1.1 SOURCES AND EFFECTS OF ELECTROMAGNETIC FIELDS

Electromagnetic theory is a prerequisite for a wide spectrum of studies in the field of Electrical Sciences and Physics. Electromagnetic theory can be thought of as generalization of circuit theory. There are certain situations that can be handled exclusively in terms of field theory. In electromagnetic theory, the quantities involved can be categorized as source quantities and field quantities. Source of electromagnetic field is electric charges: either at rest or in motion. However an electromagnetic field may cause a redistribution of charges that in turn change the field and hence the separation of cause and effect is not always visible.

Electromagnetics (EM) is a branch of physics or electrical engineering in which electric and magnetic phenomena are studied.

Sources of Electromagnetic Fields:

- Current Carrying Conductors
- Mobile Phones
- Microwave oven
- Computer and Television
- High Voltage Power lines
- Transformer
- Electric relays
- Television /Radio
- Electric Motors
- Wave guides
- Antennas
- Optical Fibers
- Radars and lasers

Effect of Electromagnetic Fields

- Plants and Animals
- Humans
- Electrical Components

Fields are classified as

- Scalar Field
- Vector Field

Electric charge is a fundamental property of matter. Charge exists only in positive or negative integral multiple of electronic charge,e^{-}, e= 1.60 × 10-19 coulombs. It may be noted here that in 1962, Murray Gell-Mann hypothesized Quarks as the basic building blocks of matters. Quarks were predicted to carry a fraction of electronic charge and the existence of Quarks has been experimentally verified.] Principle of conservation of charge states that the total charge (algebraic sum of positive and negative charges) of an isolated system remains unchanged, though the charges may redistribute under the influence of electric field. Kirchhoff's Current Law (KCL) is an assertion of the for conservative property of charges under the implicit assumption that there is no accumulation of charge at the junction.

Electromagnetic theory deals directly with the electric and magnetic field vectors where as circuit theory deals with the voltages and currents. Voltages and currents are integrated effects of electric and magnetic fields respectively. Electromagnetic field problems involve three space variables along with the time variable and hence the solution tends to become correspondingly complex. Vector analysis is a mathematical tool with which electromagnetic concepts are more conveniently expressed and best comprehended. Since use of vector analysis in the study of electromagnetic field theory results in real economy of time and thought, we first introduce the concept of vector analysis

VECTOR FIELDS

Scalars and Vectors

Vector analysis is a mathematical tool with which electromagnetic concepts are most convenient expressed and best comprehended.

A **Scalar** is a quantity that has only magnitude.

Quantities such as time, mass, distance, temperature, entropy, electric potential and population are scalar

A **Vector** is a quantity that has both magnitude and direction.

Vector quantities include velocity, force, displacement and electric field intensity.

Another class of physical quantities is called **tensors**, of which scalars and vectors are special cases.

A Scalar quantity is represented by a letter e.g., A, B, U and V.

A Vector quantity is represented by a letter with an arrow on top of it, such as $\vec{A}$ and $\vec{B}$

A field is a function that specifies a particular quantity everywhere in a region.

Unit Vector

A vector **A** that has both magnitude and direction. The magnitude of A is a scalar written as A or $|A|$.A unit vector $\mathbf{a_A}$ along **A** is defined as a vector whose magnitude is unity (i.e., 1) and its direction is along **A**, that is

$$\boldsymbol{a_A} = \frac{\boldsymbol{A}}{|\boldsymbol{A}|} = \frac{\boldsymbol{A}}{\boldsymbol{A}}$$

Notes that $|\boldsymbol{a_A}| = \mathbf{1}$

We may write **A** as

$$\boldsymbol{A} = A\boldsymbol{a_A}$$

Which completely specifies **A** in terms of its magnitude **A** and its direction $\boldsymbol{a_A}$

