CLASS – 12

WORKSHEET- ELECTROMAGNETIC WAVES

A. MAXWELLS- AMPERE'S LAW & DISPLACEMENT CURRENT

(1 Mark Questions)

1. How is displacement current produced between the plates of a parallel plate capacitor during charging?

Sol. Displacement current is produced by the time varying electric flux or electric field across the dielectric medium between capacitor plats that leads to polarization and displacement of charges.

2. The charging current for a capacitor is 0.25A. What is the displacement current across the plates?

Sol. The displacement current is equal to 0.25A, as the charging current is 0.25A.

3. A capacitor has been charged by a dc source. What are the magnitude of conduction and displacement current, when it is fully charged?

Sol. Electric flux through a plates of capacitor, $\phi_E = \frac{d\phi_E}{dt} = \varepsilon_0 \frac{d\left(\frac{q}{\varepsilon_0}\right)}{dt} = 0$, conduction current, I $= C\frac{dV}{dt} = 0$ as voltage becomes constant.

(2 Marks Questions)

4. A parallel plate capacitor of plate area A each and separation d, is being charged by an ac source. Show that the displacement current inside the capacitor is the same as the current charging the capacitor.

Sol. When an ideal capacitor is charged by dc battery, no current flows as capacitor offers infinite resistance to dc. Whereas since a capacitor offers a finite resistance to ac, when an ac source is connected then conduction current $I_C = \frac{dQ}{dt}$ flows in the connecting wire. Due to charging current, charge deposited on the plates of the capacitor charges with time. Changing charge produces varying electric field between the plats of capacitor, giving rise to displacement current $I_d = \varepsilon_0\frac{d\phi_E}{dt}$ [As displacement current is proportional to the rate of flux variation]. The electric field between the plates is $E = \frac{\sigma}{\varepsilon_0} = \frac{Q}{A\varepsilon_0}$. Electric flux, ϕ_E = EA =- $\frac{Q}{A\varepsilon_0}$A = $\frac{Q}{A\varepsilon_0}$. So $I_d = \varepsilon_0\frac{d\phi_E}{dt} = \varepsilon_0\frac{d}{dt}\left(\frac{Q}{\varepsilon_0}\right) = \frac{dQ}{dt} = I_C$. Displacement current brings continuity in the flow of current between plates of the capacitor.

5. How does Ampere-Maxwell law explain the flow of current through a capacitor when it is being charged by a battery? Write the expression for the displacement current in terms of the rate of change of electric flux.

Sol. According to Ampere-Maxwell law, the total current is the sum of displacement current and the conduction current, i.e., $i = i_c + i_d = i_c + \varepsilon_0\frac{d\phi_E}{dt}$. When a capacitor is charge through a battery then inside the capacitor plates there is no conduction current, i.e., i_c= 0 and there is only displacement current so that i_d = i. The displacement current is $i_d = \varepsilon_0\frac{d\phi_E}{dt}$

6. Why does current in a steady state not flow in a capacitor connected across a battery? However momentary current does flow during charging or discharging of the capacitor. Explain.

Sol. There is no ac voltage applied on a capacitor when it is connected across a battery so no current flows in a capacitor. When a capacitor is charging, current flows towards the positive plate (as positive charge is added to that plate) and away from the negative plate. When the capacitor is discharging, current flows away from the positive and towards the negative plate, in the opposite direction.

7. A capacitor, made of two parallel plates each of plate area A and separation d, is being charged by an external ac source. Show that the displacement current inside the capacitor is the same as the current charging the capacitor.

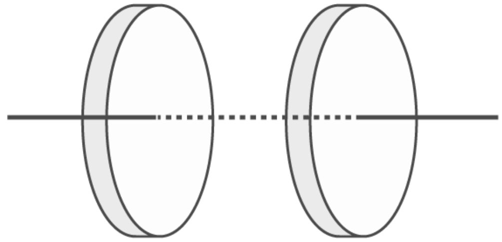
Sol. Same as Sol. 4

8. When an ideal capacitor is charged by a dc battery, no current flows. However, when an ac source is used, the current flows continuously. How does one explain this, based on the concept of displacement current?

Sol. Same as Sol. 4

(3 Marks Questions)

9. The Figure shows a capacitor made of two circular plates each of radius 12 cm and separated by 5.0 cm. The capacitor is being charged by an external source (not shown in the figure). The charging current is constant and equal to 0.15A.
(a) Calculate the capacitance and the rate of change of the potential difference between the plates.
(b) Obtain the displacement current across the plates.
(c) Is Kirchhoff's first rule (junction rule) valid at each plate of the capacitor? Explain.



Sol. Radius, $R = 12cm = 12 \times 10^{-2}m$, Plate separation, $d = 5.0mm = 5 \times 10^{-3}m$, Plate area, $A = \pi R^2 = \pi \times (12 \times 10^{-2})^2 \, m^2$.

(a) Capacitance, $C = \frac{\varepsilon_0 A}{d} = \frac{8.85\times10^{-12}\times\pi\times(12\times10^{-12})^2}{5\times10^{-3}} = 8.01 \times 10^{-12}F = 80.1 \, pF$

Now the charge at any instant on a capacitor plate is, $q = CV$.

Therefore $I = \frac{dq}{dt} = C.\frac{dV}{dt}$

Thus the rate of change of potential difference between the plate is $\frac{dV}{dt} = \frac{I}{C} = \frac{0.15}{80.1\times10^{-12}}$ $= 1.875 \times 10^9 \, Vs^{-1}$

(b) From the property of continuity, Displacement current = Conduction current

Therefore $I_D = I = 0.15A$

(c) As the sum $(I + I_D)$ is continuous, so the Kirchhoff's first law is valid at capacitor plate if the current in the law is the sum of conduction and displacement currents.

10. Write Maxwell's generalization of Ampere's Circuital Law. Show that in the process of charging a capacitor, the current produced within the plates of the capacitor is: $i = \varepsilon_0 \frac{d\phi_\varepsilon}{dt}$

ϕ_ε where is the electric flux produced during charging of the capacitor plates.

