ELECTROMAGNETIC WAVES

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Electromagnetic Waves:

For a region where there are no charges and conduction current, Faraday's and Ampere's laws take the symmetrical form:

$$\oint_{l} \vec{E} \cdot \vec{dl} = -\frac{d\Phi_B}{dt} \quad \text{and} \quad \oint_{l} \vec{B} \cdot \vec{dl} = -\mu_0\varepsilon_0 \frac{d\Phi_E}{dt}$$

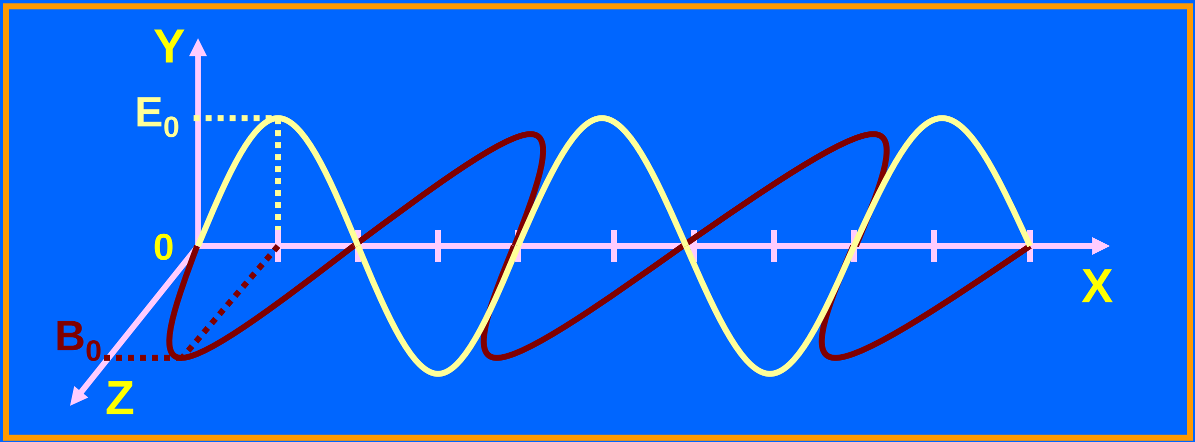
It can also be shown that time – varying electric field produces space – varying magnetic field and time – varying magnetic field produces space – varying electric field with the equations:

$$\frac{jE_y}{jx} = -\frac{jB_z}{jt} \quad \text{and} \quad \frac{jB_z}{jx} = -\mu_0\varepsilon_0 \frac{jE_y}{jt}$$

Electric and magnetic fields are sources to each other.

Electromagnetic wave is a wave in which electric and magnetic fields are perpendicular to each other and also perpendicular to the direction of propagation of wave.

Properties of Electromagnetic Waves:



1. Variations in both electric and magnetic fields occur simultaneously. Therefore, they attain their maxima and minima at the same place and at the same time.
2. The direction of electric and magnetic fields are mutually perpendicular to each other and as well as to the direction of propagation of wave.
3. The electric field vector E and magnetic field vector B are related by $c = E_0 / B_0$ where E_0 and B_0 are the amplitudes of the respective fields and c is speed of light.

4. The velocity of electromagnetic waves in free space, $c = 1 / \sqrt{\mu_0 \varepsilon_0}$

5. The velocity of electromagnetic waves in a material medium $= 1 / \sqrt{\mu\varepsilon}$ where μ and ε are absolute permeability and absolute permitivity of the material medium.

6. Electromagnetic waves obey the principle of superposition.

7. Electromagnetic waves carry energy as they propagate through space. This energy is divided equally between electric and magnetic fields.

8. Electromagnetic waves can transfer energy as well as momentum to objects placed on their paths.

9. For discussion of optical effects of EM wave, more significance is given to Electric Field, E. Therefore, electric field is called 'light vector'.

