08

Electromagnetic Waves

TREND ANALYSIS 3 YEARS

Electromagnetic Waves

Average No. of Questions Across all Sets

Types of Questions	2023	2020	2019
1 Mark	3	2	2
2 Marks	3	1	2
3 Marks	–	1	1
5 Marks	–	–	–

Displacement Current

The current which comes into existence in the region in which the electric field and the electric flux is changing with time is known as displacement current. It is expressed by

$$I_D = \varepsilon_0 \frac{d\phi_E}{dt}$$

where, ϕ_E is the electric flux and I_D is the displacement current.

Need for Displacement Current

Ampere's circuital law for conduction current during charging of a capacitor was found inconsistent. Therefore, Maxwell modified Ampere's circuital law by introducing the concept of displacement current.

Maxwell's Equations of Electromagnetic Waves

Maxwell's equations are the basic laws of electricity and magnetism.

Maxwell predicted the existence of electromagnetic waves. There are four Maxwell's equations which are given below

(i) Gauss' law in electrostatics, $\oint \mathbf{E} \cdot d\mathbf{S} = q/\varepsilon_0$

(ii) Gauss' law in magnetostatics, $\oint \mathbf{B} \cdot d\mathbf{S} = 0$

(iii) Faraday's law of electromagnetic induction,

$$\oint \mathbf{E} \cdot d\mathbf{l} = -d\phi_B/dt$$

(iv) Ampere-Maxwell's circuital law,

$$\oint \mathbf{B} \cdot d\mathbf{l} = \mu_0 (I_C + I_D)$$

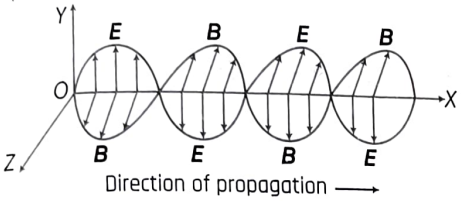
where, I_C is conduction current and I_D is displacement current.

Electromagnetic Waves

An electromagnetic wave is a wave radiated by an accelerated or oscillatory charge in which varying magnetic field is the source of electric field and varying electric field is the source of magnetic field. Thus, two fields become source of each other and the wave propagates sinusoidally in a direction perpendicular to both the fields.

Transverse Nature of Electromagnetic Waves

Electromagnetic waves are transverse in nature, i.e. electric and magnetic fields are perpendicular to each other and also perpendicular to the direction of wave propagation.



E (electric field) and **B** (magnetic field) in electromagnetic waves are in same phase.

Speed of electromagnetic wave is given by

$$c = E_0/B_0 = 1/\sqrt{\mu_0\varepsilon_0} = 3\times10^8 \text{ ms}^{-1}$$

$$\left[\text{where, } \mu_0 = 4\pi\times10^{-7}\text{Ns}^2\text{C}^{-2}, \quad \varepsilon_0 = 8.85\times10^{-12}\text{C}^2\text{N}^{-1}\text{m}^{-2}\right]$$

where, μ_0 and ε_0 are the absolute permeability and absolute permittivity of free space, respectively.

Important Characteristics of Electromagnetic Waves

There are some important characteristics of electromagnetic waves

(i) The energy in electromagnetic wave is divided on average equally between electric and magnetic fields.

(ii) Energy associated with an electromagnetic wave is

$$U = \frac{1}{2}\varepsilon_0 E^2 + \frac{B^2}{2\mu_0}.$$

(iii) Electromagnetic waves also carry momentum and energy. Linear momentum delivered to the surface by an EM wave is $p = U/c$.