Sol. Maxwell's generalization of Ampere's circuital law, $\oint \vec{B}.\vec{dl} = \mu_0 \left(i + \varepsilon_0 \frac{d\phi_E}{dy}\right)$

In the process of charging the capacitor there is charge in electric flux between the capacitor plates.

$\frac{d\phi_E}{dt} = \frac{d}{dt}(EA)$

E – electric field between the plates $= \frac{q}{A\varepsilon_0}$, A – area of plate.

So, $\frac{d\phi_E}{dt} = \frac{d}{dt}\left(\frac{q}{A\varepsilon_0} \times A\right) = \frac{1}{\varepsilon_0}\frac{dq}{dt} = \frac{i_d}{\varepsilon_0}$

Therefore $i_d = \varepsilon_0 \frac{d\phi_E}{dt}$.

B. ELECTROMAGNETIC WAVE

(1 Mark Questions)

1. Answer the following questions: (1 mark each)

(a) Long distance radio broadcasts use short-wave bands. Why?

Ans. It is because the radio waves of shortwave band are easily reflected back to the earth by the ionosphere.

(b) It is necessary to use satellite for long distance TV transmission. Why?

Ans. TV signals of high frequency are not reflected by the ionosphere. Also, ground wave transmission is possible only upto a limited range. That is why satellites are used in long distance TV transmission.

(c) Optical and radio-telescopes are built on the ground by X-ray astronomy is possible only from satellites orbiting the earth. Why?

Ans. The earth's atmosphere is transparent to visible light and radio waves but it absorbs X rays. X ray astronomy is possible only from satellites orbiting the earth. These satellites orbit at a height of 36000km, where the atmosphere is very thin and X rays are not absorbed.

(d) The small ozone layer on top of the stratosphere is crucial for human survival. Why?

Ans. Ozone layer absorbs ultraviolet radiation from the sun and prevents it from reaching the earth and causing damage to life

(e) If the earth did not have an atmosphere, would its average surface temperature by higher or lower than what it is now?

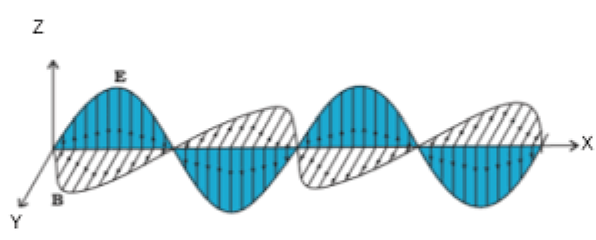
Ans. The earth radiates infrared waves which are refracted by the gases in the lower atmosphere. This phenomenon, called Green house effect, keeps the earth, warm. So if the earth did not have atmosphere, its average temperature would be low due to the absence of Green house effect.

(f) Some scientists have predicted that a global nuclear war on the earth would be followed by a severe 'nuclear winter' with a devastating effect on life on earth. What might be the basis of this prediction?

Ans. The clouds produced by global nuclear war would perhaps cover substantial parts of the sky preventing solar light from reaching many parts of the globe. This would cause a 'nuclear winter'.

2. Depict the field diagram of an electromagnetic wave propagating strong positive X-axis with its electric field along Y-axis.

Sol. In figure the velocity of propagation of em wave is along X axis and $\vec{v} = v\hat{i}$ and electric field $\vec{E}$ along Y axis and magnetic field $\vec{B}$ along z axis.



3. Illustrate by giving suitable examples, how you can show that electromagnetic waves carry both energy and momentum.

Sol. Electromagnetic waves like other waves carry energy and momentum as they travel through empty space. If light didn't carry energy and momentum, it wouldn't be able to heat stuff up or generate photocurrent in photocells.

4. How is the speed of em-waves in vacuum determined by the electric and magnetic fields?

Sol. The speed of em waves in vacuum determined by the electric (E_0) and magnetic fields (B_0) is, $c = E_0/B_0$.

5. Do electromagnetic waves carry energy and momentum?

Sol. Yes electromagnetic waves carry energy and momentum.

6. Write the relation for the speed of electromagnetic waves in terms of the amplitudes of electric and magnetic fields.

Sol. Same as 4.

7. In which direction do the electric magnetic and magnetic field vectors oscillate in an electromagnetic wave propagating along the x-axis?

Sol. When an electromagnetic wave is propagating along the x axis then, electric field vector oscillates in y axis and magnetic field vector oscillates in z axis.

8. What is the frequency of electromagnetic waves produced by oscillating charge of frequency υ?

Sol. Frequency of the electromagnetic wave produced will be equal to the frequency υ of oscillating charge.

9. A plane electromagnetic wave travels in vacuum along z-direction. What can you say about the direction of electric and magnetic field vectors?

Sol. The electric and magnetic field vectors $\vec{E}$ and $\vec{B}$ are perpendicular to each other and also perpendicular to the direction of propagating of the electromagnetic wave. If a plane electromagnetic wave is propagating along the z direction, then the electric field is along x axis, and magnetic field is along y axis.

10. A welder wears special glasses to protect his eyes mostly from the harmful effect of

(a) very intense visible light (b) infrared radiation

(c) ultraviolet rays (d) microwaves

Ans. (c)

11. Electromagnetic waves used as a diagnostic tool in medicine are
(a) X rays (b) ultraviolet rays (c) infrared radiations (d) ultrasonic waves

Ans. (a)

12. The small ozone layer on top of the stratosphere is crucial for human survival. Why?

Sol. The small ozone layer on top of the stratosphere is crucial for human survival because it absorbs harmful ultraviolet radiations present in sunlight and prevents it from reaching the earth's surface. The ultraviolet radiations can cause many types of skin diseases and is harmful to the living cells and plants.

13. Name the electromagnetic radiations used for the (a) water purification, and (b) eye surgery.

Sol. Ultraviolet Radiations with the wavelength shorter than visible light is used for Water Purification (RO + UV System) and Lasik eye surgery.

