ECE 313: Electromagnetic Waves

Lecture 1: Course introduction

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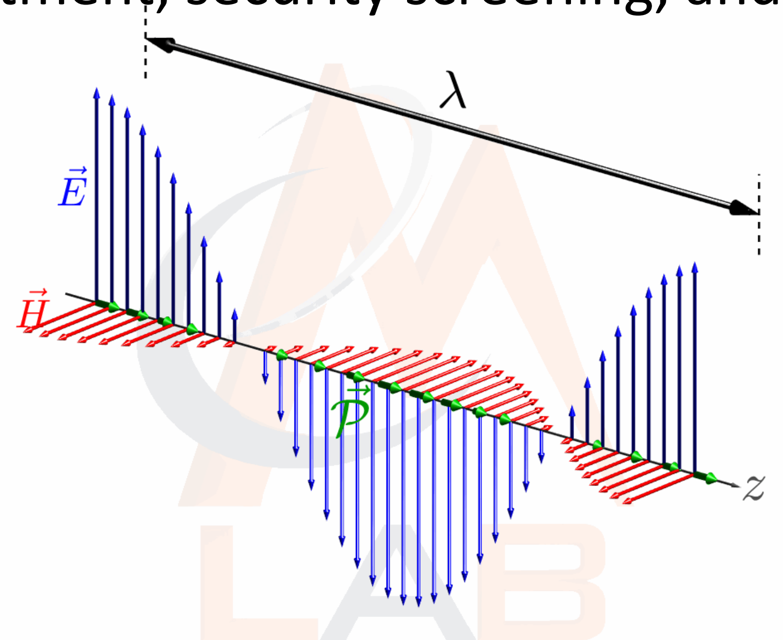
Why we Study Electromagnetics?

At high frequencies circuit theory unable to describe the fields in circuits, so wave theory must be used instead.

the electromagnetic waves has created a revolution in engineering applications, with great impacts on various fields such as communication systems, industrial/biomedical sensing, remote sensing, radar, medical imaging and treatment, security screening, and so on.

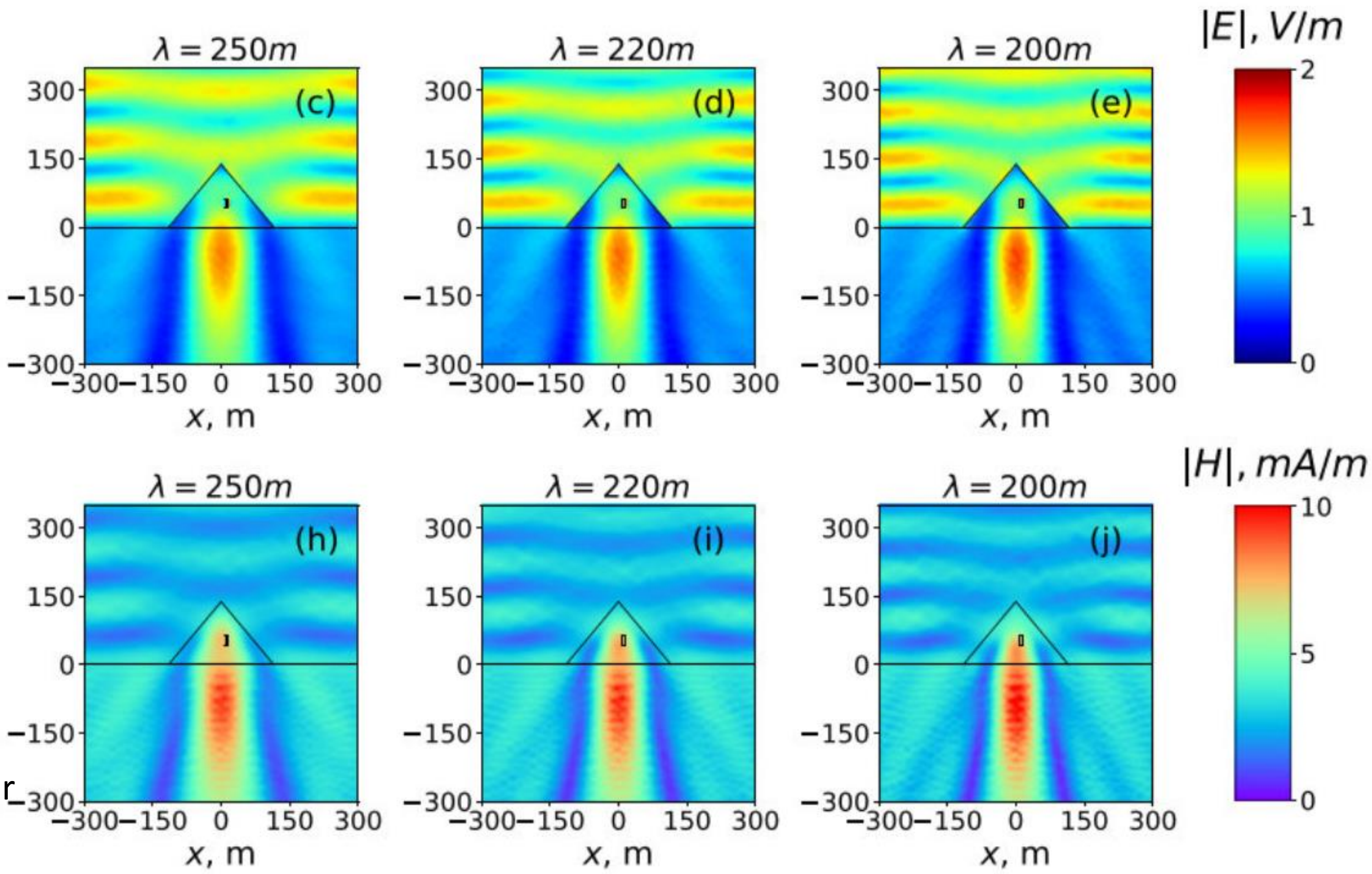
An electromagnetic field is made up of interdependent electric and magnetic fields, which is the case when the fields are varying with time.