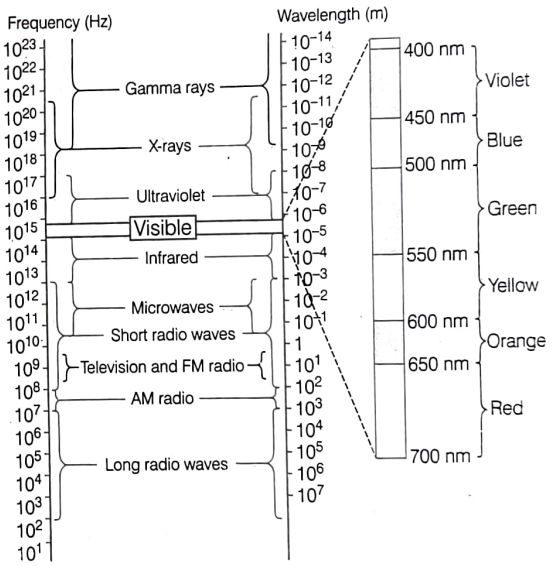
where, U = total energy transmitted by electromagnetic waves and c = speed of electromagnetic wave. Since, it has momentum an EM wave also exerts pressure called radiation pressure.

(iv) Electromagnetic waves are not deflected by electric and magnetic fields.

(v) Electromagnetic waves obey the principle of superposition. They show the properties of reflection, refraction, interference, diffraction and polarization.

Electromagnetic Spectrum

The systematic sequential distribution of electromagnetic waves in ascending or descending order of frequency or wavelength is known as electromagnetic spectrum. The wavelength range varies from 10^{-12} m to 10^4 m, i.e. from γ-rays to radio waves.



The electromagnetic spectrum with common names for various part of it

Different types of electromagnetic waves

Type	Wavelength range	Frequency range (Hz)	Production	Detection
Radio wave	>0.1 m	10^4 to 10^9	Rapid acceleration and deceleration of electrons in aerials.	Receiver's aerials
Microwave	0.1 m to 1 mm	10^9 to 10^{11}	Klystron valve or magnetron valve.	Point contact diodes
Infrared wave	1 mm to 700 nm	3×10^{11} to 4×10^{14}	Vibration of atoms and molecules.	Thermopile, Bolometer, infrared photographic film
Light	700 nm to 400 nm	4×10^{14} to 8×10^{14}	Electrons in atoms emit light when they move from one energy level to a lower energy level.	The eye, photocells, photographic film
Ultraviolet rays	400 nm to 1 nm	8×10^{14} to 8×10^{16}	Inner shell electrons in atoms moving from one energy level to a lower level.	Photocells, photographic film
X-rays	1 nm to 10^{-3} nm	1×10^{16} to 3×10^{21}	X-ray tubes or inner shell electrons.	Photographic film Geiger tubes, ionisation chamber
γ-rays	$<10^{-3}$ nm	5×10^{18} to 5×10^{22}	Radioactive decay of the nucleus.	Photographic film, ionisation chamber

Uses of Electromagnetic Waves

There are many uses of electromagnetic waves

Radio waves

(i) In radio and TV communication.

(ii) In astronomical field.

Microwaves

(i) In Radar communication.

(ii) In analysis of molecular and atomic structure.

(iii) For cooking purpose.

(iv) In long distance communication systems *via* geo-stationary satellites.

Infrared waves

(i) In knowing molecular structure.

(ii) In remote control of TV, VCR, etc.

(iii) In treatment of muscular complaints.

(iv) In green house to maintain temperature suitable for plants.

Visible rays

(i) To see things, avoid bumping from them and escape danger.

(ii) To find other living things with which to consort so to prolong the species.

Ultraviolet rays

(i) Used in burglar alarm.

(ii) To kill germs in minerals (in food preservation).

(iii) To study molecular structure.

X-rays

(i) In medical diagnosis and to cure malignant growths and untracable skin diseases as they pass through the muscles not through the bones.

(ii) In detecting faults, cracks, etc., in metal products.

Gamma rays

(i) For food preservation by killing pathogenic microorganisms.

(ii) In radiotherapy for treatment of tumour and cancer.