14. Why are microwaves considered suitable for radar systems used in aircraft navigation?

Sol. Microwaves have wavelengths of the order of a few millimeters. Due to their short wavelengths, these are not diffracted (bent) much by objects of normal dimensions. So they can be transmitted as a bean in a particular direction.

15. To which part of the electromagnetic spectrum does a wave of frequency 5×10^{19}Hz belong?

Sol. The electromagnetic spectrum of a wave of frequency 5×10^{19}Hz belong to gamma region.

16. Arrange the following electromagnetic waves in order of increasing frequency: γ-rays, Microwaves, infrared rays and Ultraviolet rays.

Sol. Micro waves, infrared waves, ultraviolet radiations, γ rays.

17. Welders wear special goggles or face masks with glass windows to protect their eyes from electromagnetic radiations. Name the radiations and write the range of their frequency.

Sol. Welders wear special goggles or face masks with glass windows to protect their eyes from Ultraviolet (UV) radiations. Their range is 8×10^{14}Hz to 3×10^{16}Hz.

18. Name the electromagnetic waves, which (i) maintain the Earth's warmth and (ii) are used in aircraft navigation.

Sol. (i) Infrared rays maintain the earth's warmth. (ii) Microwaves are used in aircraft navigation due to their short wavelength.

19. Name the physical quantity which remains same for microwaves of wavelength 1mm and UV radiations of 1600Å in vacuum.

Sol. Velocity or speed of propagation.

20. How are radio waves produced?

Sol. A radio wave is generated by a transmitter and then detected by a receiver. An antenna allows a radio transmitter to send energy into space and a receiver to pick up energy from space. Transmitters and receivers are typically designed to operate over a limited range of frequencies.

21. Write two uses of microwaves.

Sol. They are used in communications, radio astronomy, remote sensing, radar, and of course, owing to their heating application, they are used in cooking as well.

(2 Marks Questions)

22. What physical quantity is the same for X-rays of wavelength 10^{-10}m, the red light of wavelength 6800 Å and radiowaves of wavelength 500m?

Sol. The wave speed in vacuum is the same for all radiations: e = 3×10^8 m/s.

23. A plane electromagnetic wave travels in vacuum along the z-direction. What can you say about the directions of its electric and magnetic field vectors? If the frequency of the wave is 30 MHz, what is its wavelength?

Sol. The electric magnetic field vectors $\vec{E}$ and $\vec{B}$ of an em wave must be perpendicular to each other and also to the direction of propagation of the wave. Hence vectors $\vec{E}$ and $\vec{B}$ lie in xy plane in mutually perpendicular directions.

Frequency, v = 30MHz = 30×10^6Hz. Therefore wavelength, $\lambda = \frac{c}{v} = \frac{3\times10^8}{30\times10^6}$ = 10m.

24. A radio can tune in to any station in the 7.5 MHz to 12 MHz bands. What is the corresponding wavelength band?

Sol. Here v_1 = 7.5 MHz = 7.5×10^6 Hz, v_2 = 12 MHz = 1 2× 10^6 Hz, Therefore

$\lambda_1 = \frac{c}{v_1} = \frac{3\times10^8}{7.5\times10^6}$ = 40m

$\lambda_2 = \frac{c}{v_2} = \frac{3\times10^8}{12\times10^6}$= 25m

Thus the wavelength band is 40m – 25m.

25. A charged particle oscillates about its mean equilibrium position with a frequency of 10^9 Hz. What is the frequency of the electromagnetic waves produced by the oscillator?

Sol. According to Maxwell, a charged particle oscillating with a frequency of 10^9Hz, produces electromagnetic waves of the same frequency 10^9Hz.

26. The amplitude of the magnetic field part of a harmonic electromagnetic wave in vacuum is B_0=510 nT. What is the amplitude of the electric field part of the wave?

Sol. Here $B_0 = 510nT = 510\times10^{-9}T$.

Amplitude of electric field, $E_0 = cB_0 = 3 \times 10^8 \times 510 \times 10^{-9} = 153$ N/C.

27. Which of the following electromagnetic waves has (a) minimum wavelength, and (b) minimum frequency? Write one use of each of these two waves: infrared waves, Microwaves, γ-rays and X-rays.

Sol. Gamma rays have the minimum wavelength and the infrared radiations have the maximum wavelength. Note: The visible light has its own spectrum. This spectrum is called VIBGYOR. According to this spectrum, violet light has the minimum wavelength and red light has the maximum wavelength.

Infrared waves are used in remote control of television and other gadgets. Microwave rays are used for stat elite communication. X rays are used for observing fractures for treatment of bones. Gamma rays are used in medical science to kill cancer cells.

28. Gamma rays and radio waves travel with the same velocity in free space. Distinguish between them in terms of their origin and the main application.

Sol. Gamma rays: These rays are of nuclear origin and are produce in the disintegration of radioactive atomic nuclei and in the decay of certain subatomic particles. They are used in the treatment of cancer and turnouts.

Radio waves: These rays are produced by the accelerated motion of charges in conducting wires or oscillating electric circuits having inductor and capacitor. These are used in satellite, radio and television communication.

29. Why are infrared waves often called heat waves? Explain.

Sol. Infrared wave incident on a substance increase the internal energy and hence the temperature of the substance. That is why they are called heat waves.

30. Identify the electromagnetic waves whose wavelengths vary as (a) $10^{-12}m < \lambda < 10^{-8}m$ (b) $10^{-3}m < \lambda < 10^{-1}m$. Write one use for each.

Sol. (a) X rays – used to study atomic structure. (b) Microwaves – used in radar application.

31. Identify the electromagnetic waves whose wavelength vary as (a) $10^{-11}m < \lambda < 10^{-14}m$ (b) $10^{-4}m < \lambda < 10^{-6}m$. Write one use for each.

Sol. (a) Gamma rays lie between 10^{-11} m to 10^{-14}m. These rays are used in radiotherapy to treat certain cancers and tumors. (b) Infrared wave lie between 10^{-4} to 10^{-6}m. These waves are used in taking photographs during conditions of fog, smog, etc as these waves are scattered than visible rays.

