CfE
Advanced Higher

Physics Department

Unit 3 Electromagnetism

Topic 3 – Electromagnetic Radiation

Useful Websites

www.scholar.hw.ac.uk

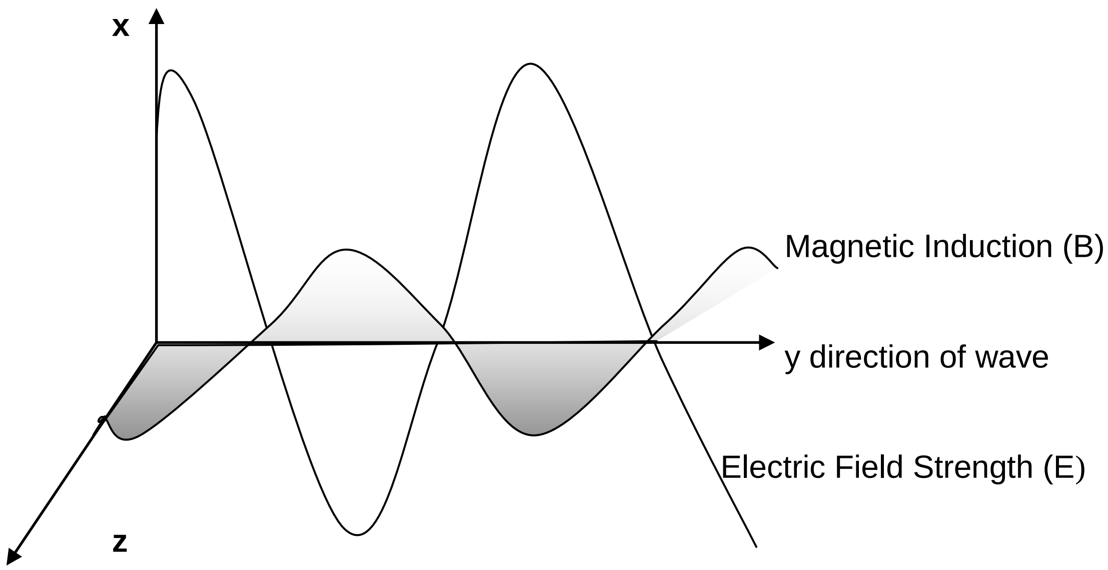
http://hyperphysics.phy-astr.gsu.edu/hbase/hframe.html

3 Electromagnetic Radiation	
Content	**Notes**
The unification of electricity and magnetism	The nature of electromagnetic radiation (EMR). EMR exhibits wave properties as it transfers energy through space. It has both electric and magnetic field components which oscillate in phase, perpendicular to each other and to the direction of energy propagation. The relationship between the speed of light and the permittivity and permeability of free space. Estimate the speed of light by determining permittivity using a parallel plate capacitor and determining permeability using a current balance.

Electromagnetic Radiation (EMR)
EMR exhibits wavelike properties as it transfers energy through space. The electric field and the magnetic field oscillate in phase and are at right angles to each other and to the direction of travel.

Electromagnetic Waves includes TV, Radio, visible light, microwaves etc which by definition all have the same speed (3×10^8 ms^{-1}) but each different wave has its own range of frequency and wavelength.

A 3-D representation of a wave can be seen as follows



Experiments have shown that when light interacts with matter (e.g. effect of light falling on a photographic film) this is due to the electric field. For this reason light “vibrations” are considered to be the variations of the electric field strength E.

Permittivity and Permeability of Free Space

Expressions for the electric and magnetic fields in free space contain the electric permittivity ε_0 and magnetic permeability μ_0 of free space.

These two quantities are not independent but are related to "c", the speed of light and other electromagnetic waves.

The magnetic constant $\mu_0 = 4\pi \times 10^{-7}$ T m/A is called the permeability of free space.
The permeabilities of most materials are very close to μ_0 since most materials will be classified as either paramagnetic or diamagnetic.

Definitions[1]

Diamagnetic materials are slightly repelled by a magnetic field and the material does not retain the magnetic properties when the external field is removed. In diamagnetic materials all the electrons are paired so there is no permanent net magnetic moment per atom. Diamagnetic properties arise from the realignment of the electron paths under the influence of an external magnetic field. Most elements in the periodic table, including copper, silver, and gold, are diamagnetic.

Paramagnetic materials are slightly attracted by a magnetic field and the material does not retain the magnetic properties when the external field is removed. Paramagnetic properties are due to the presence of some unpaired electrons, and from the realignment of the electron paths caused by the external magnetic field. Paramagnetic materials include magnesium, molybdenum, lithium, and tantalum.

Ferromagnetic materials exhibit a strong attraction to magnetic fields and are able to retain their magnetic properties after the external field has been removed. Ferromagnetic materials have some unpaired electrons so their atoms have a net magnetic moment. They get their strong magnetic properties due to the presence of magnetic domains. In these domains, large numbers of atom's moments (10^{12} to 10^{15}) are aligned parallel so that the magnetic force within the domain is strong. When a ferromagnetic material is in the unmagnitised state, the domains are nearly randomly organised and the net magnetic field is zero. When a magnetising force is applied, the domains become aligned to produce a strong magnetic field within the material. Iron, nickel, and cobalt are examples of ferromagnetic materials.

1 ttp://www.ndt-ed.org/EducationResources/CommunityCollege/MagParticle/Physics/MagneticMatls.htm

In ferromagnetic materials the permeability may be very large and it is convenient to characterise these materials using a relative permeability.

Having established the magnetic permeability, the electric permittivity can be calculated from the relationship

$c = 1/\sqrt{(\varepsilon_0 \mu_0)}$
where the speed of light is given by
$c = 2.99792458 \times 10^{8}$ m/s (exact)

This gives a value of free space permittivity
$\varepsilon_0 = 8.854187817 \times 10^{-12}$ F/m
which in practice is often used in the form

$k = 1/4 \pi \varepsilon_0 = 8.987552 \text{ X}10^{9}\ \text{Nm}^2/\text{C}^2$ = Coulomb's constant

These expressions contain the units F for Farad, the unit of capacitance, and C for Coulomb, the unit of electric charge.

The electric permittivity is
- connected to the energy stored in an electric field
- involved in the expression for capacitance because it affects the amount of charge which must be placed on a capacitor to achieve a certain net electric field.

In the presence of a polarisable medium, it takes more charge to achieve a given net electric field and the effect of the medium is often stated in terms of a relative permittivity.

The magnetic permeability is connected to the energy stored in a magnetic field. It is involved in the expression for inductance because in the presence of a magnetisable medium, a larger amount of energy will be stored in the magnetic field for a given current through the coil. The effect of the medium is often stated in terms of a relative permeability.

Experiments to Measure:

- permittivity using a parallel plate capacitor
  Use Virtual Advanced Higher Physics

- permeability using a current balance
  Use Virtual Advanced Higher Physics.