PYQs Previous Years Questions

1 Mark Questions

Multiple Choice Questions

1. **E** and **B** represent the electric and the magnetic field of an electron magnetic wave, respectively. The direction of propagation of the wave is along **CBSE 2023**

(a) **B** (b) **E**
(c) **E** × **B** (d) **B** × **E**

2. An electromagnetic wave is produced by a charge
(a) moving with a constant velocity **CBSE 2023**
(b) moving with a constant speed parallel to a magnetic field
(c) moving with an acceleration
(d) at rest

3. The ratio of the magnitude of the electric field and magnetic field of a plane electromagnetic wave is **CBSE 2023**

(a) 1 (b) $\frac{1}{c}$ (c) c (d) $\frac{1}{c^2}$

4. The electromagnetic waves used in RADAR systems are **CBSE 2023**
(a) Infrared waves
(b) Ultraviolet rays
(c) Microwaves
(d) X-rays

5. The electromagnetic radiations used to kill germs in water purifiers are called **CBSE 2023**

(a) Infrared waves (b) X-rays
(c) Gamma rays (d) Ultraviolet rays

6. Which one of the following electromagnetic radiation has the least wavelength? **CBSE 2023**

(a) Gamma rays (b) Microwaves
(c) Visible light (d) X-rays

7. Which of the following statement is not true about the properties of electromagnetic waves? **CBSE SQP 2022-23**
(a) These waves do not require any material medium for their propagation.
(b) Both electric and magnetic field vectors attain the maxima and minima at the same time.
(c) The energy in electromagnetic wave is divided equally between electric and magnetic fields.
(d) Both electric and magnetic field vectors are parallel to each other.

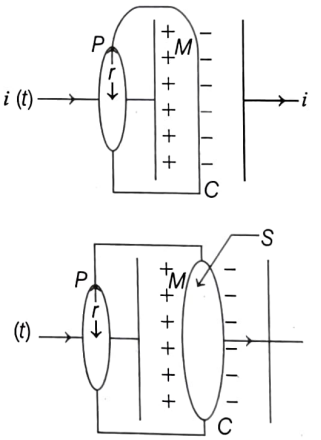
KEY idea
As we know that, electromagnetic waves are transverse in nature and polarised.

Assertion-Reason Questions

Directions (Q. Nos. 8-11) *In the following questions, two statements are given- one labelled Assertion (A) and the other labelled Reason (R). Select the correct answer to these questions from the codes (a), (b), (c) and (d) as given below*

(a) If both Assertion and Reason are correct and Reason is the correct explanation of Assertion.
(b) If both Assertion and Reason are correct but Reason is not the correct explanation of Assertion.
(c) If Assertion is correct but Reason is incorrect.
(d) If both Assertion and Reason are incorrect.

8. **Assertion** The current through surface P is zero in the cases shown in figure .



Reason While applying Ampere's circuital law to given surfaces with same perimeter, the left hand side of equation $\oint B \cdot dl = \mu_0 i(t)$ has not changed but the right hand side is zero.

9. **Assertion** In electromagnetic wave, the direction of variations of electric and magnetic fields are perpendicular to each other and also perpendicular to the direction of wave propagation.

Reason Electromagnetic waves are transverse in nature.

10. **Assertion** The frequency of the electromagnetic wave naturally equals the frequency of oscillations of the charge.

Reason The energy associated with the propagating wave comes at the expense of the energy of the source.

11. **Assertion** When the sunshine on our hand, we feel the energy being absorbed from the electromagnetic waves (our hands get warm).

Reason Electromagnetic waves transfer momentum to our hand but because c is very large, the amount of momentum transferred is extremely small and we do not feel the pressure.

Very Short Answer Questions

12. Give the ratio of velocity of the two light waves of wavelengths 4000 Å and 8000 Å travelling in vacuum. **CBSE SQP 2020-21**

13. An AC source with variable frequency is connected to a parallel plate capacitor. How will the displacement current be affected with the decrease in frequency of the source? **All India 2020**

14. Depict the field diagram of an electromagnetic wave propagating along positive X-axis with its electric field along Y-axis. **Delhi 2020**

