Al-Mustaqbal University

College of Engineering & Technology

Biomedical Engineering Department

Subject Name: - Electromagnetics Fields ---

3th Class, Second Semester

Subject Code: [Insert Subject Code Here]

Academic Year: 2024-2025

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Lecture No.:- 1

Lecture Title: [Electromagnetics Fields]

Lecture QR

ELECTROMAGNETIككCS I

<u>Electromagnetics</u> (EM) - the study of electric and magnetic phenomena.
A knowledge of the fundamental behavior of *electric* and *magnetic* fields is necessary to understand the operation of such devices as resistors, capacitors, inductors, diodes, transistors, transformers, motors, relays, transmission lines, antennas, waveguides, optical fibers and lasers.
All electromagnetic phenomena are governed by a set of four equations known as *Maxwell's equations*.

<u>Maxwell's Equations</u>

$$\nabla \times \boldsymbol{E} = -\frac{\partial \boldsymbol{B}}{\partial t}$$

$$\nabla \times \boldsymbol{H} = \boldsymbol{J} + \frac{\partial \boldsymbol{D}}{\partial t}$$

$$\nabla \cdot \boldsymbol{D} = \rho_v$$

$$\nabla \cdot \boldsymbol{B} = 0$$

E - electric field intensity
H - magnetic field intensity
D - electric flux density
B - magnetic flux density
J - current density
ρ_v - volume charge density

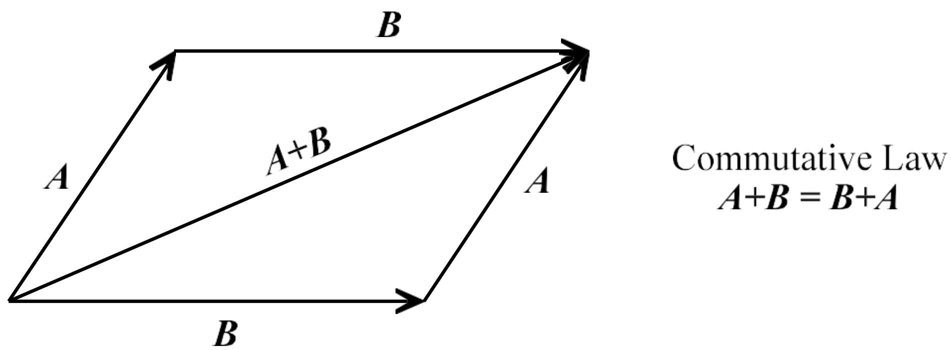
Vector Algebra

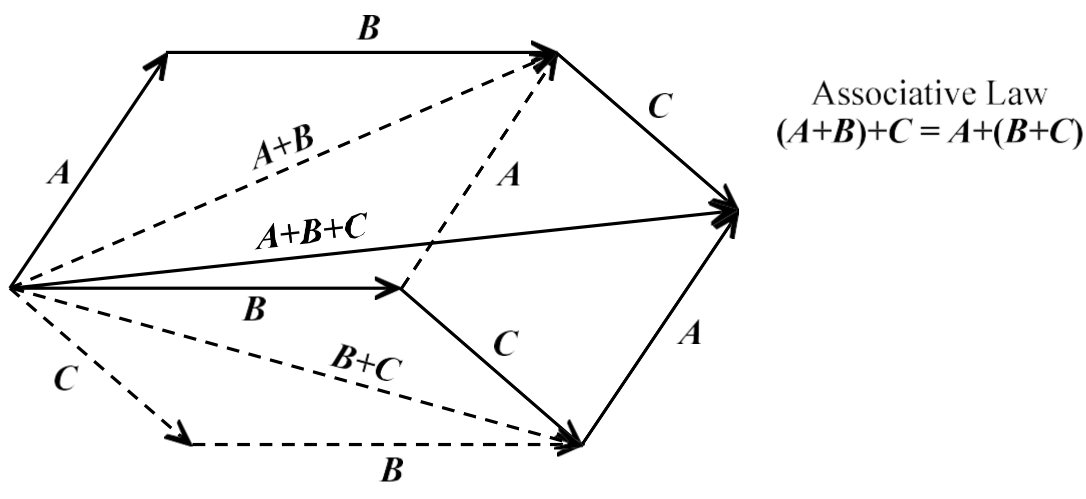
The quantities of interest appearing in Maxwell's equations along with other quantities encountered in the study of EM can almost always be classified as either a *scalar* or a *vector* (*tensors* are sometimes encountered in EM but will not be covered in this class).

> Scalar - a quantity defined by magnitude only.
> [examples: distance (x), voltage (V), charge density (ρ_v), etc.]
>
> Vector - a quantity defined by magnitude and direction. [examples: velocity ($\boldsymbol{v}$), current ($\boldsymbol{I}$), electric field ($\boldsymbol{E}$), etc.]