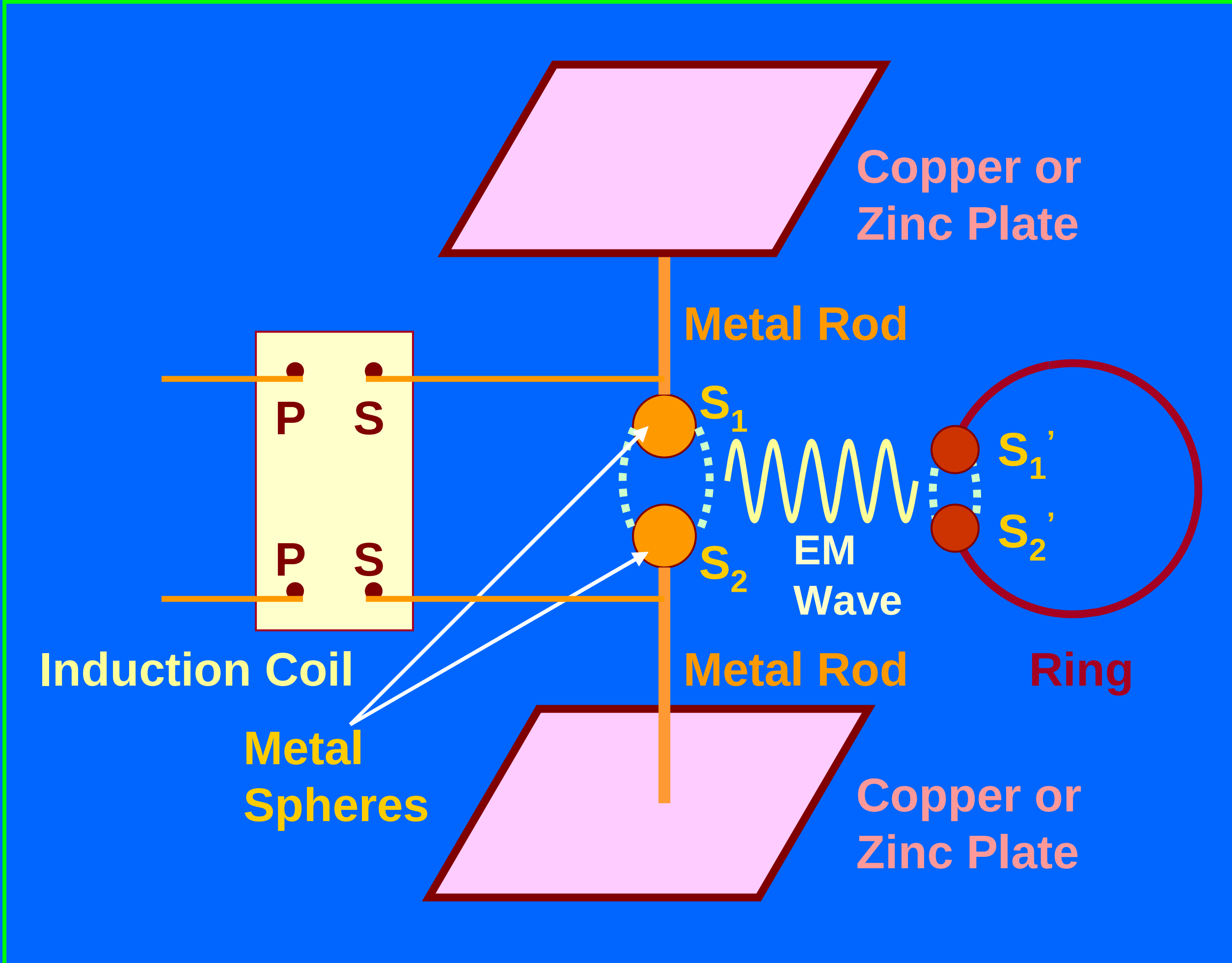
10. Electromagnetic waves do not require material medium to travel.

11. An oscillating charge which has non-zero acceleration can produce electromagnetic waves.

Hertz Experiment:

The copper or zinc plates are kept parallel separated by 60 cm. The metal spheres are slided over the metal rods to have a gap of 2 to 3 cm. Induction coil supplies high voltage of several thousand volts.

The plates and the rods (with spheres) constitute an LC combination.



An open metallic ring of diameter 0.70 m having small metallic spheres acts as a detector.

This constitutes another LC combination whose frequency can be varied by varying its diameter.

Due to high voltage, the air in the small gap between the spheres gets ionised. This provides the path for the discharge of the plates. A spark begins to pass between the spheres.

A very high frequency oscillations of charges occur on the plates. This results in high frequency oscillating electric field in the vertical gap S_1S_2. Consequently, an oscillating magnetic field of the same frequency is set up in the horizontal plane and perpendicular to the gap between the spheres.

These oscillating electric and magnetic fields constitute electromagnetic waves. The electromagnetic waves produced are radiated from the spark gap.

The detector is held in a position such that the magnetic field produced by the oscillating current is perpendicular to the plane of the coil. The resultant electric field induced by the oscillating magnetic field causes the ionisation of air in the gap between the spheres. So, a conducting path becomes available for the induced current to flow across the gap. This causes sparks to appear at the narrow gap.

It was observed that this spark was most intense when the spheres S_1S_2 and $S_1'S_2'$ were parallel to each other. This was a clear evidence of the polarisation of the electromagnetic waves.

Hertz was able to produce electromagnetic waves of wavelength nearly 6 m. After seven years, J.C. Bose succeeded in producing the em waves of wavelength ranging from 25 mm to 5 mm.

Electromagnetic Spectrum:

S. No.	EM Wave	Range of λ	Range of ν	Source	Use
1	Radio Wave	A few km to 0.3 m	A few Hz to 10^9 Hz	Oscillating electronic circuits	Radio and TV broadcasting
2	Microwave	0.3 m to 10^{-3} m	10^9 Hz to 3×10^{11} Hz	Oscillating electronic circuits	Radar, analysis of fine details of atomic and molecular structures & Microwave oven
3	Infra Red wave	10^{-3} m to 7.8×10^{-7} m	3×10^{11} Hz to 4×10^{14} Hz	Molecules and hot bodies	Industry, medicine, astronomy, night vision device, green house, revealing secret writings on ancient walls, etc.
4	Light or Visible Spectrum	7.8×10^{-7} m to 3.8×10^{-7} m	4×10^{14} Hz to 8×10^{14} Hz	Atoms and molecules when electrons are excited	Optics and Optical Instruments, Vision, photography, etc.

S. No.	EM Wave	Range of λ	Range of v	Source	Use
5	Ultra Violet Rays	3.8×10^{-7} m to 6×10^{-10} m	8×10^{14} Hz to 3×10^{17} Hz	Atoms and molecules in electrical discharges and Sun	Medical application, sterilization, killing bacteria and germs in food stuff, detection of invisible writing, forged documents, finger print, etc.
6	X - Rays	10^{-9} m to 6×10^{-12} m	3×10^{17} Hz to 5×10^{19} Hz	Inner or more tightly bound electrons in atoms	X-ray photography, treatment of cancer, skin disease & tumor, locating cracks and flaws in finished metallic objects, detection of smuggled goods in bags of a person, study of crystal structure, etc.
7	γ-Rays	They overlap the upper limit of the X-Ray. 10^{-10} m to 10^{-14} m	3×10^{18} Hz to 3×10^{22} Hz	Radioactive substances	Information about structure of nuclei, astronomical research, etc.