15. Name the electromagnetic waves that are widely used as a diagnostic tool in medicine. **CBSE SQP 2018-19**

16. Name the current which can flow even in the absence of electric charge. **CBSE SQP 2018-19**

17. Which part of the electromagnetic spectrum is used in RADAR? Give its frequency range. **All India 2019**

18. How are electromagnetic waves produced by accelerating charges? **All India 2019**

19. Name the electromagnetic radiations used for (i) water purification, and (ii) eye surgery. **CBSE 2018**

20. Do electromagnetic waves carry energy and momentum? **All India 2017**

21. How is the speed of electromagnetic waves in vacuum determined by the electric and magnetic fields? **Delhi 2017**

22. In which directions do the electric and magnetic field vectors oscillate in an electromagnetic wave propagating along the X-axis? **All India 2017**

23. Why are microwaves considered suitable for RADAR systems used in aircraft navigation? **Delhi 2016**

24. The charging current for a capacitor is 0.25 A. What is the displacement current across its plates? **Foreign 2016**

25. To which part of the electromagnetic spectrum does a wave of frequency 5×10^{19} Hz belong? **All India 2014**

26. To which part of the electromagnetic spectrum does a wave of frequency 3×10^{13} Hz belong? **All India 2014**

27. Arrange the following electromagnetic waves in order of increasing frequency : γ-rays, microwaves, infrared rays and ultraviolet rays. **Foreign 2014**

28. Welders wear special goggles or face masks with glass windows to protect their eyes from electromagnetic radiation. Name the radiations and write the range of their frequency. **All India 2013**

29. A capacitor has been charged by a DC source. What are the magnitudes of conduction and displacement current, when it is fully charged? **Delhi 2013**

30. What are the directions of electric and magnetic field vectors relative to each other and relative to the direction of propagation of electromagnetic waves? **All India 2012**

31. Name the electromagnetic waves which
(i) maintain the earth's warmth and
(ii) are used in aircraft navigation. **Foreign 2012**

32. A plane electromagnetic wave travels in vacuum along z-direction. What can you say about the direction of electric and magnetic field vectors? **Delhi 2011**

33. How are radio waves produced? **All India 2011**

34. Write two uses of microwaves. **Foreign 2011**

35. Write two uses of infrared rays. **Foreign 2011**

36. Write two uses of X-rays. **Foreign 2011**

37. What is the frequency of electromagnetic waves produced by oscillating charge of frequency $\nu = 10^5$ Hz? **Delhi 2011C**

38. How are infrared waves produced? What is the range of their wavelength? **Delhi 2010C**

39. Which of the following has the shortest wavelength?
Microwaves, Ultraviolet rays, X-rays. **All India 2010**

40. Name the part of electromagnetic spectrum whose wavelength lies in the range of 10^{-10} m. Give its one use. **All India 2010**

41. Arrange the following in descending order of wavelength.
X-rays, radio waves, blue light, infrared light. **All India 2010**

42. Which part of electromagnetic spectrum has largest penetrating power? **Delhi 2010**

43. Which part of electromagnetic spectrum is absorbed from sunlight by ozone layer? **Delhi 2010**

44. Which part of electromagnetic spectrum is used in RADAR systems? **Delhi 2010**

45. Name the electromagnetic radiation used to destroy cancer cells and write its frequency range. **Foreign 2010**

46. Which part of the electromagnetic spectrum is used in satellite communication? **Foreign 2010**

47. In what way, are the directions of the electric and magnetic field vectors representing an electromagnetic wave related to each other? **Delhi 2010C**

48. Express the velocity of propagation of an electromagnetic waves in terms of the peak value of the electric and magnetic fields. **All India 2010C**

2 Marks Questions

49. How are infrared waves produced? Why are these waves referred to as heat waves? Give any two uses of infrared waves. **CBSE 2023**

50. How are X-rays produced? Give any two uses of these. **CBSE 2023**

51. Identify the electromagnetic radiation and write its wavelength range, which is used to kill germs in water purifier. Name the two sources of these radiations. **CBSE 2023**

52. Write any two characteristics of an electromagnetic wave. Why are microwave used in RADAR systems? **CBSE 2023**

53. What is a displacement current? How is it different from a conduction current? **CBSE 2023**

54. What is meant by the term 'displacement current'? Briefly explain how this current is different from a conduction current. **CBSE 2023**

