

**COURSE TITLE: ELECTROMAGNETIC THEORY I**

**COURSE CODE: ELE 303**

**COURSE UNIT: 3**

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Electrostatic fields due to distribution of charge, Magnetic fields in and around current carrying conductors. Review of electromagnetic laws in integral form; Gauss's law Ampere's and Laplace's equations and methods of solution. Boundary values problems.

**Electrostatic fields due to distribution charge, Magnetic fields in and around current carrying conductors:** The source of electrostatic vector field is static (fixed) electric charge can be spatially distributed in many ways. The source of the magnetostatic vector field is electric charge moving without acceleration (steady electric current). These fields are obtained from two famous experimental laws: Coulomb's and the Biot-Savart law, respectively. The fields are introduced by means of these laws. These laws lead to superposition to integrals for determining the electrostatic and magnetostatic fields from completely general charge and current distributions, respectively.

**Coulomb's law and Electric Field Intensity:** Considering two point charges  $Q_1$  and  $Q$  as shown below. Consider  $Q_1$  to be the source of a vector force field  $F$ , and this force (the response) is exerted on the second charge  $Q$ . Coulomb's law gives the force on  $Q$  due to  $Q_1$  as:

$$F = \frac{Q_1 Q (r - r')}{4\pi\epsilon_0 |r - r'|^3} \quad (\text{N}) \quad \text{Coulomb's law}$$

$\epsilon_0 \approx 8.85 \times 10^{-9}$  is a constant called the permittivity of vacuum (or free space) (F/m)

Coulomb's law can also be written:

$$F = \frac{Q_1 Q a_R}{4\pi\epsilon_0 R^2}$$

Where  $a_R = (r - r')/|r - r'|$  and  $R = |r - r'|$

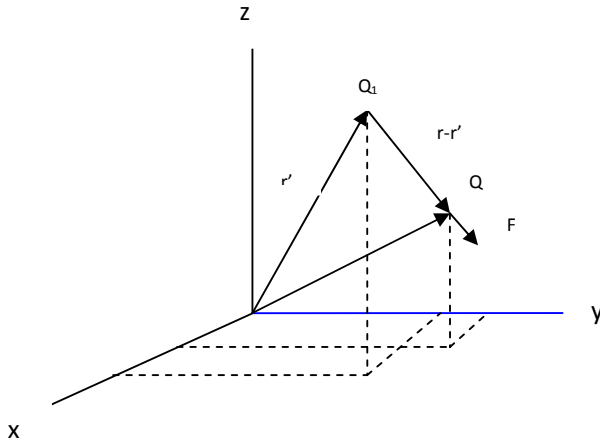


Figure 1.1 Geometry for two point charges for finding the force on Q due to Q<sub>1</sub> (Coulomb's law)

The electrostatic field intensity E is defined as the force on Q when Q= 1C. That is, it is the force per unit charge (newtons/coulomb= volts/meter). Therefore  $E = F/Q$  becomes

$$E = \frac{Q_1 a_R}{4\pi\epsilon_0 R^2} \text{ (V/m)}$$

### The Electrostatic potential Field

The electric field was defined as the force on a unit positive charge, so force on any point charge Q in arbitrary electric field is:  $F= QE$  (N).

Since work is force times distance, the incremental work done by the external source is:

$$\Delta W = -QE \cdot a_1 \Delta l = -QE \cdot \Delta l \text{ (J)}.$$

The unit of force is the newton and the unit of work is joule.

### GAUSS'S LAW

Electric flux density, symbolized by D, is related to electric field intensity in a very simple manner for a vacuum:

$$D = \epsilon_0 E \text{ (C/m}^2\text{)}$$

Where  $\epsilon_0$ , the permittivity of a vacuum. Gauss's law states that the net flux of D, or electric flux, symbolized by  $\Psi_E$ , out of any closed surface is equal to the net positive charge enclosed by that surface, or

$$\Psi_E = Q \text{ (C) Gauss's law}$$

$$\oint_S D \cdot ds = \iiint_{vol} \rho_v dv \text{ Gauss's law}$$

Where the volume for the integral on the right is that within the surface of the left integral even though  $\rho_v$  may be zero in some smaller volumes within the original.

### Dielectrics

Materials can be broadly classified into four types:

1. If the characteristics of the material do not depend on position (x,y,z), the material is said to be homogeneous.
2. If the characteristics of the material are independent of the direction of the vector fields, material is isotropic.
3. If the parameters of the material do not depend on the magnitude of the field quantities, then the material is linear.
4. In general the parameters of a material may be frequency-dependent.

### Biot-Savart law and Magnetic Field Intensity

Force given in differential form being due to differential current elements. The differential force on dQ is  $d(dF) = \frac{\mu_0 u dQ \times (u_1 dQ_1 \times a_R)}{4\pi R^2}$  (N)

Where the constant  $\mu_0$  is

$$\mu_0 = 4\pi \times 10^{-7} \text{ (H/m)}$$

and is called the permeability of free space.

The magnetic flux density B is related to the magnetic field intensity H (in a vacuum) by:

$$B = \mu_0 H \text{ (Wb/m}^2\text{)}$$

$$H = B/\mu_0 \text{ (A/m)}$$

The Biot-Savart law is usually stated in terms of H,

$$dH(r) = \frac{1 dl(r') \times a_R}{4\pi R^2}$$

The Biot-Savart law states that the differential magnetic field intensity is proportional to the vector product of the vector differential current element and the unit vector directed from the current element toward the field point. It is inversely proportional to the square of the distance from the source point to the field point.

### AMPERE'S CIRCUITAL LAW

Ampere's circuital law states that the circulation of the magnetic field intensity equals the net electric current enclosed by the path. The path is completely arbitrary. The direction of the current is that of an advancing right-hand threaded screw turned in the direction in which the closed path is traversed (right-hand rule).

$$\oint H \cdot dl = I_{enc} = \iint J \cdot ds \quad \text{Ampere's Law}$$

## Magnetic Materials

The magnetic dipole moment is defined as  $m = I\mathbf{s}$  magnetic dipole moment where  $\mathbf{s}$  is the vector area whose direction is determined by the right-hand rule with the thumb of the right hand pointing in the direction of the current  $I$ .

A magnetic dipole in the form of a filamentary circular loop with current  $I$  in the direction of  $\mathbf{a}_\phi$  with radius  $a$ , and with its center at the origin has a moment  $m = \pi a^2 I \mathbf{a}_z$ .

### Classes of magnetic materials

1. In diamagnetic materials (bismuth) spin moments tend to dominant and produce fields that oppose the external field. Thus, the internal magnetic field is reduced slightly compared to the external field.
2. If the dipole moments dominate slightly, then the internal field is increased slightly over the external field and the material is paramagnetic (tungsten).
3. Large dipole moments are produced in certain regions and domains for the ferromagnetic materials (iron). A random domain alignment exists for virgin ferromagnetic material. When an external field is applied and then removed, a net alignment occurs giving permanent magnetization and hysteresis effect.
4. In ferromagnetic materials, adjacent atoms develop unequal, but oppositely directed moments, allowing a rather larger response to external fields.
5. The magnetic tape used for audio and video recording is superparamagnetic material and is composed of an array of small ferromagnetic particles.