Study reveals the Great Pyramid of Giza can focus electromagnetic energy

by Anastasia Komarova, ITMO University

Physicists interest in how the Great Pyramid would interact with electromagnetic waves of a resonant length wavelength from 200 to 600m (i.e. @**radio waves**). Calculations(modeling and simulation) showed that in the resonant state, the pyramid can concentrate electromagnetic energy in the its internal chambers as well as under its base, where the third unfinished chamber is located.

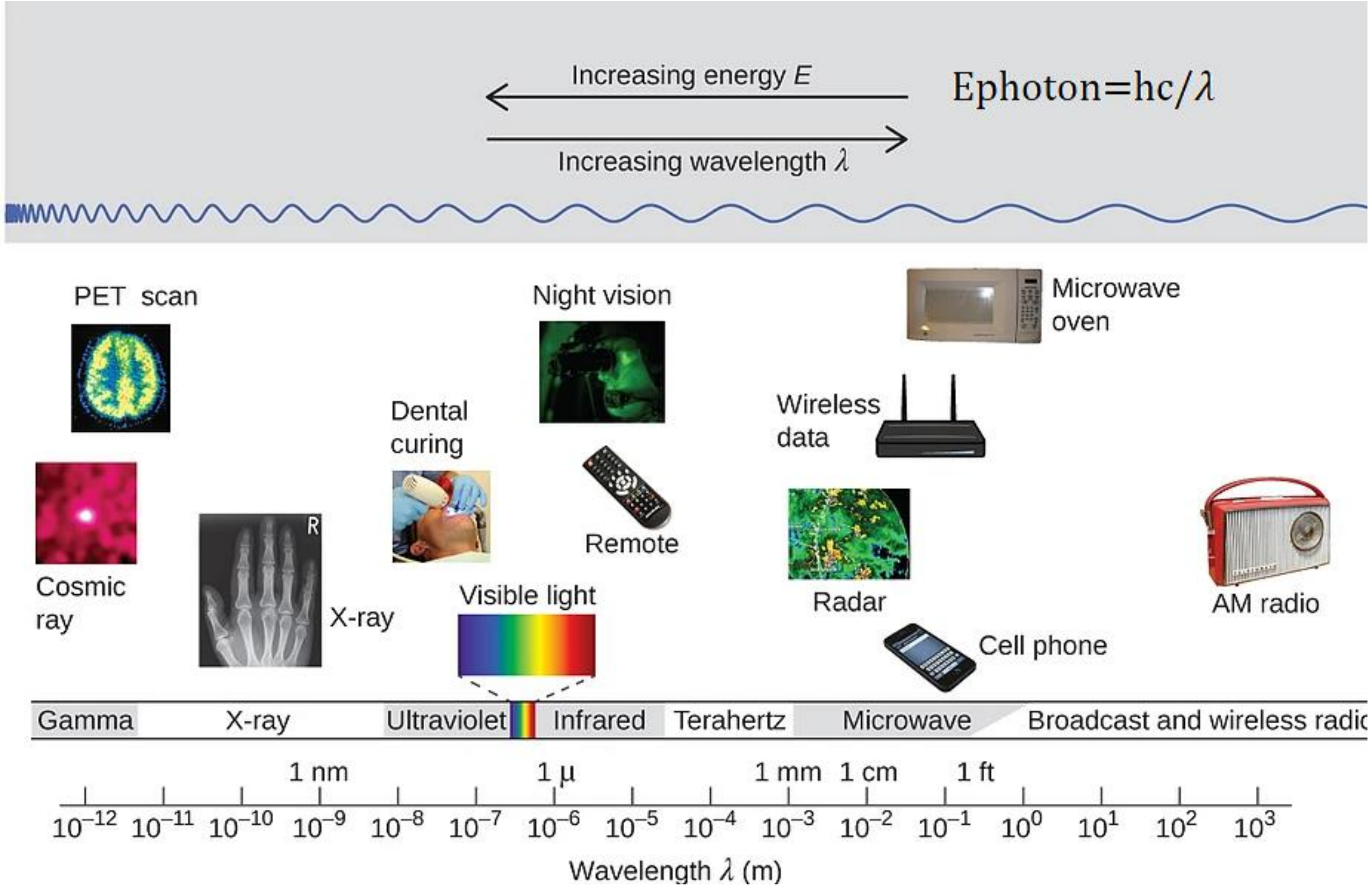


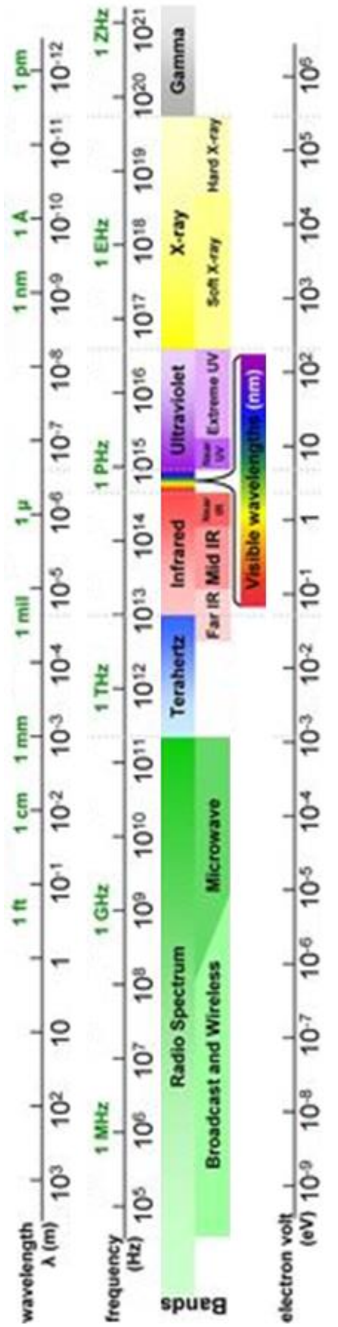
Propagation of electromagnetic waves inside the pyramids of Cheops at different lengths of radio waves (from 200 to 400 meters). The black rectangular position of the so-called King's Chamber. Credit: ITMO University, Laser Zentrum Hannover

the scientists plan to use the results to reproduce similar effects at the nanoscale. "Choosing a material with suitable electromagnetic properties, we can obtain pyramidal nanoparticles with a promise for practical application in nanosensors and effective solar cells," *says Polina Kapitainova, Ph.D., a member of the Faculty of Physics and Technology of ITMO University*.