55. Identify the electromagnetic wave whose wavelengths range is from about
(i) 10^{-12} m to about 10^{-8} m
(ii) 10^{-3} m to about 10^{-1} m
Write one use of each. **CBSE 2023**

56. Gamma rays and radiowaves travel with the same velocity in free space. Distinguish between them in terms of their origin and the main application. **Delhi 2020**

57. Compare the following
(i) Wavelengths of the incident solar radiation absorbed by the earth's surface and the radiation re-radiated by the earth.
(ii) Tanning effect produced on the skin by UV radiation incident directly on the skin and that coming through glass window. **CBSE SQP 2018-19**

58. How is the equation for Ampere's circuital law modified in the presence of displacement current? Explain. **All India 2019**

59. How are electromagnetic waves produced by oscillating charges? What is the source of the energy associated with the EM waves? **All India 2019**

60. A capacitor made of two parallel plates, each of area A and separation d is charged by an external DC source. Show that during charging, the displacement current inside the capacitor is the same as the current charging the capacitor. **All India 2019**

61. (i) Why are infrared waves often called heat waves? Explain.
(ii) What do you understand by the statement, "electromagnetic waves transport momentum"? **CBSE 2018**

62. (i) Give one use of electromagnetic radiations obtained in nuclear disintegrations.
(ii) Give one example each to illustrate the situation where there is (i) displacement current but no conduction current and (ii) only conduction current but no displacement current. **All India 2018**

63. Identify the electromagnetic waves whose wavelengths vary as
(i) $10^{-12}\ \text{m} < \lambda < 10^{-8}\ \text{m}$ (ii) $10^{-3}\ \text{m} < \lambda < 10^{-1}\ \text{m}$
Write one use for each. **All India 2017**

64. (i) How does oscillating charge produce electromagnetic waves?
(ii) Sketch a schematic diagram depicting oscillating electric and magnetic fields of an EM wave propagating along positive Z-direction. **Foreign 2014**

65. (i) How are electromagnetic waves produced?
(ii) How do you convince yourself that electromagnetic waves carry energy and momentum? **Delhi 2013C**

66. (i) Arrange the following electromagnetic waves in the descending order of their wavelengths.
(a) Microwaves (b) Infrared rays
(c) Ultraviolet radiation (d) γ-rays
(ii) Write one use each of any two of them. **Delhi 2013C**

67. (i) An electromagnetic wave is travelling in a medium, with a velocity $\mathbf{v} = v\hat{\mathbf{i}}$. Draw a sketch showing the propagation of the electromagnetic wave, indicating the direction of the oscillating electric and magnetic fields.
(ii) How are the magnitudes of the electric and magnetic fields related to velocity of the electromagnetic wave? **Delhi 2013**

68. A capacitor of capacitance C is being charged by connecting it across a DC source along with an ammeter. Will the ammeter show a momentary deflection during the process of charging? If so, how would you explain this momentary deflection and the resulting continuity of current in the circuit? Write the expression for the current inside the capacitor. **All India 2012**

> **KEY idea**
> The current inside the capacitor, the conduction current is equal to the displacement current which is $I_C = I_D$.

69. 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? **Delhi 2012**

70. Explain briefly how electromagnetic waves are produced by an oscillating charge? How is the frequency of the electromagnetic waves produced related to that of the oscillating charge? **Foreign 2012**

71. Name the constituent radiation of electromagnetic spectrum, which is used for
(i) aircraft navigation
(ii) studying the crystal structure
Write the frequency range for each. **Delhi 2011C**

72. Draw a sketch of a plane electromagnetic wave propagating along the z-direction. Depict clearly the directions of electric and magnetic fields varying sinusoidally with Z. **All India 2011**

73. Arrange the following electromagnetic radiations in ascending order of their frequencies.
(i) Microwaves (ii) Radio waves
(iii) X-rays (iv) γ-rays
Write two uses of any one of these. **Delhi 2010**