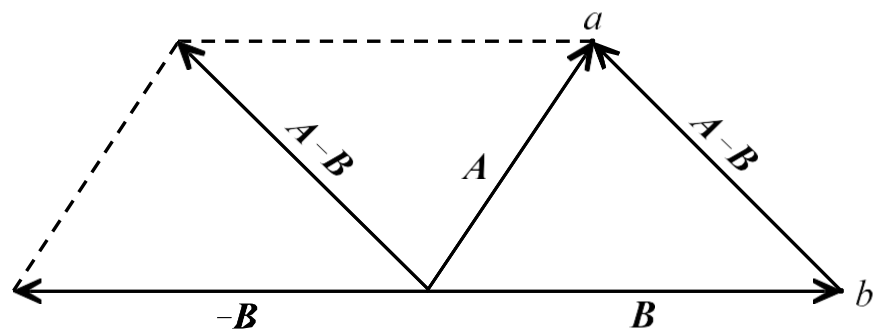
Note that vectors are denoted with boldface letters. The magnitude of a vector may be a real-valued scalar or a complex-valued scalar (phasor).

Vector Addition (Parallelogram Law)





Vector Subtraction



$$\boldsymbol{A} - \boldsymbol{B} = \boldsymbol{A} + (-\boldsymbol{B})$$

Note:

(1) The magnitude of the vector $\boldsymbol{A} - \boldsymbol{B}$ is the separation distance d between the points a and b located by the vectors $\boldsymbol{A}$ and $\boldsymbol{B}$, respectively $[d = |\boldsymbol{A} - \boldsymbol{B}| = |\boldsymbol{B} - \boldsymbol{A}|]$.

(2) The vector $\boldsymbol{A} - \boldsymbol{B}$ is the vector pointing from b (origination point) to a (termination point).

Multiplication and Division By a Scalar

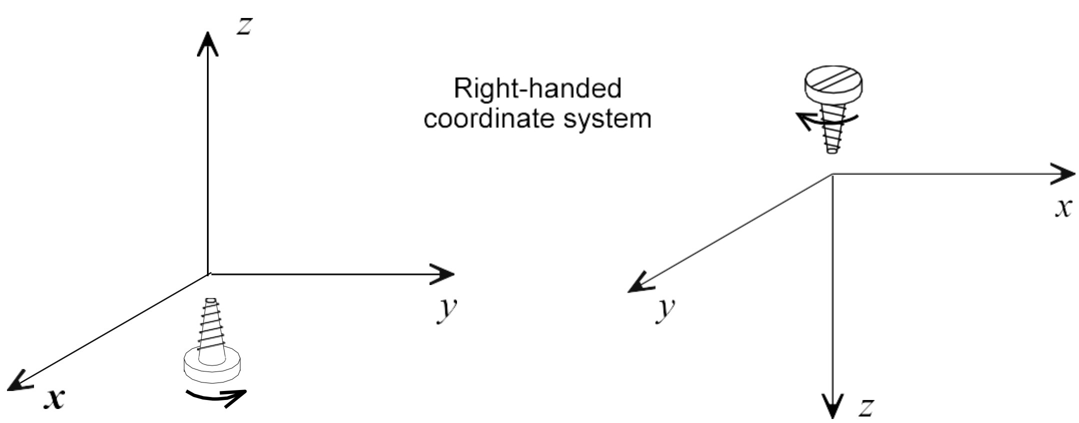
$$a(\boldsymbol{A} + \boldsymbol{B}) = a\boldsymbol{A} + a\boldsymbol{B} \qquad \text{(Distributive law)}$$

$$\frac{\boldsymbol{A} + \boldsymbol{B}}{a} = \frac{1}{a}\boldsymbol{A} + \frac{1}{a}\boldsymbol{B}$$

