EEL 3470: Electromagnetic Fields

Lecture 1

Shady Elashhab, Ph.D.

Welcome to EEL 3470

- Instructor: Shady Elashhab, Ph.D.
- Office: VW 11-258
- email: shady.elashhab@ucf.edu
- Office Hours: Virtually via Zoom on
  Mondays from 1:30 to 3:00 p.m. or on
- Fridays from 1:30 to 3:00 p.m.
- Course Syllabus
  - ..\3- Handouts\Electromagnetic Fields Fall20_ Syllabus.pdf

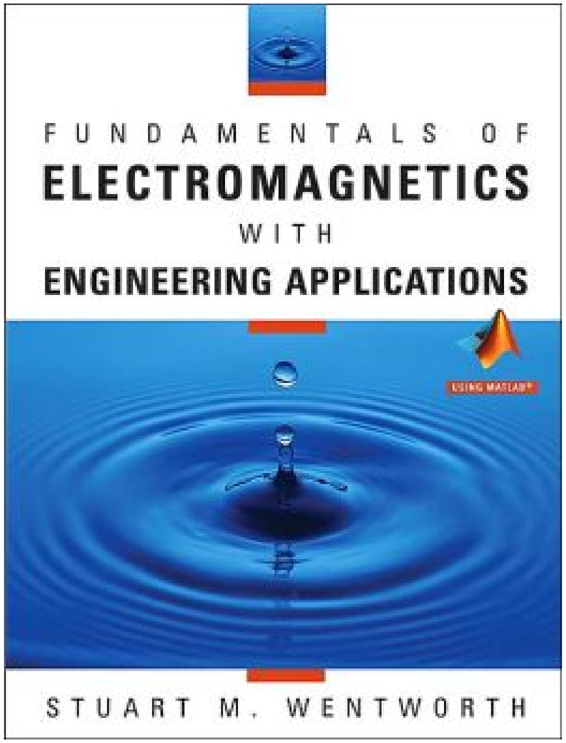
Rules for submitting your homework assignments:

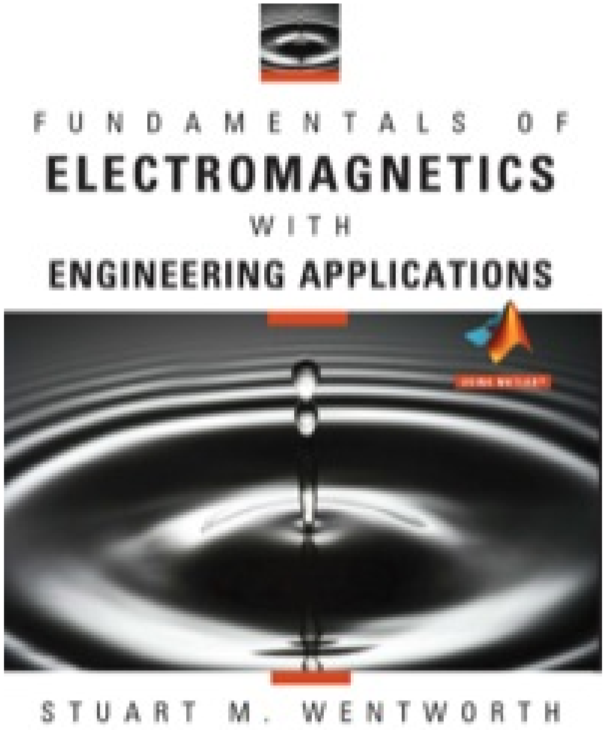
- All homework assignments are due in one week unless otherwise is mentioned (Recording Academic Activity assignment is due on 8/28/2020) .
- All homework assignments **must be submitted via Webcourses, as a file upload.**
  - You must tern in your homework solution as a .pdf file.
  - Use the following format to name your .pdf file:

    YourName_HW#?_EEL3470_F20.pdf
  - If your name is "Joe Smith" and you are submitting homework assignment # 1, your uploaded file name should be as follows:

    JoeSmith_HW#1_EEL3470_F20.pdf

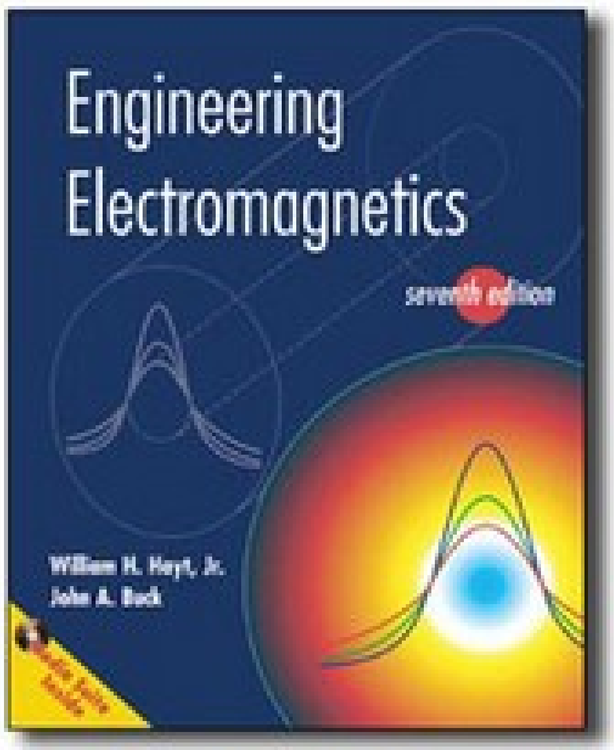
Textbook:





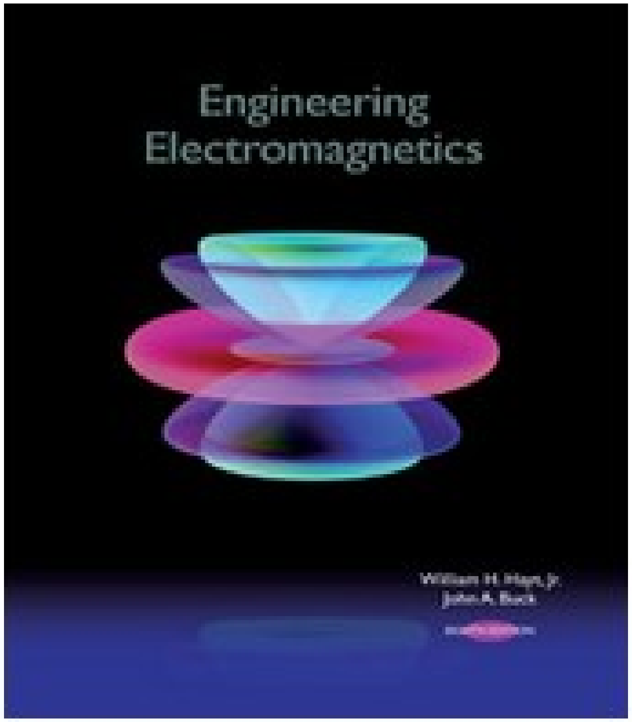
Reading the textbook in IMPARATIVE

Reference book:



7th Edition

Or



8th Edition

- **What does the word “Electromagnetism” mean to you?**
  - The branch of science dealing with the observations and laws relating electricity to magnetism.
  - Electromagnetism is based upon the fundamental observations that a moving electric charge produces a magnetic field and that a charge placed in the magnetic field will experience a force.
  - The magnetic field produced by a current is related to the current, the shape of the conductor, and the magnetic properties of the medium around it (Ampere's law).
  - The association of electricity and magnetism is also shown by electromagnetic induction, in which a magnetic field sets up an electric field within a conductor and causes the charges to move in the conductor.

- Knowledge of the fundamental behavior of *electric* and *magnetic* fields is necessary to better understand the operation of electromagnetic components such as capacitors, inductors, diodes, transistors, transformers, motors, relays, transmission lines, antennas, waveguides, optical fibers and lasers.
  - Circuit theory is a simple part of EM, so it was taught first.
  - However, there are many cases in EE where circuit theory fails (e.g. faster computers, higher communications frequencies, power electronics, power system transients,), and EM must supplement circuit theory.
- All electromagnetic phenomena are governed by a set of four equations known as *Maxwell's equations*.

Maxwell's equations (Derivative form)

Gauss's law	$\nabla \cdot \mathbf{D} = \rho_v$
Gauss's law for magnetic fields	$\nabla \cdot \mathbf{B} = 0$
Faraday's law	$\nabla \times \mathbf{E} = -\dfrac{\partial \mathbf{B}}{\partial t}$
Ampére's circuital law	$\nabla \times \mathbf{H} = \mathbf{J}_c + \dfrac{\partial \mathbf{D}}{\partial t}$

Lorentz force equation	$\mathbf{F} = q(\mathbf{E} + \mathbf{v} \times \mathbf{B})$
Constitutive relations	$\begin{cases} \mathbf{D} = \varepsilon \mathbf{E} \\ \mathbf{B} = \mu \mathbf{H} \\ \mathbf{J} = \sigma \mathbf{E} \text{ (Ohm's law)} \end{cases}$
Current continuity equation	$\nabla \cdot \mathbf{J} = -\dfrac{\partial \rho_v}{\partial t}$