https://phys.org/news/2018-07-reveals-great-pyramid-giza-focus.html

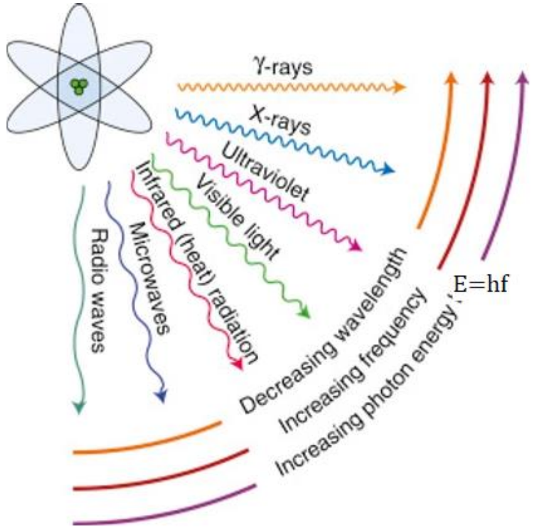
Examples for electromagnetic Applications through electromagnetic spectrum





How do electromagnetic waves differ?
Different electromagnetic waves carry different amounts of energy.

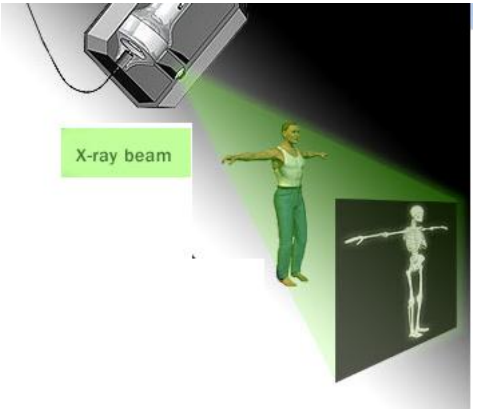
•The amount of energy carried by an electromagnetic wave depends on the wavelength: the shorter the wavelength, the higher its energy, so X-rays carry more energy than microwaves.



When electromagnetic waves hit a surface, they can be reflected, absorbed or transmitted.
-behaves of the wave depend on their energy and the material the wave hits.
-as light waves are reflected by skin but X-rays pass straight through.

How X-Ray work:
-The soft tissue in your body is composed of smaller atoms, and so does not absorb X-ray photons particularly well. The calcium atoms that make up your bones are much larger, so they are better at **absorbing X-ray photons**.

-A camera on the other side of the patient records the pattern of X-ray light that passes all the way through the patient's body. The X-ray camera uses the same film technology as an ordinary camera, but X-ray light sets off the chemical reaction instead of visible light.



What is Electromagnetics
It is study of effects of electric charges at rest and in motion

Source of Electric fields: positive & negative electric charges
Source of magnetic fields: moving charges (current)

What is Field: it is a spatial distribution of quantity(ie function of (x,y,z) or(r,θ,ϕ) or (ρ ,ϕ,z)) which may or may not function of time t

-time varying electric and magnetic fields are coupled → time varying electromagnetic fields → Radiating waves

What did you learn

	Electrostatic	Magnetostatic
Source	Static electric charges	Steady state current
Equations	$\nabla . \bar{D} = \rho$ $\nabla \times \bar{E}=0$	$\nabla . \bar{B} = 0$ $\nabla \times \bar{H} = \bar{J}$

What will we learn

Time varying electromagnetics
Time varying currents
$\nabla . \bar{D} = \rho$ $\nabla . \bar{B} = 0$ $\nabla \times \bar{E} = -\frac{\partial B}{\partial t}$ $\nabla \times \bar{H} = \bar{J} + \frac{\partial D}{\partial t}$

E,H (x,y,z) function of space only
Independently defined

E,H (x,y,z) function of space & time
E & H coupled

Time varying fields governing equations are ordinary differential equations, these fields are vectors with magnitude and direction so their representation and manipulation require knowledge of vector algebra and vector calculus

Even in static case the governing equations are partial differential equations.

