Engineering Physics

(PHY1701)

Dr. B. Ajitha
Assistant Professor
Division of Physics
VIT University
Chennai, India
ajitha.b@vit.ac.in

Contents

- Physics of Divergence, Gradient and Curl (DJG 13-20),
- Qualitative understanding of surface and volume integral (DJG 24, 26, 27),
- Maxwell Equations (Qualitative) (DJG 232, 321-327),
- Wave Equation (Derivation) (DJG 364-366), &
- EM Waves, Phase velocity, Group velocity, **Group index***, (DJG 405)
- **Hertz Experiment**

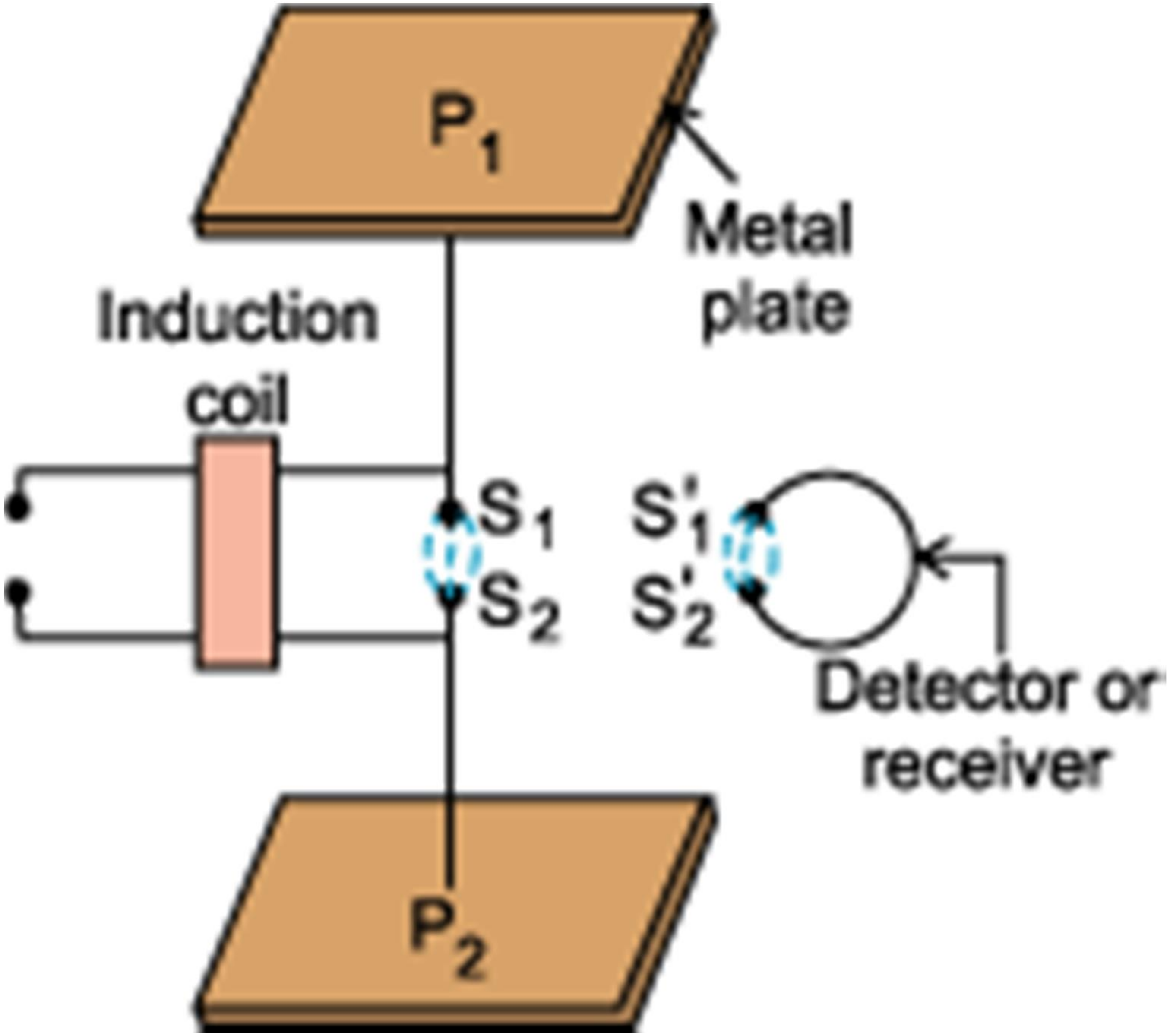
❖ William Silfvast, Laser Fundamentals, 2008, Cambridge University Press.