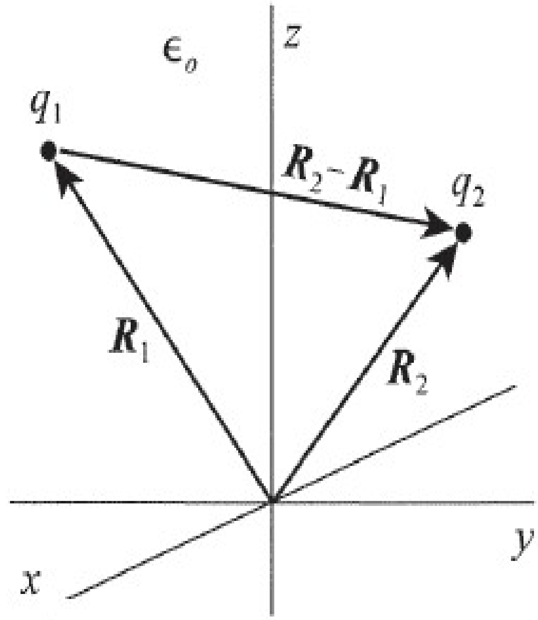
E - electric field intensity	V/m
H - magnetic field intensity	A/m
D - electric flux density	C/m^2
B - magnetic flux density	Wb/m^2
J - current density	A/m^2
ρ_v - volume charge density	C/m^3

Review of some basic concepts

- **Electric Charge**
  - Particles could exhibit positive or negative charges. They could also remain neutral.
  - The smallest negative charge is the charge of an electron; which is approximately $-1.6\text{x}10^{-19}$ C.
  - The smallest positive charge is the charge of a proton; which is approximately $1.6\text{x}10^{-19}$ C.
  - Coulombs Law explains the force applied by one charge on another when they are in close proximity.

Coulomb's Law

Given point charges [q_1, q_2 (units=C)] in air located by vectors $\boldsymbol{R}_1$ and $\boldsymbol{R}_2$, respectively, the vector force acting on charge q_2 due to q_1 [$\boldsymbol{F}_{12}$ (units=N)] is defined by Coulomb's law as



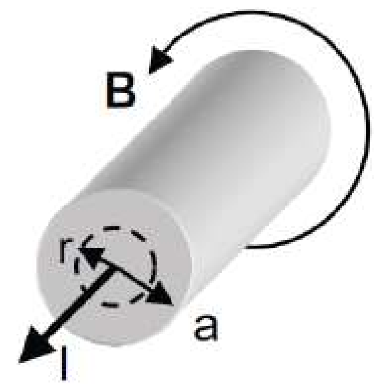
$$\boldsymbol{F}_{12} = \frac{q_1 q_2}{4\pi\epsilon_o |\boldsymbol{R}_2 - \boldsymbol{R}_1|^2}\hat{\boldsymbol{a}}_{12} \quad \text{(Coulomb's law)}$$

where $\hat{\boldsymbol{a}}_{12}$ is a unit vector pointing from q_1 to q_2 and ϵ_o is the free-space *permittivity* [$\epsilon_o = 8.854\times10^{-12}$ F/m].

Positive force is repulsive and negative force is attractive.

Review of some basic concepts

- **Magnetic Flux Density.**
  - When a current is passing through a wire in a given direction, a magnetic field develops around the wire.
  - The right hand rule determines the direction of the circulating magnetic field.
  - The magnetic flux density is perpendicular to the current

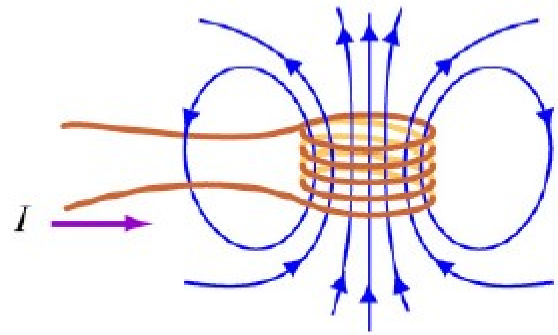


$$B = \frac{\mu_o I}{2\pi r}$$

μ_o is the permeability of free space $\approx 4\pi \times 10^{-7}$ H/m.