74. How are X-rays produced? Write their two important uses. **Foreign 2010; Delhi 2010**

75. How are infrared rays produced? Write their two important uses. **Foreign 2010; All India 2010C**

76. How are microwaves produced? Write their two important uses. **Foreign 2010**

3 Mark Questions

77. Electromagnetic waves with wavelength
(i) λ_1 is suitable for RADAR systems used in aircraft navigation. **CBSE SQP 2022-23**
(ii) λ_2 is used to kill germs in water purifiers.
(iii) λ_3 is used to improve visibility in runways during fog and mist conditions.
Identify and name the part of the electromagnetic spectrum to which these radiations belong. Also arrange these wavelengths in ascending order of their magnitude.

78. (i) Depict a plane electromagnetic wave propagating along the X-axis. Write the expressions for its oscillating electric and magnetic fields.
(ii) Write three characteristics of electromagnetic waves. **CBSE 2022 (Term-II)**

79. Electromagnetic waves of wavelengths λ_1, λ_2, and λ_3 are used in RADAR systems, in water purifiers and in remote switches of TV, respectively.
(i) Identify the electromagnetic waves and
(ii) Write one source of each of them. **CBSE 2022 (Term-II)**

80. Name the electromagnetic waves which are produced by the following
(i) Radioactive decays of nucleus
(ii) Welding arcs
(iii) Hot bodies
Write one use each of these waves. **CBSE 2022 (Term-II)**

81. Name the electromagnetic waves with their frequency range, produced in
(i) some radioactive decay,
(ii) sparks during electric welding and
(iii) TV remote. **All India 2020**

82. (i) Identify the part of the electromagnetic spectrum used in (a) RADAR and (b) eye surgery. Write their frequency range.

(ii) Prove that the average energy density of the oscillating electric field is equal to that of the oscillating magnetic field. **Delhi 2019**

83. The magnetic field in a plane electromagnetic wave is given by

$B_y = 12 \times 10^{-8} \sin (120 \times 10^7 z + 3.60 \times 10^{15} t)$ T.

Calculate the

(i) energy density associated with the electromagnetic wave and

(ii) speed of the wave **CBSE SQP 2017-18**

84. How are electromagnetic waves produced by oscillating charges?

Draw a sketch of linearly polarised electromagnetic waves propagating in the z-direction. Indicate the directions of the oscillating electric and magnetic fields. **Delhi 2016**

85. (i) Identify the part of the electromagnetic spectrum which is

(a) suitable for RADAR system used in aircraft navigation,

(b) produced by bombarding a metal target by high speed electrons.

(ii) Why does galvanometer show a momentary deflection at time of charging and discharging a capacitor? Write the necessary expression to explain this observation. **All India 2016**

86. (i) Which segment of electromagnetic waves has highest frequency? How are these waves produced? Give one use of these waves.

(ii) Which EM waves lie near the high frequency end of visible part of EM spectrum? Give its one use. In what way, this component of light has harmful effects on humans? **Foreign 2016**

87. Name the parts of the electromagnetic spectrum which is

(i) suitable for RADAR systems in aircraft navigations.

(ii) used to treat muscular strain.

(iii) used as a diagnostic tool in medicine.

Write in brief, how these waves can be produced. **All India 2015**

88. Answer the following questions.

(i) Name the waves which are produced during radioactive decay of a nucleus. Write their frequency range.

(ii) Welders wear special glass goggles while working. Why? Explain.

(iii) Why are infrared waves often called as heat waves? Give their one application. **Delhi 2014**

89. Answer the following questions:

(i) Show, by giving a simple example, how EM waves carry energy and momentum.

(ii) How are microwaves produced? Why is it necessary in microwaves ovens to select the frequency of microwaves to match the resonant frequency of water molecules?

(iii) Write two important uses of infrared waves. **Delhi 2014C**

90. State clearly how a microwave oven works to heat up a food item containing water molecules.

Why are microwaves found useful for the raw systems in aircraft navigation? **Foreign 2011**

91. (i) Describe briefly how electromagnetic waves are produced by oscillating charges?