Introduction and Principle of Hertz Experiment

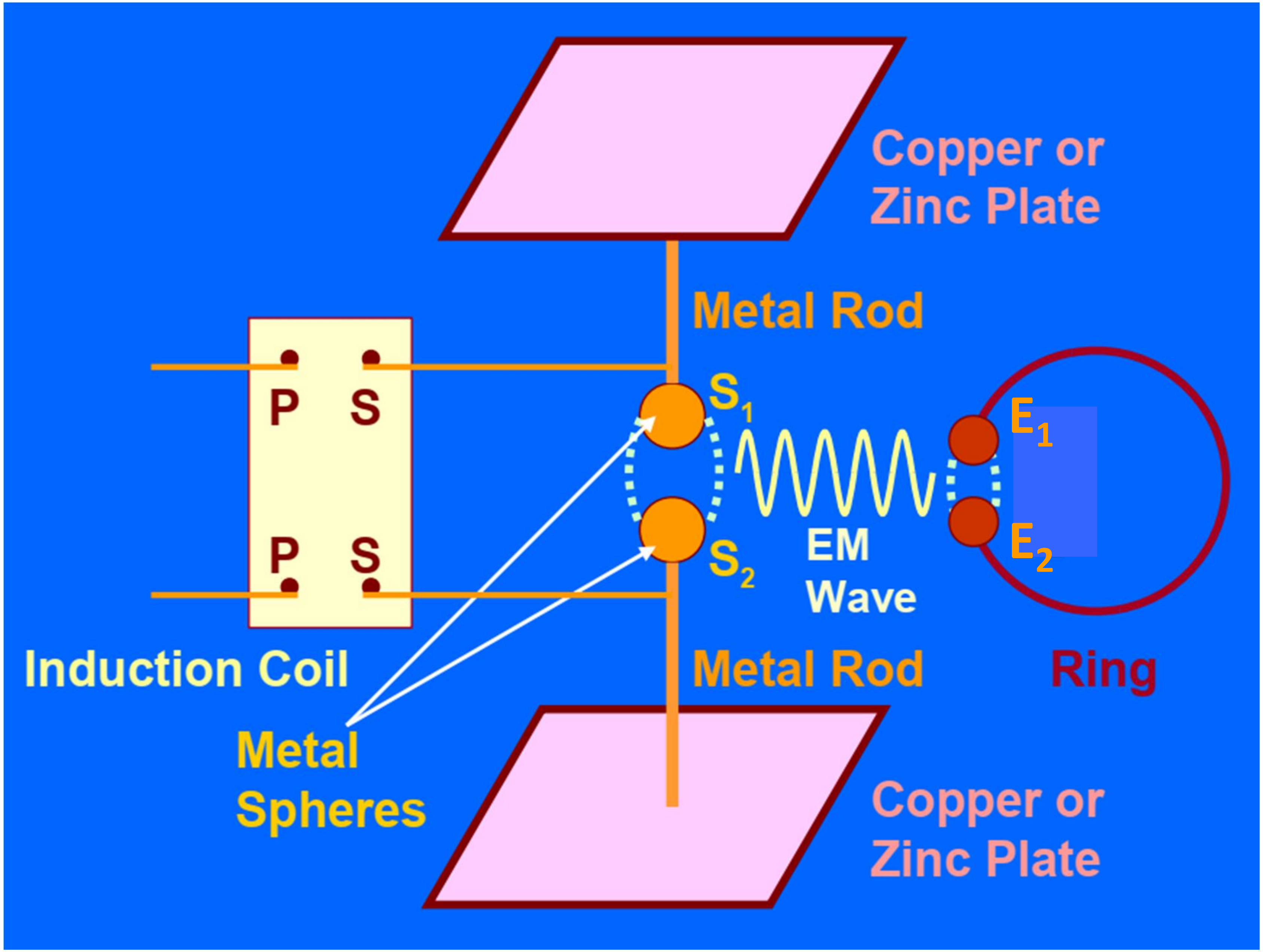
- In 1865, Maxwell theoretically predicted the existence of electromagnetic waves in the form of varying electric and magnetic fields.
- He concluded that accelerated charge is the source of electromagnetic waves. However, it was in 1887 that Heinrich Hertz experimentally proved the existence of electromagnetic waves.
- Hertz experimentally demonstrated the production and detection of electromagnetic waves in the laboratory.

Principle: Hertz showed that oscillating electric charge radiates electromagnetic waves. The energy carried by the waves is actually transformed kinetic energy of the oscillating charge. It was found that the distance of oscillation of charge was closely related to wavelength of the radiation.

Hertz Experiment



Hertz Experiment



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 ionized.
- This provides the path for the discharge of the plates. A spark begins to pass between the spheres.

Hertz Experiment

- 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.

Hertz Experiment

- The resultant electric field induced by the oscillating magnetic field causes the ionization 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 E_1E_2 were parallel to each other. This was a clear evidence of the polarization 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.

Important points

- Oscillating electric charge radiates electromagnetic waves.
- Velocity of electromagnetic wave, $c = \lambda . \nu$

  where λ is the wavelength and ν is the frequency of electromagnetic wave.
- Frequency $\nu = \frac{1}{2\pi\sqrt{LC}}$

  where C is the capacitance and L is the inductance.