Storing Magnetic Energy

- The energy is stored in the magnetic field generated by the current flowing in the inductor (solenoid)
- In an ideal inductor, the energy is stored without loss
- The energy stored in the magnetic field of the solenoid is given by

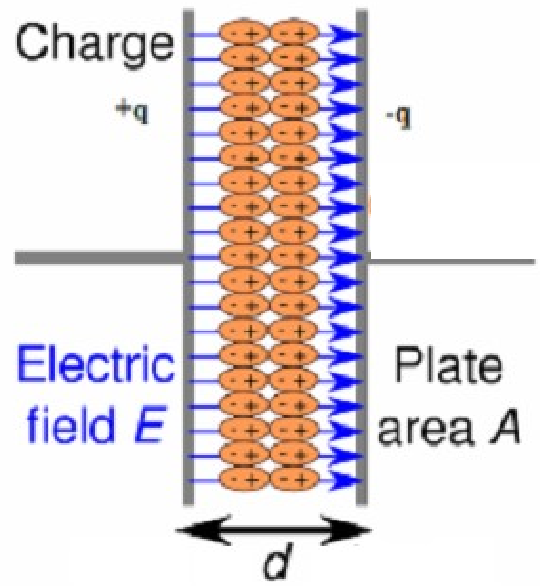


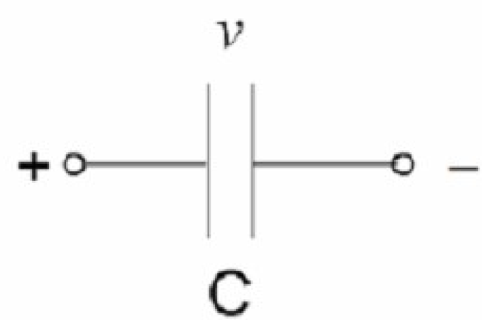
$$W = \frac{B^2}{2\varepsilon_0} lA$$

Storing Electric Energy in a Capacitor

- A capacitor is an electric component that stores energy (voltage) in its electric field.
- A capacitor consists of two conducting plates separated by an insulator (or dielectric).
- When a voltage source is connected to the capacitor, the source deposits a positive charge, $+q$, on one plate and a negative charge, $-q$, on the other.
- The amount of charge is directly proportional to the voltage so that

$$q = C\,v$$





$$q = Cv$$

- the constant of proportionality C, is called the capacitance of the capacitor.
- C is measured in Farads, F.

- *Capacitance is the ratio of the charge on one plate of a capacitor to the voltage difference between the two plates, measured in Farad (F). Thus, 1F = 1 coulomb/volt*

- In reality, the value of C depends on the surface area of the plate, the spacing between the plates, and the permittivity of the material.

$$C = \frac{\varepsilon A}{d}$$

ε: permittivity of the dielectric A: Area of the plate

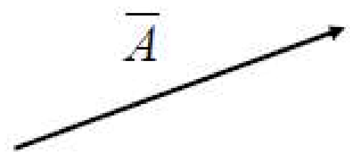
d: distance between plates

What do you expect to learn from this course

- You have studied electromagnetic concepts before
- In this course you will learn how to develop powerful techniques to analyze electromagnetic fields and better understand them.
- You need some mathematical knowledge to handle this subject with ease such as
  - Vectors and Vector Calculus
  - Ordinary Differential Equations
  - Partial Differential Equations.
- Matlab® will be introduced for computer modeling and simulation

Review of Vectors

A vector represents a physical quantity which has magnitude and direction.

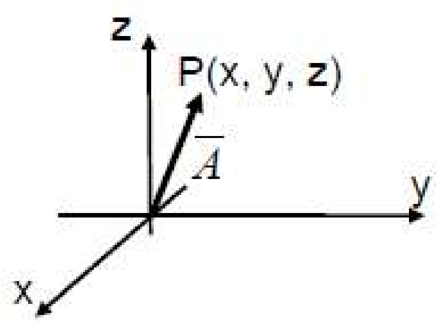


One can write: $\overline{A} = A\,\hat{a}_A$

Where $A = |A|$ = magnitude

$$\hat{a}_A = \frac{\overline{A}}{|A|} = $$ unite vector represents the direction of $\overline{A}$.

