

# ELECTROMAGNETIC THEORY

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## Abstract

An introduction to Electromagnetic Theory is given with emphasis on wave propagation phenomena in free space and inside wave guides. We also discuss the radiation emitted by moving electric charges, an issue which is particularly important in accelerator physics.

## 1. INTRODUCTION

The topics that will be covered in this lecture are the following:

- Maxwell Equations
- Conservation of Energy - The Poynting vector
- Propagation of Electromagnetic (EM) Waves
- Power Absorption by Conducting Surfaces
- Propagation of EM Waves in Wave Guides
- Energy Flow and Power Losses in Wave Guides
- Potentials - Radiation by Moving Charges

All material covered in this lecture and details of the calculations involved can be found in standard textbooks (see for instance [1, 2, 3]). In writing this lecture I have benefited from lectures given in previous CERN schools ( see [4] ).

## 2. MAXWELL EQUATIONS

We start by reviewing Maxwell's equations :

Electric charges whose density is  $\rho$  are the sources of the electric field  $\vec{E}$ . In the *MKSA* system this is expressed by Gauss's law

$$\nabla \cdot \vec{E} = \frac{1}{\epsilon_0} \rho . \quad (1)$$

Electric currents with density  $\vec{J} = \rho \vec{u}$  are the sources of the magnetic induction field  $\vec{B}$ . This is expressed by Ampere's law

$$\nabla \times \vec{B} = \mu_0 \vec{J} . \quad (2)$$

Field lines of  $\vec{B}$  are closed. This is equivalent to the statement that there are no magnetic monopoles. Mathematically this is expressed by the equation

$$\nabla \cdot \vec{B} = 0 . \quad (3)$$

The electromotive force around a closed circuit is proportional to the rate of change of flux of the field  $\vec{B}$  through the circuit (Faraday's law). In differential form this law is expressed by the following formula

$$\nabla \times \vec{E} = - \frac{\partial \vec{B}}{\partial t} . \quad (4)$$

Within material media having polarization  $\vec{P}$  and magnetization  $\vec{M}$  the above laws still hold with the following replacements

$$\rho \Rightarrow \rho - \nabla \cdot \vec{P} \quad , \quad \vec{J} \Rightarrow \vec{J} + \nabla \times \vec{M} + \frac{\partial \vec{P}}{\partial t} + \epsilon_0 \frac{\partial \vec{E}}{\partial t} .$$

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