Thus we must know -Vector calculus such as Gradient, Divergence, curl,…

-some theorem as stokes and divergence theorem

Divergence theorem

$$\int_v \nabla . \underline{D} dv = \oint_s \underline{D} . \underline{ds}$$

Stocks' Theorem

$$\int_s (\nabla \times \overline{E}) . d\overline{s} = \oint_c \overline{E} . d\overline{l}$$

Symbols and units of field quantities	Field quantity	Symbol	Unit
Electric	Electric field intensity	E	V/m
	Elctric flux density (electric displacement)	D	C/m^2
Magnetic	Magnetic flux density	B	$T(\text{or } wb/m^2)$
	Magnetic field intensity	H	A/m

Material properties determine Relation Between D&E B&H Through constitutive relations of a medium

$\underline{J}$ electric current density A/m^2 ρ electric charge density (C/m^3)

Constitutive Relations

Free Space:

$$\overline{D} = \varepsilon_0 \overline{E} \qquad \varepsilon_0 (permitivity) = 8.85 \times 10^{-12} \ F/m$$

$$\overline{B} = \mu_0 \overline{H} \qquad \mu_0 (permeability) = 4\pi \times 10^{-7} \ H/m$$

Constitutive Equation

Vacuum response; material response

$$\overline{D} = \varepsilon \overline{E} = \varepsilon_0 \varepsilon_r \overline{E} = \boxed{\varepsilon_0 \overline{E} + \overline{P}} = \underbrace{\varepsilon_0 \overline{E}}_{\text{Vacuum response}} + \underbrace{\varepsilon_0 \chi_e \overline{E}}_{\text{material response}} = \varepsilon_0 \overline{E}(1 + \chi_e)$$

$$\rightarrow \varepsilon_r = (1 + \chi_e) \qquad \chi_e : electric\ susceptibility$$

Electric susceptibility χ_e is a measure of how easily Bound charges are displaced due to an applied electric field

$$\overline{B} = \mu \overline{H} = \mu_0 \mu_r \overline{H} = \boxed{\mu_0 \overline{H} + \mu_0 \overline{M}} = \underbrace{\mu_0 \overline{H}}_{\text{Vacuum response}} + \underbrace{\mu_0 \chi_m \overline{H}}_{\text{magnetic response}} = \mu_0 \overline{H}(1 + \chi_m)$$

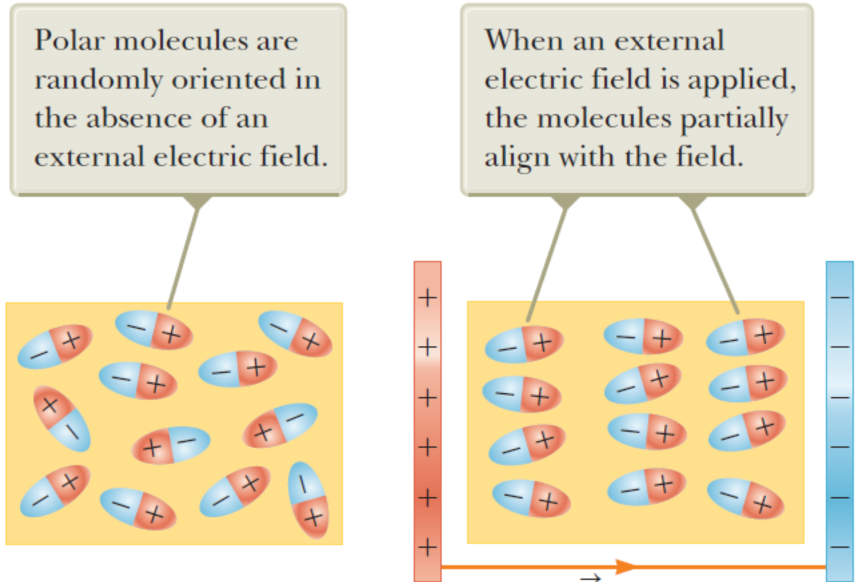
$$\rightarrow \mu_r = (1 + \chi_m) \qquad \chi_m : magnetic\ susceptibility$$

Meaning of Permitivity

$$\overline{D} = \varepsilon_0 \overline{E} + \overline{P}$$

Polarization vector of induced Electric dipoles

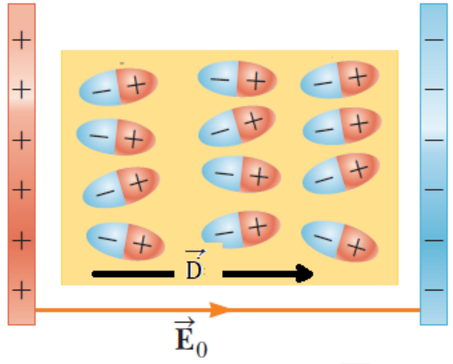
So relative permittivity is a measure of the ease with which a material is polarized by an electric field relative to vacuum.
It is defined by the magnitude of the dielectric polarization (dipole moment per unit volume) induced by a unit field.