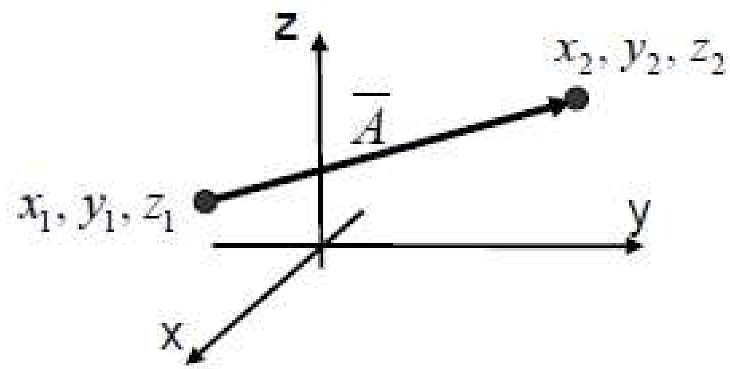
<u>Position vector</u>



A position vector is directed from the origin to the point P(x, y, z) as shown. It can be expressed as: $\overline{A} = x\,\hat{a}_x + y\,\hat{a}_y + z\,\hat{a}_z$

$$|A| = \sqrt{x^2 + y^2 + z^2}$$

A vector joining two points in the Cartesian space



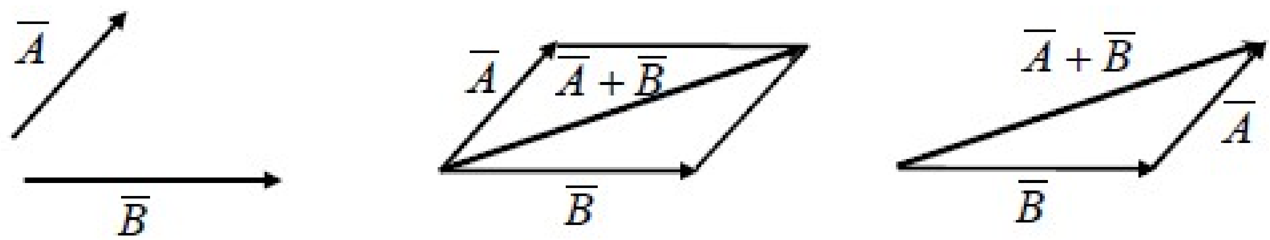
Can be expressed as:

$$\overline{A} = (x_2 - x_1)\,\hat{a}_x + (y_2 - y_1)\,\hat{a}_y + (z_2 - z_1)\,\hat{a}_z$$

$$|A| = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2}$$

Vector Algebra

Given two vectors $\overline{A}$ and $\overline{B}$ they can be added as:



Parallelogram　　Head to Tail

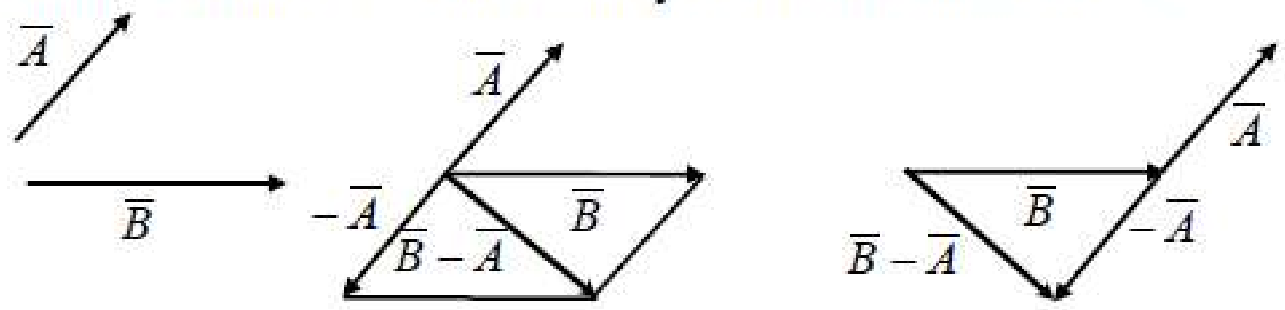
Properties of vector addition

Commutative $\quad \overline{A}+\overline{B}=\overline{B}+\overline{A}$

Associative $\quad \overline{A}+(\overline{B}+\overline{C})=(\overline{A}+\overline{B})+\overline{C}$

Subtraction

Given two vectors $\overline{A}$ and $\overline{B}$ they can be subtracted as:



Parallelogram

Head to Tail

Announcements

- Recording Academic Activity assignment is assigned (due date: 8/28/2020)
- Check Webcourses for course handouts.
  - Webcourses will be used for distributing class handouts/assignments, submitting your homework assignments, and recording grades ONLY.
- USE EMAIL IF YOU HAVE ANY QUESTIONS REGARDING COURSE MATERIAL
- Have a wonderful semester!