Coordinate Systems

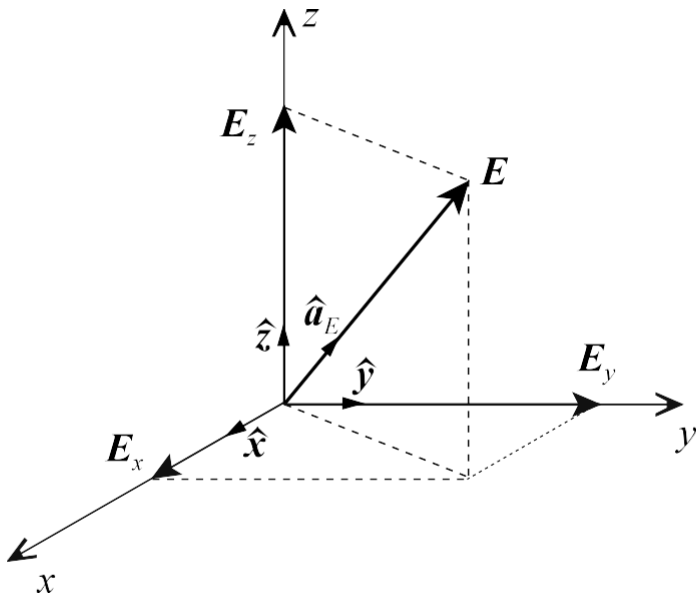
A coordinate system defines points of reference from which specific vector directions may be defined. Depending on the geometry of the application, one coordinate system may lead to more efficient vector definitions than others. The three most commonly used coordinate systems used in the study of electromagnetics are *rectangular* coordinates (or *cartesian* coordinates), *cylindrical* coordinates, and *spherical* coordinates.

<u>Rectangular Coordinates</u>



The rectangular coordinate system is an *orthogonal* coordinate system with coordinate axes defined by x, y, and z. The coordinate axes in an orthogonal coordinate system are mutually perpendicular. By convention, we choose to define rectangular coordinates as a *right-handed* coordinate system. This convention ensures that the three coordinate axes are always drawn with the same orientation no matter how the coordinate system may be rotated. If we position a right-handed screw normal to the plane containing the x and y axes, and rotate the screw in the direction of the x axis rotated toward the y axis, the direction that the screw advances defines the direction of the z axis in a right-handed coordinate system.

Component Scalars and Component Vectors



Given an arbitrary vector $\boldsymbol{E}$ in rectangular coordinates, the vector $\boldsymbol{E}$ can be described (using vector addition) as the sum of three *component vectors* that lie along the coordinate axes.

$$\boldsymbol{E} = \boldsymbol{E}_x + \boldsymbol{E}_y + \boldsymbol{E}_z$$

Component Vectors

The component vectors can be further simplified by defining *unit vectors* along the coordinate axes: $\hat{\boldsymbol{x}}, \hat{\boldsymbol{y}}$ **and** $\hat{\boldsymbol{z}}$. Each of these unit vectors have magnitudes of unity and directions parallel to the respective coordinate axis. The component vectors can be written in terms of the unit vectors as

$$\boldsymbol{E}_x = |\boldsymbol{E}_x|\,\hat{\boldsymbol{x}} = E_x\,\hat{\boldsymbol{x}}$$

$$\boldsymbol{E}_y = |\boldsymbol{E}_y|\,\hat{\boldsymbol{y}} = E_y\,\hat{\boldsymbol{y}}$$

$$\boldsymbol{E}_z = |\boldsymbol{E}_z|\,\hat{\boldsymbol{z}} = E_z\,\hat{\boldsymbol{z}}$$

$$\boldsymbol{E} = \boldsymbol{E}_x + \boldsymbol{E}_y + \boldsymbol{E}_z = E_x\,\hat{\boldsymbol{x}} + E_y\,\hat{\boldsymbol{y}} + E_z\,\hat{\boldsymbol{z}}$$

Component Scalars

Thus, using *component scalars*, any rectangular coordinate vector can be uniquely defined using three scalar quantities that represent the magnitudes of the respective component vectors.

To define a unit vector in the direction of $\boldsymbol{E}$, we simply divide the vector by its magnitude.

$$\hat{\boldsymbol{a}}_E = \frac{\boldsymbol{E}}{|\boldsymbol{E}|} = \frac{E_x\,\hat{\boldsymbol{x}} + E_y\,\hat{\boldsymbol{y}} + E_z\,\hat{\boldsymbol{z}}}{\sqrt{E_x^2 + E_y^2 + E_z^2}} \qquad \left(\begin{array}{c}\textbf{unit vector in the}\\ \textbf{direction of } \boldsymbol{E}\end{array}\right)$$

where the magnitude of $\boldsymbol{E}$ is the diagonal of the rectangular volume formed by the three component scalars.

Example (Unit vector)

Given the vector $\boldsymbol{E} = (x+y)\hat{\boldsymbol{x}} + 3\hat{\boldsymbol{y}} + z^2\hat{\boldsymbol{z}}$, determine the unit vector in the direction of $\boldsymbol{E}$ at the rectangular coordinate location of (1,1,1).

$$E_x = x + y$$
$$E_y = 3$$
$$E_z = z^2$$

Note that two of the component scalars are functions of position (the direction of the vector changes with position).