(a) Polar molecules in a dielectric

(b) An electric field is applied to the dielectric.

When an external field $\mathbf{E_0}$ due to charges on the capacitor plates is applied, a torque is exerted on the dipoles, causing them to partially align with the field as shown in Figure. The dielectric is now polarized.
The degree of alignment of the molecules with the electric field depends On temperature and the magnitude of the field.
In general, the alignment increases with decreasing temperature and with increasing electric field.



$$\overline{P} = (\varepsilon - \varepsilon_0)\overline{E}$$

Teflon $\varepsilon_r = 2.2$

Water $\varepsilon_r = 81$ (a very polar molecule, fairly free to rotate)

Styrofoam $\varepsilon_r = 1.03$

Quartz $\varepsilon_r = 5$

Note: $\varepsilon_r > 1$ for most materials:

$$\varepsilon_r \equiv 1 + \chi_e, \quad \chi_e > 0$$

Note: permittivity (ε), permeability (μ), and the conductivity (σ), are spatially dependent for inhomogeneous media, orientation dependent (tensor) for anisotropic media, and field dependent for nonlinear media.

They are simple scalar constants for linear homogeneous isotropic (LHI) media(which is our concern in this course)

Simple linear media

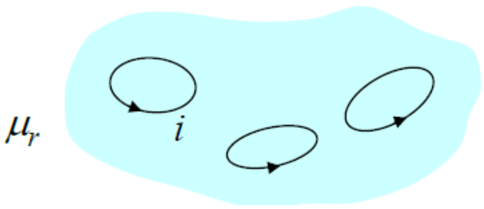
Magnetic media:

Magnetic Susceptibility χ_m

The magnetic susceptibility is a measure of how easily magnetic dipoles are aligned due to an applied magnetic field

$$\overline{B} = \mu_0 \overline{H} + \mu_0 \overline{M} = \mu_0 (1+\chi_m)\overline{H} = \mu_0 \mu_r \overline{H}$$

Magnetic media:

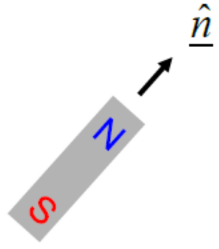


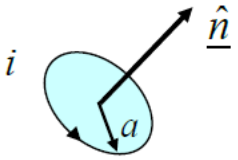
Magnetic dipoles

(from electron spin)

Magnetic moment per unit volume:

$$\underline{\mathcal{M}} \equiv \frac{1}{\Delta V} \sum_{\Delta V} \underline{m}_i$$





$$\underline{m} = \underline{\hat{n}}(i\,A), \quad A = \pi a^2$$

Each magnetic dipole acts like a small bar magnet.

Permanent magnets are made from "hard" ferromagnetic materials such as alnico and ferrite that are subjected to special processing in a strong magnetic field during manufacture to align their internal microcrystalline structure, making them very hard to demagnetize.

-ferromagnetic has large positive susceptibility, they retain their magnetism to some degree when external field is removed.

object	Relative permeability
wood	1.00000043
aluminium	1.000022
colbalt	250
nickel	600
Iron	200000

Iron has large permeability :as its molecular structure inside easily able to induce magnetic fields

Syllabus First part:

- Vector calculus
-Time-varying fields and Maxwell's Equations
- The displacement current
- Potential functions and wave equation
- Plane Wave in free space
- TEM Waves in a dielectric medium
- Skin Depth and Plane Wave in a Lossy Medium
- Group and Phase Velocities
- Poynting vector
- Wave Polarization

References:

Textbook:

- W. Hayt: “Engineering Electromagnetics”, sixth edition, McGraw-Hill(CH1,CH10,CH11)

Recommended book:

- David K. Cheng: “Field and Wave Electromagnetics”, Addison-Wesley, second edition.CH7,8

Course assessment

	Degrees	first part
Assignments		10
Oral exam	30	5
Midterm& Quizzes	30	15
Final exam	90	45
Total	150	75