion of a charged particle in a uniform magnetic field**

- (a) Be familiar with all aspects of the circular motion of a charged particle in a uniform magnetic field. Also understand how helical motion can arise in a uniform magnetic field.
- (b) Understand the working of the velocity selector and mass spectrometer.

*Suggested Study Procedure for Objective 17:*

Read Ch.27-4 for Obj 17(a) and study both the worked examples at the end of this section. Read Ch.27-5 for Obj 17(b) and study both the worked examples at the end of this section.

*Suggested Problems for Objective 17:*

Problems 27-15,21,26,27,29,59,63,69\*,70\* (starred problems are a bit more challenging).

### **Objective 18: Biot-Savart Law**

(a) Know how to calculate the magnetic field at any point in space due to a current element at a given location using the Biot-Savart law.

(b) Know how to calculate the magnetic field at any point in space due to an infinitely long current carrying wire.

*Suggested Study Procedure for Objective 18:*

Read Ch.28-1 and 2 for Obj 18(a). We will be concerned mainly with the fields of current elements, described by Equations (28.6) and (28.7) of the text. Equation (28.2) is useful as background for this development, but we will not use it. You can therefore skip over worked example 28.1, but everyone should read worked example 28.2. Read Ch.28-3 for Obj 18(b) and study both the worked examples at the end of this section.

*Suggested Problems for Objective 18:*

Problems 28-7,8,11,14,17,18,54,55

### **Objective 19: Forces between parallel conductors**

(a) Know how to calculate the force between two parallel conductors carrying currents in the same or opposite directions.

(b) Know how to calculate the force on a conductor due to any number of parallel current carrying conductors using the principle of superposition.

*Suggested Study Procedure for Objective 19:*

Read Ch.28-4 and study both worked examples at the end of this section.

*Suggested Problems for Objective 19:*

Problems 28-20,22,59,61

### **Objective 20: Magnetic fields of simple current configurations**

(a) Know the magnetic field at the center of a circular current loop, and understand qualitatively how the field varies along the axis.

(b) Know how to use the superposition principle to calculate the magnetic field at a point in space due to a combination of wires consisting of straight and circular portions.

(c) Understand the depiction of magnetic fields in space by magnetic field lines

*Suggested Study Procedure for Objective 20:*

Read Ch.28-5, taking note of the important Eq.(28.17). You should also understand the character of the on-axis field described by Eq.(28.15) even if you are a little uneasy with the integral that leads to it.

*Suggested Problems for Objective 20:*  
Problems 28-24,27,29,64,68,74

**Objective 21: Magnetic field of a solenoid**

Know the nature of the magnetic field inside an ideal solenoid and understand how it depends on the geometry of the solenoid and the current in its windings.

*Suggested Study Procedure for Objective 21:*

Study Example 28.10. You will be unable to understand the derivation of the solenoid field based on Ampere's Law, because we will not discuss this law in class. However you should understand what the crucial formula (28.3) says and know how to apply it in practice. A qualitative justification of Eq.(28.23) will be presented in lecture.

*Suggested Problems for Objective 21:*  
Problems 28-34,35,36

**Objective 22: Magnetic flux**

Understand the meaning of magnetic flux and know how to calculate it for a planar surface of arbitrary shape oriented at an arbitrary angle to a uniform magnetic field.

*Suggested Study Procedure for Objective 22:*

Go back to Ch.27 and read Section 27-3 "Magnetic field lines and magnetic flux". Pay particular attention to all the equations and remarks on p.1027. You can ignore Gauss' law of magnetism, given in Eq.(27.8).

*Suggested Problems for Objective 22:*  
Problems 27-12,13

**Objective 23: Faraday's law and Lenz's law**

(a) Know how the magnitude of the induced emf around a closed loop depends on the changing magnetic flux through that loop (Faraday's law). Note that an induced emf can arise around a closed loop in a variety of ways:

- (1) because the magnetic field through the loop changes with time
- (2) because the area of the loop changes with time
- (3) because the angle between the loop and the magnetic field changes with time
- (4) through a combination of two or more of the above factors

You should be familiar with each of the above cases and know how to treat them.

(b) Know how to determine the direction of the induced emf, and the resulting current if there is one, through a closed loop in a changing magnetic field (Lenz's law).

*Suggested Study Procedure for Objective 23:*

Read Ch.29-1,2 for Obj 24(a). The worked examples in this chapter are especially important because they illustrate all the main principles and your conference time is limited. Study examples 29.1,2 and 3 and pay attention to the Problem Solving Strategy for Faraday's law at the top of p.1112. You may skip over examples 29.4 and 5, which may be too much for some of you.

However look at examples 29.6 and 7. Understanding these worked examples should help you solve many of the assigned problems.

Read Ch.29-3 for Obj 24(b). Note that pp.1110-1 of the previous section also gives an easily applied method for determining the direction of the induced emf (and current). Study Conceptual Examples 29.8 and 9.

Those of you who would like to see what Maxwell's equations look like can see all four of them given, in integral form, on p.1131. Those of you who would like to read something about Maxwell can visit the website:

<http://www-groups.dcs.st-and.ac.uk/~history/Mathematicians/Maxwell.html>

*Suggested Problems for Objective 23:*

Problems 29-3,4,11 (changing B); 29-9,25,53,64,65\*,69\* (changing area);  
29-1,2,5,50 (changing orientation); 29-15,16,17,18,19 (Lenz's law).

Starred problems may require integration or more careful thinking.

### **Homework Assignment #13 (due Mon 12/8)**

This assignment is to be submitted via the web. In your web browser, go to [www.masteringphysics.com](http://www.masteringphysics.com). Then login with the username and password you have chosen. After logging in, click on Assignment List and select Assignment #13. As before, you will get 4 chances to submit the correct answer. If your first answer is incorrect, you should consider making use of the hints.

### **Homework Assignment #14 (due Wed 12/10)**

Problems 28-9,12,21.

### **Homework Assignment #15 (due Fri 12/12)**

Problems 28-28,67,37.

### **Homework Assignment #16 (due Mon 12/15)**

Problems 27-11, 29-6,24 (see worked examples 29.6,7).