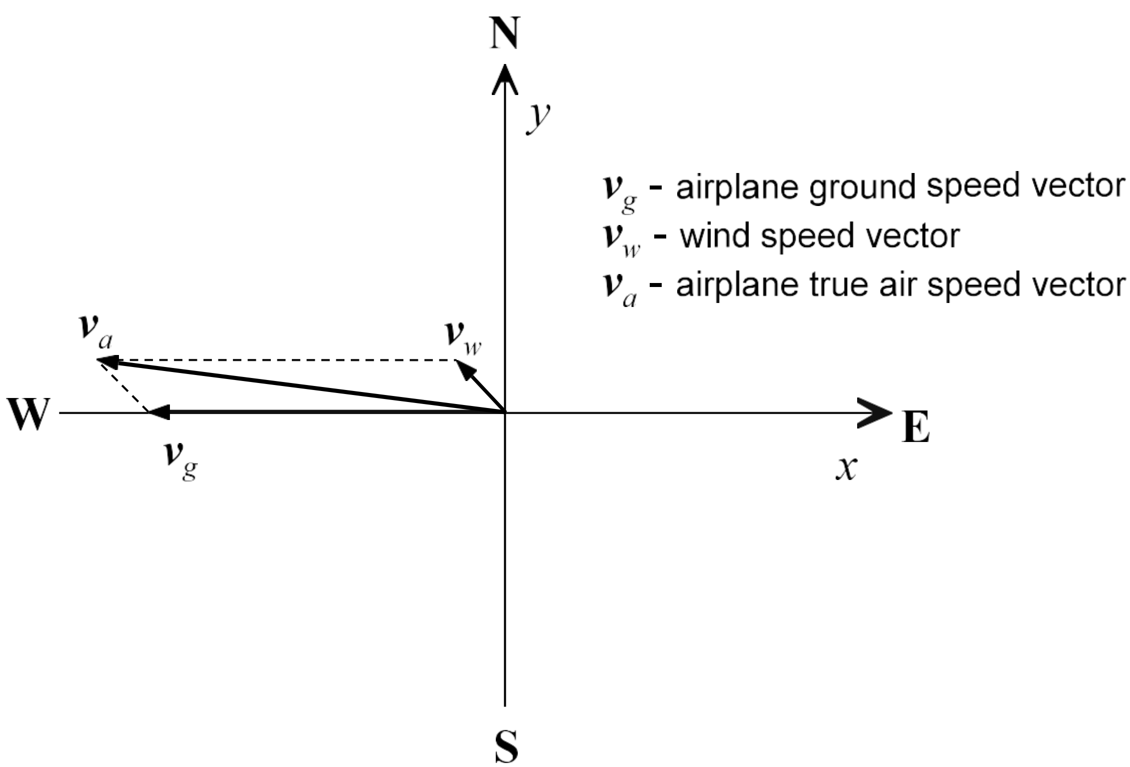
$$\hat{\boldsymbol{a}}_E = \frac{\boldsymbol{E}}{|\boldsymbol{E}|} = \frac{(x+y)\hat{\boldsymbol{x}} + 3\hat{\boldsymbol{y}} + z^2\hat{\boldsymbol{z}}}{\sqrt{(x+y)^2 + 9 + z^4}} \qquad \left(\begin{array}{c}\textbf{unit vector as a}\\ \textbf{function of position}\end{array}\right)$$

At the point (1,1,1) [x = 1, y = 1, z = 1], the unit vector is

$$\hat{\boldsymbol{a}}_E = \frac{1}{\sqrt{14}}(2\hat{\boldsymbol{x}} + 3\hat{\boldsymbol{y}} + \hat{\boldsymbol{z}})$$

Example (Vector addition)

An airplane with a ground speed of 350 km/hr heading due west flies in a wind blowing to the northwest at 40 km/hr. Determine the true air speed and heading of the airplane.



$$\boldsymbol{v}_g = 350(-\hat{\boldsymbol{x}}) = -350\hat{\boldsymbol{x}}$$

$$\boldsymbol{v}_w = 40\cos 45^o(-\hat{\boldsymbol{x}}) + 40\sin 45^o(\hat{\boldsymbol{y}}) = -28.3\hat{\boldsymbol{x}} + 28.3\hat{\boldsymbol{y}}$$

$$\boldsymbol{v}_a = \boldsymbol{v}_g + \boldsymbol{v}_w = -350\hat{\boldsymbol{x}} - 28.3\hat{\boldsymbol{x}} + 28.3\hat{\boldsymbol{y}} = -378.3\hat{\boldsymbol{x}} + 28.3\hat{\boldsymbol{y}}$$

$$|\boldsymbol{v}_a| = \sqrt{(378.3)^2 + (28.3)^2} = 379.4 \text{ km/hr}$$

$$\theta = \tan^{-1}\frac{28.3}{378.3} = 4.28^o \text{ north of west}$$