32. Name the types of em radiations which (i) are used in destroying cancer cells, (ii) cause tanning of the skin and (iii) maintain the earth's warmth. Write briefly a method of producing any one of these waves.

Sol. (i) Gamma rays (ii) UV rays (iii) Infrared radiations.
Infrared waves are produced by hot bodies and molecules. Infrared waves are referred to as heat waves, because water molecules present in most materials readily absorb infrared waves (many other molecules for example CO_2, NH_3, also absorb infrared waves). After absorption, their thermal motion increases, that is they heat up and heat their surroundings.

33. (a) Arrange the following electromagnetic waves in the descending order of their wavelengths: (i) Microwaves (ii) Infra-red rays (iii) Ultra-violet radiation (iv) Gamma rays
(b) Write one use each of any two of them.

Sol. (a) Descending order of wavelengths of given electromagnetic waves is: Microwaves (10^{-3} 10^{-1}m); Infrared rays ($7.5 \times 10^{-7} - 10^{-3}$)m; Ultraviolet radiation ($10^{-9} - 4 \times 10^{-7}$)m, ; Gamma rays ($< 10^{-12}$)m.
(b) Microwaves: Frequency range – 3×10^8 Hz – 3×10^{11}Hz. These are suitable for the radar system used in aircraft navigation.
Gamma rays: Frequency range - > 3×10^{21}Hz. Theses waves are used for treatment of cancer cells.

34. Name the constituent radiation of electromagnetic spectrum which is used for
(i) aircraft navigation (ii) studying crystal structure. Write the frequency range for each.

Sol. (i) Microwaves are used in radar system for aircraft navigation. The frequency range is 3×10^8Hz to 3×10^{11}Hz. (ii) X rays are used for studying crystal structure of solids. Their frequency range is 3×10^{16}Hz to 3×10^{21} Hz.

35. What does an electromagnetic wave consist of? On what factors does its velocity in a vacuum depend?

Sol. An electromagnetic wave consists of electric and magnetic fields, oscillating sinusoidally both in time and space. The two fields are perpendicular to each other as well as to the direction of propagation of the wave.
The velocity of an e, wave in vacuum depends on its performability (μ_0) and permittivity (ε_0).

36. What oscillates in electromagnetic waves? Are these waves transverse or longitudinal?

Sol. (i) In em waves, electric and magnetic fields oscillate in mutually perpendicular directions.
(ii) These waves are transverse in nature.

37. What is the role of ozone in the atmosphere?

Sol. The ozone layer in the stratosphere absorbs a portion of the radiation from the sun, preventing it from reaching the planet's surface. Most importantly, it absorbs the portion of UV light called UVB. UVB is a kind of ultraviolet light from the sun (and sun lamps) that has several harmful effects.

(3 Marks Questions)

38. The terminology of different parts of the electromagnetic spectrum is given in the text. Use the formula E = hν (for the energy of a quantum of radiation: photon) and obtain the photon energy in units of eV for different parts of the electromagnetic spectrum. In what way are the different scales of photon energies that you obtain related to the sources of electromagnetic radiation?

Sol. Photon energy for λ = 1m is given by $E = h\nu = \frac{hc}{\lambda} = \frac{6.63\times10^{-34}\times3\times10^{8}}{1}$ J

$= \frac{6.63\times10^{-34}\times3\times10^{8}}{1.6\times10^{-19}}$ eV = 12.43×10^{-7}eV = 1.24×10^{-6}eV.

Photon energy for other wavelengths in the figure for electromagnetic spectrum can be obtained by multiplying appropriate power to ten.

Photon energy that a source produces indicates the spacings of the relevant energy levels of the source. For example, $\lambda = 10^{-12}$m corresponds to photon energy = 1.24×10^{6}eV = 1.24MeV.

39. In a plane electromagnetic wave, the electric field oscillates sinusoidally at a frequency of 2.0×10^{10} Hz and amplitude 48 V m^{-1}.

(a) What is the wavelength of the wave?

(b) What is the amplitude of the oscillating magnetic field?

(c) Show that the average energy density of the $\vec{E}$ field equals the average energy density of the $\vec{B}$ field.

Sol. (a) Wavelength, $\lambda = \frac{c}{\nu} = \frac{3\times10^{8}}{2.0\times10^{10}} = 1.5\times10^{-2}$m

(b) $B_0 = \frac{E_0}{c} = \frac{48}{3\times10^{8}} = 1.6 \times 10^{-7}$T

(c) Average energy density of $\vec{E}$ field, $u_E = \frac{1}{4} \varepsilon_0 E_0^2$.

Average energy density of $\vec{B}$ field, $u_B = \frac{1}{4\mu_0} B_0^2$

But $E_0 = cB_0$ and $c^2 = \frac{1}{\mu_0\varepsilon_0}$

Therefore $\frac{1}{4} \varepsilon_0 E_0^2 = \frac{1}{4} \varepsilon_0 (cB_0)^2 = \frac{1}{4}\varepsilon_0 . \frac{1}{\mu_0\varepsilon_0} . B_0^2 = \frac{1}{4\mu_0} B_0^2 = u_B$

40. About 5% of the power of a 100W light bulb is converted to visible radiation. What is the average intensity of visible radiation: (a) at a distance of 1m from the bulb (b) at a distance of 10m?

Sol. The bulb, as a point source, radicates light in all directions. At a distance of r m, the surface area of the surrounding sphere, $A = 4\pi r^2$.

There average intensity, $\frac{\text{Energy/Time}}{\text{Area}} = \frac{\text{Power}}{\text{Area}} = \frac{\text{Power}}{4\pi r^2}$

(a) Average intensity of visible radiation at distance of 1m = $\frac{5\% \text{ of } 100\text{W}}{4\pi(1\text{m})^2}$ = 0.4 Wm^{-2}.

(b) Average intensity of visible radiation at distance of 10m = $\frac{5\% \text{ of } 100\text{W}}{4\pi(10\text{m})^2}$ = 0.004 Wm^{-2}.