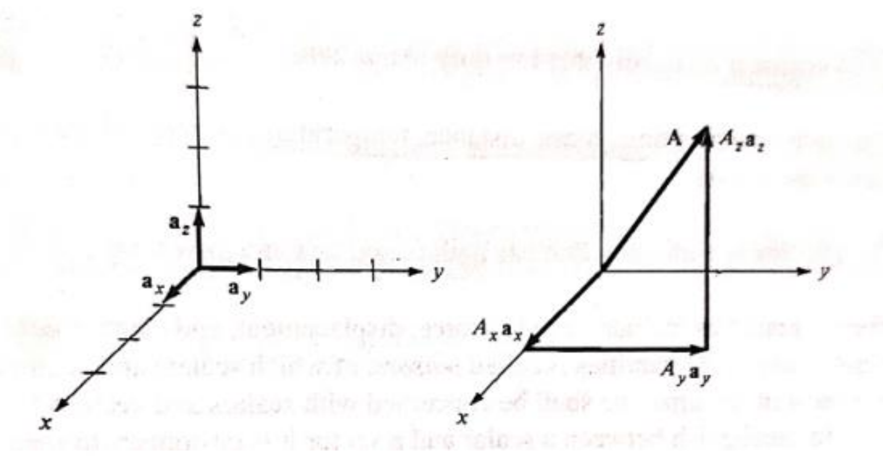

Figure 1.1.1 Unit Vectors

[Source: "Elements of Electromagnetics" by Matthew N.O.Sadiku, page-06]

A Vector **A** in Cartesian or rectangular coordinates represented by

$$(A_x, A_y, A_z) \quad \textbf{or} \quad A_x\boldsymbol{a_x} + A_y\boldsymbol{a_y} + A_z\boldsymbol{a_z}$$

A_x, A_y, A_z are called the components of **A** in the ***x, y, z*** directions respectively**;** a_x, a_y, a_z are unit vector in the ***x, y, z*** directions respectively

The magnitude of vector **A** is given by

$$A = \sqrt{A_x^2 + A_y^2 + A_z^2}$$

and the unit vector along **A** is given by

$$a_A = \frac{A_x a_x + A_y a_y + A_z a_z}{\sqrt{A_x^2 + A_y^2 + A_z^2}}$$

Sum and Difference of two vectors

The sum of two vectors is the resultant of two vectors.

Two vectors **A** and **B** can be added together to give to another vector **C**

$$C = A + B$$

The vector addition is carried out components by component. Thus if

$$\vec{A} = A_x\vec{a}_x + A_y\vec{a}_y + A_z\vec{a}_z$$

$$\vec{B} = B_x\vec{a}_x + B_y\vec{a}_y + B_z\vec{a}_z$$

Sum of two vectors $C = A + B$

$$\vec{A} + \vec{B} = (A_x\vec{a}_x + A_y\vec{a}_y + A_z\vec{a}_z) + (B_x\vec{a}_x + B_y\vec{a}_y + B_z\vec{a}_z)$$

$$\vec{A} + \vec{B} = (A_x + B_X)\vec{a_x} + (A_y + B_y)\vec{a_y} + (A_z + B_z)\vec{a_z}$$

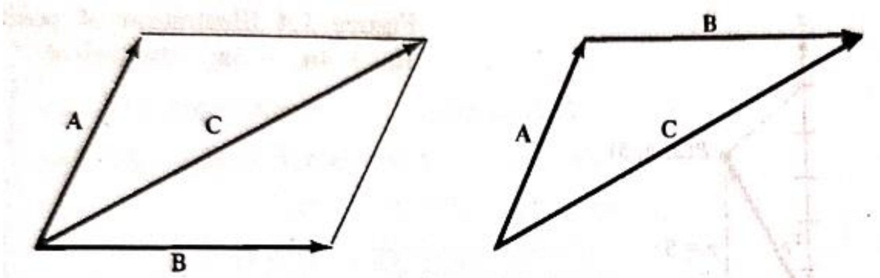

Figure 1.1.2 Vector Addition

[Source: "Elements of Electromagnetics" by Matthew N.O.Sadiku, page-07]

Difference of two vectors $\boldsymbol{C} = \boldsymbol{A} - \boldsymbol{B}$

$$\vec{A} - \vec{B} = (A_x\vec{a}_x + A_y\vec{a}_y + A_z\vec{a}_z) - (B_x\vec{a}_x + B_y\vec{a}_y + B_z\vec{a}_z)$$

$$\vec{A} - \vec{B} = (A_x - B_X)\vec{a_x} + (A_y - B_y)\vec{a_y} + (A_z - B_z)\vec{a_z}$$