Refractive index

- In optics, the refractive index (also known as refraction index or index of refraction) of a material is a dimensionless number that describes how fast light travels through the material.
- It is defined as, $$n = \frac{c}{v}$$

  where c is the speed of light in vacuum and v is the phase velocity of light in the medium.
- Increasing the refractive index corresponds to decreasing the speed of light in the material.

Group index

- "group velocity refractive index", usually called as group index. $n_g = \frac{c}{v_g}$ where v_g is the group velocity.
- This value should not be confused with n, which is always defined with respect to the phase velocity.
- When the dispersion is small, the group velocity can be linked to the phase velocity by the relation,

$$\boldsymbol{v_g = v_p - \lambda \left(\frac{dv_p}{d\lambda}\right)}$$ where λ is the wavelength in the medium

- In this case the group index can thus be written in terms of the wavelength dependence of the refractive index as

$$n_g = \frac{n}{1 + \frac{\lambda}{n}\frac{dn}{d\lambda}}$$

Electromagnetic Waves

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

$$\oint_{l} \vec{E}\,.\,d\vec{l} = -\frac{d\Phi_B}{dt} \qquad \text{and} \qquad \oint_{l} \vec{B}\,.\,d\vec{l} = -\mu_0\varepsilon_0 \frac{d\Phi_E}{dt}$$

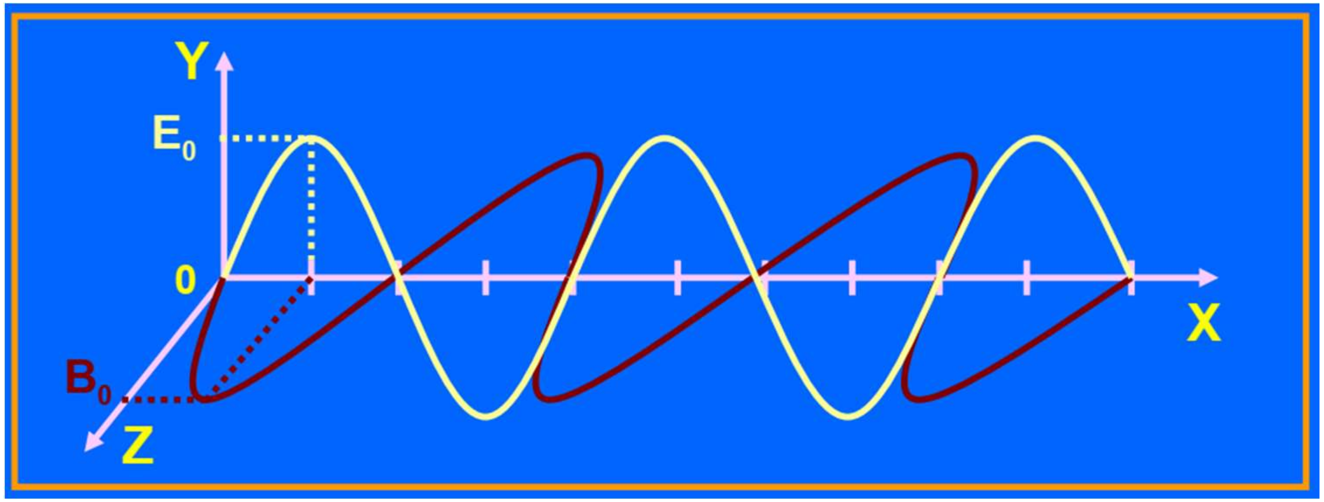
It can also be shown that time – varying electric field produces space – varying magnetic field and time – varying magnetic field produces space – varying electric field with the equations:

$$\frac{\partial E_y}{\partial x} = -\frac{\partial B_z}{\partial t} \qquad \text{and} \qquad \frac{\partial B_z}{\partial x} = -\mu_0\varepsilon_0 \frac{\partial E_y}{\partial t}$$

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



- 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.
- The direction of electric and magnetic fields are mutually perpendicular to each other and as well as to the direction of propagation of wave.

Properties of Electromagnetic Waves

- 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.
- The velocity of electromagnetic waves in free space, $c = 1 / \sqrt{\mu_0 \varepsilon_0}$
- The velocity of electromagnetic waves in a material medium $= 1 / \sqrt{\mu\varepsilon}$. where μ and ε are absolute permeability and absolute permittivity of the material medium.
- Electromagnetic waves obey the principle of superposition.
- Electromagnetic waves carry energy as they propagate through space. This energy is divided equally between electric and magnetic fields.

Properties of Electromagnetic Waves

- Electromagnetic waves can transfer energy as well as momentum to objects placed on their paths.
- For discussion of optical effects of EM wave, more significance is given to Electric Field, E. Therefore, electric field is called ‘light vector’.
- Electromagnetic waves do not require material medium to travel.
- An oscillating charge which has non-zero acceleration can produce electromagnetic waves.