41. Write the expression for the generalized form of Ampere's circuital law. Discuss its significance and describe briefly how the concept of displacement current is explained through charging/discharging of a capacitor in an electric circuit.

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42. Prove that the average energy density of the oscillating electric field is equal to that of the oscillating magnetic field.

Sol. In an electromagnetic wave, both E and B field vary sinusoidally in space and time. The average energy density u of an em wave can be obtained by replacing E and B by their rms value.

$u = \frac{1}{2}\varepsilon_0 E_{rms}^2 + \frac{1}{2\mu_0} B_{rms}^2$ or $u = \frac{1}{4}\varepsilon_0 E_0^2 + \frac{1}{4\mu_0} B_0^2$ $[\because E_{rms} = \frac{E_0}{\sqrt{2}}, B_{rms} = \frac{B_0}{\sqrt{2}}]$

Moreover, $E_0 = cB_0$ and $c^2 = \frac{1}{\mu_0 \varepsilon_0}$, therefore

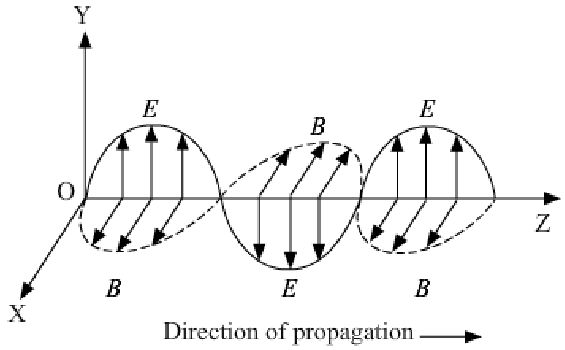
$u_E = \frac{1}{4}\varepsilon_0 E_0^2 = \frac{1}{4}\varepsilon_0 (cB_0)^2$

$u_E = \frac{1}{4}\varepsilon_0 . \frac{B_0^2}{\mu_0 \varepsilon_0} = \frac{1}{4\mu_0} B_0^2 = u_B$

43. How are e.m. waves produced by oscillating charges? Draw a sketch of linear polarized e.m. waves propagating in the z-direction. Indicate the directions of the oscillating electric and magnetic fields.

Sol. An oscillating or accelerated charge is supposed to be a source of an electromagnetic wave. An oscillating charge produces an oscillating electric field in space which further produces an oscillating magnetic field which in turn is a source of electric field. These oscillating electric and magnetic field hence, keep on regenerating each other and an electromagnetic wave is produced.

A plane electromagnetic wave is said to be linearly polarized. The transverse electric field wave accompanied by a magnetic field wave is illustrated.



44. Answer the following questions:
(i) Show by giving a simple example, how e.m. waves carry energy and momentum.
(ii) How are microwaves produced? Why is it necessary in microwave ovens to select the frequency of microwaves to match the resonant frequency of water molecules?
(iii) Write two important used of infrared waves.

Sol. (i) Consider a plane perpendicular to the direction of propagation of the wave. An electric charge, on the plane will be set in motion by the electric and magnetic fields of em wave, incident on this plane. This illustrates that em waves carry energy an momentum.
(ii) Microwaves are produced by special vacuum tube like the klystron, magnetron and Gunn diode. The frequency of microwaves is selected to match the resonant frequency of water molecules, so that energy is transformed efficiently to the kinetic energy of the molecules.
(iii) Uses of infrared waves: (a) They are used in night vision devices during warfare. This is because they can pass through haze, fog and mist. (b) Infrared waves are used in remote switches of household electrical applainaces.

45. State clearly how a microwave oven works to heat up a food item containing water molecules. Why are microwaves found useful for the radar systems in aircraft navigation?

Sol. In microwave oven, the frequency of the microwave is selected to match the resonant frequency of water molecules so that the energy from the waves get transferred efficiently to the kinetic energy of the molecules. This kinetic energy raises the temperature of any food containing water. Microwaves are short wavelength radio waves, with frequency of order GHz. Due to short wavelength, they have high penetrating power with respect to atmosphere and less diffraction in the atmospheric layers. So these waves are suitable for the radar system used in aircraft navigation.

46. Give one use of each of the following: (i) Microwaves (ii) Ultraviolet rays (iii) Infra-red rays (iv) Gamma rays.

Sol. (i) Microwaves: These are used in Radar system for aircraft navigation. (ii) Ultraviolet rays: These are used to destroy the bacteria and for sterilizing surgical instruments. (iii)

Infrared rays: These are used to treat muscular pain. (iv) Gamma rays: These are used for the treatment of cancer.

47. The velocity of propagation (in vacuum) and the frequency of (i) X-rays and (ii) radio-waves are denoted by (v_x, n_x) and (v_R, n_R) respectively. How do the values of (a) v_x and v_R (b) n_x and n_R, compare with each other?

Sol. (a) $v_x = v_R$ (ii) $n_X > n_R$.

48. An e.m. wave is travelling in a medium with a velocity $\vec{v} = v\hat{i}$. The electric field oscillations, of this e.m. wave, are along the y-axis. (a) Identify the direction in which the magnetic field oscillations are taking place, of the e.m. wave. (b) How are the magnitudes of the electric field and magnetic fields in the electromagnetic wave related to each other?

Sol. (a) Here em wave travels in x direction and electric field oscillates along y direction. But the em wave propagates in the direction of $\vec{E} \times \vec{B}$. Hence magnetic field must oscillate along z direction because $(+\hat{j}) = (+\hat{k}) = +\hat{i}$

(b) $\frac{E_0}{B_0}$ = c. speed of light.

49. The oscillating magnetic field in a plane electromagnetic wave is given by:

$$B_y = (8\times10^{-6}) \sin[2\times10^{11}t + 300\ \pi x]T$$

(i) Calculate the wavelength of the electromagnetic wave (ii) Write down the expression for the oscillating electric field.