(ii) Give one use of each of the following.

(a) Microwaves (b) Ultraviolet rays

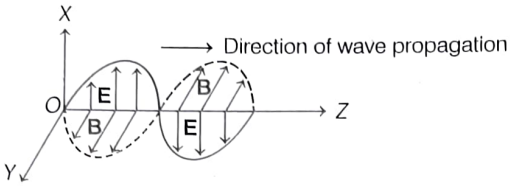
(c) Infrared rays (d) γ-rays **All India 2011C**

Case Based Question (4 Marks) (For Complete Chapter)

Direction (Q.No. 92) *This question is Case Study based question. Read the following paragraph and answer the questions.*

92. **Oscillating Electric Field**

An oscillating charge is an example of accelerating charge. It produces an oscillating electric field in space, which produces an oscillating magnetic field, which in turn produces an oscillating electric fields and so on. The oscillating electric and magnetic fields regenerate each other as a wave which propagates through space.



(i) Electromagnetic waves can be deflected by **(1)**
(a) only electric field
(b) only magnetic field
(c) Both (a) and (b)
(d) None of the above

(ii) Total energy density of electromagnetic waves in vacuum is given by the relation **(1)**

(a) $\frac{1}{2}\cdot\frac{E^2}{\varepsilon_0}+\frac{B^2}{2\mu_0}$ (b) $\frac{1}{2}\varepsilon_0 E^2+\frac{1}{2}\mu_0 B^2$

(c) $\frac{E^2+B^2}{c}$ (d) $\frac{1}{2}\varepsilon_0 E^2+\frac{B^2}{2\mu_0}$

(iii) The speed of electromagnetic wave in vacuum depends upon the source of radiation **(1)**
(a) increases as we move from γ-rays to radio waves
(b) decreases as we move from γ-rays to radio waves
(c) is same for all of them
(d) None of the above

(iv) Solar radiation is **(1)**
(a) transverse electromagnetic wave
(b) longitudinal electromagnetic wave
(c) stationary wave
(d) None of the above

Or (v) A plane electromagnetic wave of frequency 25 MHz travels in free space along the x-direction. At a particular point in space and time, $\mathbf{E}=6.3\,\hat{\mathbf{j}}$ V/m. The corresponding magnetic field at that point will be **(1)**

(a) $2.1\times10^{-8}\,\hat{\mathbf{k}}$T (b) $2.1\times10^{8}\,\hat{\mathbf{k}}$T
(c) $3.5\times10^{6}\,\hat{\mathbf{k}}$T (d) $3.0\times10^{5}\,\hat{\mathbf{k}}$T

Explanations

1. (c) The direction of propagation of the electromagnetic wave is always perpendicular to the plane in which **E** and **B** lies.
Thus, $c=\mathbf{E}\times\mathbf{B}$

2. (c) Electromagnetic waves are also produced when fast moving electrons are suddenly stopped by metal target of high atomic number.

3. (c) The ratio of E_0 and B_0 gives the speed of electromagnetic wave.
i.e. $c=\frac{E_0}{B_0}$

4. (c) In RADAR systems microwaves are used.

5. (d)

6. (a) Gamma rays have the lowest wavelength.

7. (d) Electromagnetic waves are the combination of mutually perpendicular to electric field and magnetic field. So, option (d) is not correct.

8. (a) On applying Ampere's circuital law to such surfaces with the same perimeter, we find that the left hand side of equation $\oint B\cdot dl=\mu_0 i(t)$ has not changed but the right hand side is zero.
Since, no current passes through the surface, i.e. $i=0$
$\therefore \quad \oint B\cdot dl=0$

9. (a) As per Maxwell's equations, electric and magnetic fields in an electromagnetic wave are perpendicular to each other and also perpendicular to the direction of wave propagation. Hence, electromagnetic waves are transverse in nature.

10. (b) The frequency of the electromagnetic wave naturally equals the frequency of oscillation of the charge. The energy associated with the propagating wave comes at the expense of the energy of the source, the accelerated charge.

