

## Advanced General Physics 323/324

### Electricity and Magnetism Unit E3: Magnetostatics

**Prerequisite: E2**

#### **Overview**

When we discussed electrostatics we dealt with a situation in which all the charges are stationary. When we discussed currents we had moving charges and just assumed that the same electrostatic forces held. This is, in fact, true, but when charges move there is in addition a new phenomenon called magnetism which is introduced in this unit. Recall that we can treat the forces in electrostatics in two steps: source charges produce electric fields which then act on other charges. Here we find that moving source charges produce magnetic fields which act on other moving charges. The CGS units used by Purcell are also used for the most part in the discussions here and in the quizzes. More information on the SI (MKS) units used in most more recent books can be found in the asides in Purcell, while a conversion table can be found in Appendix E there. Some of the more mathematically complex sections (for example the discussion of the magnetic vector potential) will be skipped.

**Magnetic Fields and Forces on Currents and Moving Charges Read:**

E. M. Purcell, *Electricity and Magnetism, Berkeley Physics Course, Vol. 2, 2nd Ed.* , Chap. 5 - The Fields of Moving Charges, Sec. 5.1-5.2, ;Chap. 6 - The Magnetic Field, Sec. 6.1-6.2, 6.4 (begin with p. 225), 6.5; study Problem 6.22 and the solution to it below; read the last paragraph of p. 407 ending at the top of p. 408 and study Fig. 11.5.

#### **Understand:**

(a) How the concept of a magnetic field acts as an intermediary in determining the force between currents, just as the electric field acts as an intermediary in determining the force between charges.

(b) The magnetic field due to a current element (magnitude and direction).

(c) The magnitude and direction of the force on a current element placed in a magnetic field .

(d) The field due to a whole wire in some simple cases.

(e) Magnetic field lines.

(f) Ampere's Law .

We have no deeper explanation for any of these facts. Investigations aimed at the foundations of the subject have been conducted over the years and are still being conducted: for example, the equality of the magnitudes of the charges of the electron and proton have been tested with ever increasing accuracy. Experiments have been and are still being conducted at the world's largest accelerators to search for particles with non-integral charges. Current theories of particle physics suggest that there are particles called quarks with  $1/3$  or  $2/3$  the charge of the electron. The size of the electron charge and the relation of the electromagnetic force to the other forces in the universe are still among the greatest puzzles in physics.

**Conservation of Charge:** Although charge can move and change, the total amount of charges remains constant. For example, if an electron (charge  $-e$ ) interacts with a positron (an anti-electron with charge  $+e$ ) the two particles can annihilate, resulting in two chargeless gamma rays. The algebraic sum of the total charge, however, is zero before and after the reaction. For situations where there is a continuous distribution of charge of density (charge per volume)  $\rho$ , there is an associated current density  $\mathbf{j} = \rho\mathbf{v}$ , where  $\mathbf{v}$  is the velocity with which the charge moves. Now consider a certain volume of space  $V$  surrounded by a closed surface  $S$ . Then

$$i = \oint_S \mathbf{j} \cdot d\mathbf{S}$$

is the rate at which charge moves out of the

is the net rate at which charge leaves the volume  $V$ . (We assume that  $d\mathbf{S}$  is in the direction of the *outward* normal to the surface.) The total amount of charge  $q$  in the volume, however, is just

$$q = \int_V \rho dV.$$

Therefore we must have

$$i = -dq/dt,$$

the minus sign accounting for the fact that if charge is escaping out through the surface  $S$  ( $i$  positive) then the total amount of charge in the volume  $V$  surrounded by the surface must be decreasing. In terms of the surface and volume integrals this gives the "equation of continuity":

$$\oint_S \mathbf{j} \cdot d\mathbf{S} = - \int_V \rho dV.$$

This expresses the connection between current and charge density that must hold if charge is to be conserved.

**Problems:** Chap. 6: 1,2,,4,11,24

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