Sol. Given $B_y = (8\times10^{-6}) \sin[2\times10^{11}t + 300\ \pi x]T$

Standard equation is $B_y = B_0 \sin [\sin 2\pi\left(\frac{x}{\lambda} + \frac{t}{T}\right)]$

On comparing, $\frac{2\pi}{\lambda} = 300\pi$ and $B_0 = 8 \times 10^{-6}T$

(i) Wavelength, $\lambda = \frac{2\pi}{300\pi} = \frac{1}{150}$ m = 0.67cm

(ii) $E_0 = cB_0 = 3 \times 10^8 \times 10^{-6} = 2400\ Vm^{-1}$

S $\lambda = \frac{2\pi}{300\pi} = \frac{1}{150}$ m = 0.67c

The magnetic field is perpendicular to the direction of propagation (x axis) and the direction of the electric field (y axis). So the expression for the oscillating electric field is $E_z = 2400 \sin [2 \times 10^{11}t + 300\pi x]\ Vm^{-1}$

50. The oscillating electric field of an electromagnetic wave is given by:

$$E_y = 30 \sin[2\times10^{11}\ t + \pi x]\ Vm^{-1}$$

(i) Obtain the value of wavelength of the electromagnetic wave (ii) Write down the expression for the oscillating magnetic field.

Sol. Given: $E_y = 30 \sin[2\times10^{11}\ t + \pi x]\ Vm^{-1}$

Standard equation is $E_y = E_0 \sin\left[2\pi\left(\frac{x}{\lambda} + \frac{t}{T}\right)\right]$

On comparing, $\frac{2\pi}{\lambda} = 300\pi$ and $E_0 = 30\ Vm^{-1}$

(i) Wavelength, $\lambda = \frac{2\pi}{300\pi} = \frac{1}{150}$ m = 0.67cm

(ii) $B_0 = \frac{E_0}{c} = \frac{30}{3\times10^8} = 10^{-7}$ T

The magnetic field is perpendicular to the direction of propagation (x axis) and the direction of the electric field (y axis). So the expression for the magnetic field is

$E_z = 10^{-7} \sin[2 \times 10^{11}t + 300\,\pi x]$T.

(5 Marks Questions)

51. Suppose that the electric field amplitude of an electromagnetic wave is $\vec{E}_0$**=120N/C^{-1}** and that its frequency is v = 50 MHz.(a) Determine $\vec{B}_0$**; ω, k and λ** (b) Find expressions for $\vec{E}$ and $\vec{B}$.

Sol. Here $E_0 = 120NC^{-1}$, v = 50.0 MHz = 50×10^6Hz

(a) $B_0 = \frac{120NC^{-1}}{3\times10^8 ms^{-1}} = 4 \times 10^7$T

$\omega = 2\pi v = 2 \times 3.14 \times 50 \times 10^6 = 3.14 \times 10^8$ rad s^{-1}

$k = \frac{\omega}{c} = \frac{3.14\times10^8}{3\times10^8} = 1.05\ \mu^{-1}$

$\lambda = \frac{c}{v} = \frac{3\times10^8}{50\times10^6} = 6.00$m

(b) If wave is propagating along x axis, then field $\vec{E}$ will be along y axis and field $\vec{B}$ along z axis

Therefore $\vec{E} = E_0 \sin(kx - \omega t)\hat{j}$ or $\vec{E} = 120\sin(1.05x - 3.14 \times 10^8 t)\,\hat{j}$ NC^{-1}.

Where x is in meter and t in second.

$\vec{B} = B_0\sin(kx - \omega t)\hat{k} = 4\times 10^{-7} \sin(1.05x - 3.14 \times10^8 t)\,\hat{j}$ tesla.

52. Suppose that the electric field of an electromagnetic wave in vacuum is (1 mark each)

$\vec{E} = 3.1(N/C)\cos[(18 rad/m)y + (5.4\times10^8 rad/s)t]\hat{i}$

(a) What is the direction of the propagation?

(b) What is the wavelength λ?

(c) What is the frequency ν?

(d) What is the amplitude of the magnetic field part of the wave?

(e) What is the expression for the magnetic field part of the wave?

Sol. (a) The wave is propagating along the negative y direction or its direction is $-\hat{j}$.

(b) Comparing the given equation with the standard equation, $\vec{E} = E_0\cos\left[2\pi\left(\frac{y}{\lambda} + vt\right)\right]$, we get. $\frac{2\pi}{\lambda} = 1.8$.

Therefore, wavelength, $\lambda = \frac{2\pi}{1.8} = \frac{2\times3.14}{1.8} = 3.5$m.

(c) Also $2\pi v = 5.4\times10^6$

Therefore $v = \frac{5.4\times10^6}{2\pi} = \frac{5.4\times10^6}{2\times3.14} = 85.9\times10^6$Hz = 86 MHz.

(d) $B_0 = \frac{E_0}{c} = \frac{3.1NC^{-1}}{3\times10^8} = 10.3\times10^{-9}$T = 10.3nT

(e) $\vec{B} = B_0\cos(ky + \omega t)\hat{k}$ = (10.3nT)cos[(1.8rad/m)y = + (5.4×10^8 rad/s)t] $\hat{k}$.

53. Given below are some famous numbers associated with electronic radiation in different contexts in physics. State the part of the e.m. spectrum to which each belongs:
(a) 21cm (wavelength emitted by atomic hydrogen in interstellar space).
(b) 1057 MHz (frequency of radiation arising from two close energy levels in hydrogen; known as Lamb shift)
(c) 27K (temperature associated with the isotropic radiation filling all space thought to be a relic of the 'big-bang' origin of universe)
(d) 5890C – 5896 C (doublet lines of sodium)
(e) 14.4 keV(energy of a particular transition) in Fe^{57} nucleus associated with a famous high resolution spectroscopic method (Mossbauer spectroscopy)

Sol. (a) Radio wave (short wavelength end).
(b) Radio wave (high frequency or short wavelength end).
(c) Here T = 2.7K,
By Wien's law, $\lambda_m T = 0.029$cmK.
Therefore $\lambda_m = 0.29\text{cmK}/2.7\text{K} = 0.11$cm
This wavelength lies in the microwave region of the em spectrum.
(d) Yellow part of the visible region of the em spectrum.
(d) Here $E = 14.4\text{ keV} = 14.4 \times 10^3 \times 1.6 \times 10^{-19}$J
As E = hv, so $v = \frac{E}{h} = \frac{14.4\times1.6\times10^{-16}}{6.6\times10^{-34}} = 3.5\times10^{18}$Hz
This frequency lies in the X ray or soft γ ray region of the em sperctrum.