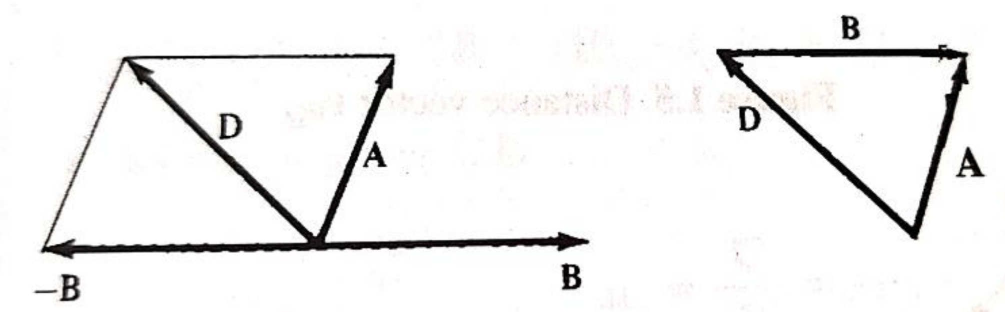

Figure 1.1.2 Vector Subtraction

[Source: "Elements of Electromagnetics" by Matthew N.O.Sadiku, page-07]

Multiplication of a Scalar and a Vector

When two vectors **A** and **B** are multiplied, the result is either a scalar or a vector depending on they are multiplied. Thus there are two types of vector multiplication:

- Scalar or dot product : $\boldsymbol{A}.\boldsymbol{B}$
- Vector or Cross product: $\boldsymbol{A} \times \boldsymbol{B}$

Multiplication of three vectors **A**, **B** and **C** can result in either

- Scalar triple product:$\boldsymbol{A}.(\boldsymbol{B} \times \boldsymbol{C})$
- Vector triple product: $\boldsymbol{A} \times (\boldsymbol{B} \times \boldsymbol{C})$

Dot Product or Scalar Product

The **dot product** of two vectors **A** and **B** written as **A.B** is called either the scalar product because it is scalar or the dot product due to the dot sign. If

$$\vec{A} = A_x\vec{a}_x + A_y\vec{a}_y + A_z\vec{a}_z$$

$$\vec{B} = B_x\vec{a}_x + B_y\vec{a}_y + B_z\vec{a}_z$$

$$\vec{A}.\vec{B} = (A_x\vec{a}_x + A_y\vec{a}_y + A_z\vec{a}_z).(B_x\vec{a}_x + B_y\vec{a}_y + B_z\vec{a}_z)$$

$$\vec{A}.\vec{B} = (A_xB_x + A_yB_y + A_zB_z)$$

$$\vec{a}_x.\vec{a}_x = \vec{a}_y.\vec{a}_y = \vec{a}_z.\vec{a}_z = 1$$

$$\vec{a}_x.\vec{a}_y = \vec{a}_y.\vec{a}_z = \vec{a}_z.\vec{a}_{xz} = 0$$

Cross Product or Vector Product

The **Cross Product** of two vectors **A** and **B** written **A*XB*,** is a vector quantity whose magnitude is the area of the parallelogram formed by **A** and **B** and is in the direction of advance of a right handed screw as **A** is turned into **B**

The vector product is given by

$$A.B = AB\cos\theta$$

Let **A** and **B** are two vectors

$$\vec{A} = A_x\vec{a}_x + A_y\vec{a}_y + A_z\vec{a}_z$$

$$\vec{B} = B_x\vec{a}_x + B_y\vec{a}_y + B_z\vec{a}_z$$

Where $\vec{a}_x$, $\vec{a}_y$ and $\vec{a}_z$ are unit vectors in the direction of **x, y, z**

$$|A \times B| = \begin{vmatrix} \vec{a}_x & \vec{a}_y & \vec{a}_z \\ A_x & A_y & A_z \\ B_x & B_y & B_z \end{vmatrix}$$

Note:

$$\vec{a}_x.\vec{a}_y = \vec{a}_z$$

$$\vec{a}_y . \vec{a}_z = \vec{a}_x$$

$$\vec{a}_z . \vec{a}_x = \vec{a}_y$$

The vector $\boldsymbol{B} \times \boldsymbol{A}$ has the same magnitude but the opposite direction

$$\boldsymbol{B} \times \boldsymbol{A} = -\boldsymbol{A} \times \boldsymbol{B}$$