C. CASE STUDY

1. **Microwave Owen**: The spectrum of electromagnetic radiation contains a part known as microwaves. These waves have frequency and energy smaller than visible light and wavelength larger than it. What is the principle of a microwave oven and how does it work? Our objective is to cook food or warm it up. All food items such as fruits, vegetables, meat, cereals, etc, contain water as a constituent. Now, what does it mean when we say that a certain object has become warmer? When the temperature of a body rises, the energy of the random motion of atoms and molecules increases and the molecules travel or vibrate or rotate with higher energies. The frequency of rotation of water molecules microwaves of this frequency, its molecules absorb the radiation, which is equivalent to heating up water. These molecules share this energy with neighbouring food molecules, heating up the food. One should use porcelain vessels and non metal containers in a microwave oven because of the danger of getting a shock from accumulated electric charges. Metals may also melt from heating. The porcelain container remains unaffected and cool, because its large molecules vibrate and rotate with much smaller frequencies, and thus cannot absorb microwaves. Hence they do not get eaten up. Thus the basic principle of a microwave oven is to generate microwave radiation of appropriate frequency in the working space of the oven where we keep food. This ay energy is not wasted in hating up the vessel. In the conventional hating method, the vessel on the burner gets heated first and then the food inside gets heated because of transfer of energy from the vessel. In the microwave oven, on the hand, energy is directly delivered to water molecules which is shared by the entire food.

(i) As compared to visible light microwave has frequency and energy:
(a) more visible than visible light (b) less than visible light

(c) equal to visible light (d) frequency is less but energy is more.

Sol. (b)

Microwaves have frequency and energy smaller than visible light and wavelength larger than it.

(ii) When the temperature of a body rises

(a) the energy of the random motion of atoms and molecules increases.

(b) the energy of the random motion of atoms and molecules decreases

(c) the energy of the random motion of atoms and molecules remain same.

(d) the random motion of atoms and molecules becomes steamlined.

Sol. (a)

When the energy of the random motion o atoms and molecules of a substance increases and the molecules travel or vibrate or rotate with higher energies, the substance becomes hot.

(iii) The frequency of rotation of water molecules is about

(a) 2.45 MHz (b) 2.45 kHz (c) 2.45 GHz (d) 2.45 THz

Sol. (c)

The frequency of rotation of water molecules is about 2.45 gigahertz

(iv) What should one use porcelain vessels and non-metal containers in a microwave oven?

(a) Because it will get too much hot

(b) Because it may crack due to high frequency

(c) Because of the danger fo getting a shock from accumulated electric charge.

Sol. (d)

One should use porcelain vessels and non metal containers in a microwave oven because of the danger of getting a shock from accumulated electric charges. Metals may also melt from heating. The porcelain container remains unaffected and cool, because its large molecules vibrate and rotate with much smaller frequencies, and thus cannot absorb microwaves. Hence they do not get eaten up.

(v) In the microwave oven,

(a) Energy is directly delivered to water molecules which is shared by the entire food.

(b) The vessel gets heated first and then the food grains inside.

(c) The vessel gets heated first and then the water molecules collect heat from the body of the vessel.

(d) Energy is directly delivered to the food grains.

Sol. (a)

In the conventional heating method, the vessel on the burner gets heated first and then the food inside gets heated because of transfer of energy from the vessel. In the microwave oven, on the other hand, energy is directly delivered to water molecules which is shared by the entire food.

2. **LASER:** Electromagnetic radiation is a natural phenomenon found in almost all areas of daily life, from radio waves to sunlight to x rays. Laser radiation – like all light – is also a form of electromagnetic radiation. Electromagnetic radiation that has a wavelength between 380nm and 780nm is visible to the human eye and is commonly referred to as light. At wavelength more than 780nm, optical radiation is termed infrared (IR) and is invisible to the eye. At wavelengths shorter than 380nm, optical radiation is termed ultraviolet (UV) and is also invisible to the eye. The term "laser light" refers to a much

broader range of the electromagnetic spectrum than just the visible spectrum, anything between 150nm up to 11000 nm (i.e., from the UV up to the far IR). The term laser is an acronym which stands for " light amplification by stimulated emission of radiator." Einstein explained the stimulated emission. In an atom, electron may move to higher energy level by absorbing a photon. When the electron comes back to lower energy level it releases the same photon. This is called spontaneous emission. This may also so happen that the excited electron returns to the lower energy state. This is known as stimulate emission.

Laser emission is therefore a light emission, whose energy is used on lithotripsy, for targeting the ablating eh stone inside human body organ.

Apart from medical usage, laser is used for optical disk drive, printer, barcode reader etc.

(i) What is the full form of LASER?

(a) light amplified by stimulated emission of radiation
(b) light amplification by stimulated emission of radiation
(c) light amplification by simultaneous emission of radiation
(d) light amplified by synchronous emission of radiation

Sol. (b)

(ii) The "stimulated emission" is the process of

(a) Release of a photon when electron cones back from higher to lower energy level.
(b) release of two photons by absorbing one photon when electron comes back from higher to lower energy level
(c) absorption of a photon when electron moves from lower to higher energy level.
(d) none of the above

Sol. (b)

Einstein explained the stimulated emission. In an atom, electron may move to higher energy level by absorbing a photon. When the electron comes back to lower energy level it releases the same photon. This is called spontaneous emission. This may also so happen that the excited electron returns to the lower energy state. This is known as stimulate emission.

(iii) What is the range of amplitude of LASER?

(a) 150nm-400nm (b) 700nm-11000nm (c) both of these (d) none of these

Sol. (c)

The term "laser light" refers to a much broader range of the electromagnetic spectrum than just the visible spectrum, anything between 150nm up to 11000 nm (i.e., from the UV up to the far IR).

(iv) Lithotripsy is

(a) an industrial application (b) a medical application
(c) laboratory application (d) process control application

Sol. (b) Laser emission is therefore a light emission, whose energy is used on lithotripsy, for targeting the ablating eh stone inside human body organ.

(v) LASER is used in

(a) Optical disc drive (b) Transmitting satellite signal
(c) Radio communication (d) Ionization

Sol. (a)

An optical disc drive (ODD) is a disc drive that used laser light or electromagnetic waves within or near the visible light spectrum as part of the process of reading or writing data or form optical discs.

D. ASSERTION REASON TYPE QUESTION:

(a) If both assertion and reason are true and reason is the correct explanation of assertion.

(b) If both assertion and reason are true but reason is not the correct explanation of assertion.

(c) If assertion is true but reason is false **(d) If both assertion and reason are false**

(e) If assertion is false but reason is true.

1. Assertion: Light can travel in vacuum whereas sound cannot do so.
Reason: Light is an electromagnetic wave nature wave whereas sound is mechanical wave.

Ans. (a) Both assertion and reason are true and reason is the correct explanation of assertion.
Light being electromagnetic wave does not require any material medium for its propagation. Hence light can travel in vacuum. On the other hand, sound is a mechanical wave and requires a material medium for its propagation. Hence sound cannot travel in vacuum.

2. Assertion: Greater is the height of TV transmitting antenna, greater is its range.
Reason: The range of TV transmitting antenna is proportional to square root of its height.

Ans. (a) Both assertion and reason are true and reason is the correct explanation of assertion.
Since range d = $\sqrt{2RH}$ i.e., d $\propto \sqrt{h}$. Thus greater is the value of h, the larger is the value of d

3. Assertion: X rays in vacuum travel faster than light waves in vacuum.
Reason: The energy of X rays photon is greater than that of light photon.

Ans. (e) Assertion is false but reason is true.
All electromagnetic waves including X rays travel with same velocity in vacuum. The energy of X rays is greater than energy of the light because energy is inversely proportional to wavelength ($E = hc/\lambda$) and wavelength of X rays are smaller than light waves.

4. Assertion: Infrared waves sometimes referred as heat waves.
Reason: Infrared waves heat up the earth surface.

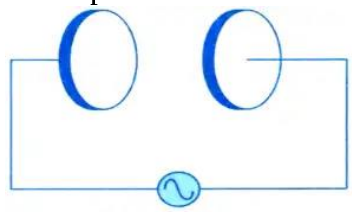
Ans. (b) Both assertion and reason are true but reason is not the correct explanation of assertion.
Infrared waves are sometimes called heat waves. This is because water molecules present in most materials readily absorbs infrared waves. After absorption their thermal motion increases, that , they heat up and heat their surroundings.

5. Assertion: X-rays astronomy is possible only from satellitesorbiting the earth.
Reason: Efficiency of X rays telescope is large as compared to any other telescope.

Ans. (c) Assertion is true but reason is false.
The earth’s atmosphere is transparent to visible light and radio-waves, but absorbs X rays. Therefore X rays telescope cannot be used on earth surface.

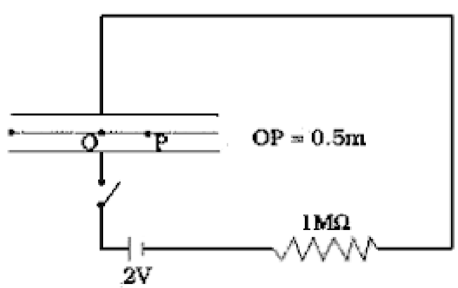
E. CHALLENGING PROBLEMS

1. A parallel plate capacitor made of circular plates each of radius R = 6.0 cm has a capacitance C = 100 pF. The capacitor is connected to a 230 V ac supply with an (angular) frequency of 300 rad s^{-1}.
(a) What is the rms value of the conduction current?
(b) Is the conduction current equal to the displacement current?
(c) Determine the amplitude of B at a point 3.0 cm from the axis between the plates.



Sol. Here R = 6.0cm, C = 100pF = 10^{-10}F, V_{rms} = 230V, ω = 300 rad s^{-1}.
(a) Impedance of the capacitor is $X_C = \frac{1}{\omega C}$
$\therefore \mathbf{I_{rms}} = \frac{V_{rms}}{X_C} = \mathbf{V_{rms}.\omega C}$ = 230 × 300 × 10^{-10}A = 3.9 × 10^{-6}A = 6.9 μA.
(b) Yes, the conduction current is equal to the displacement current if I is oscillating in time.
(c) The formula, $B = \frac{\mu_0}{2\pi}\frac{r}{R^2}\mathbf{I_D} = \frac{\mu_0}{2\pi}\frac{r}{R^2}\mathbf{I}$
Is valid even if I_D (and hence B) oscillates in time. The formula shows that B and I_D are in phase.
Hence, $B_0 = \frac{\mu_0}{2\pi}\frac{r}{R^2}\mathbf{I_0}$ where B_0 and I_0 are the amplitudes of the oscillating magnetic field and current, respectively.
Now, $I_0 = \sqrt{2}\mathbf{I_{rms}} = \sqrt{2} \times \mathbf{6.9\mu A = 9.76\mu A}$
$\therefore B_0 = \frac{2\times10^{-7}\times3\times10^{-2}\times9.76\times10^{-6}}{(6\times10^{-2})^2}$ = 1.63 × 10^{-11}T.

2. A parallel plate capacitor with circular plates of radius 1 m has a capacitance of 1 nF. At t = 0, it is connected for charging in series with a resistor R = 1 MΩ across a 2V battery (Fig. 8.3). Calculate the magnetic field at a point P, halfway between the centre and the periphery of the plates, after t = 10–3 s. (The charge on the capacitor at time t is q (t) = CV [1 – exp (–t/τ)], where the time constant τ is equal to CR.)



SPACE FOR ROUGH WORK

SPACE FOR NOTES