11. (b) When the sunshine on our hand, we feel the energy being absorbed from the electromagnetic waves (our hands get warm).
Electromagnetic waves also transfer momentum to our hand but because c is very large, the amount of momentum transferred is extremely small and we do not feel the pressure.
Since, momentum $p=\frac{v}{c}\Rightarrow p\propto\frac{1}{c}$ $(\because v=\text{constant})$

12. Given that, $\lambda_1=4000$ Å, $\lambda_2=8000$ Å
Ratio of velocities $=\frac{\text{Velocity of 4000 Å light}}{\text{Velocity of 8000 Å light}}$
Ratio $=\frac{c}{c}=\frac{3\times10^8\,\text{m/s}}{3\times10^8\,\text{m/s}}=\frac{1}{1}$

Hence, the ratio of the two velocities will be 1 : 1.

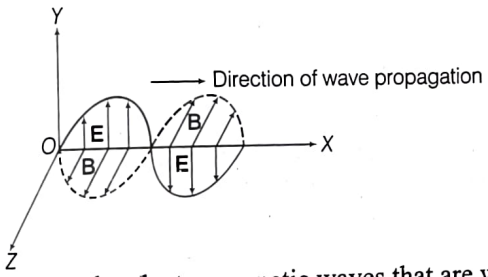
Concept Enhancer When a light travels in the medium, its velocity changes but in vacuum velocity of the light is constant which is 3×10^8 m/s.

13. Capacitive reactance, $X_C = \frac{1}{\omega C} = \frac{1}{2\pi \nu C}$

$$\therefore \quad X_C \propto \frac{1}{\nu}$$

As frequency decreases, X_C increases. As the conduction current is inversely proportional to X_C. So, displacement current also decreases, because the conduction current is equal to the displacement current.

14. An electromagnetic wave propagating along positive X-axis with its electric field along Y-axis, will have its magnetic field along Z-axis, as shown below



15. X-rays are the electromagnetic waves that are widely used as diagnostic tool in medicine.

16. Displacement current is the current which can flow even in the absence of electric charge.

17. Microwaves are used in RADAR systems of aircraft navigation. Its frequency range is 1 GHz to 300 GHz.

18. Electromagnetic waves are produced by accelerating charged particle. When the charge moves with acceleration, both the magnetic and electric fields charge continuously. This charge produces electromagnetic waves.

19. (i) Ultraviolet radiation
(ii) Infrared radiation

20. Yes, electromagnetic waves carry energy and momentum. Its momentum, $p = h/\lambda$ and energy density $= \frac{1}{2}\varepsilon_0 E^2$.

21. To determine speed of light in vacuum, we use the formula, $c = E_0 / B_0$
where, E_0 and B_0 are maximum electric field and magnetic field component respectively of electromagnetic waves.

22. Electric field vector **E** and magnetic field vector **B** are always perpendicular to each other and also perpendicular to direction of propagation of light.

As, the wave is propagating along $\hat{\mathbf{i}}$ or X-axis.
Hence, **E** is along $\hat{\mathbf{j}}$ or $+Y$-axis and **B** is along $\hat{\mathbf{k}}$ or $+Z$-axis.

23. On account of smaller wavelength of microwaves, they can be transmitted as a beam signals in a particular direction. They also do not bend around the corners of the obstacles coming in their way. Thus, it is considered suitable for RADAR systems used in aircraft navigation system.

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

25. A wave of frequency of 5×10^{19} Hz belongs to γ-rays of electromagnetic spectrum.

26. A wave of frequency of 3×10^{13} Hz belongs to infrared waves of electromagnetic spectrum.

27. Electromagnetic waves arranged in increasing order of frequency is as follows : Microwaves < Infrared rays < Ultraviolet rays < γ-rays.

28. Welders wear special goggles or face mask with glass windows to protect their eyes from ultraviolet rays (UV rays). The range of UV rays is 10^{15} Hz to 10^{17} Hz.

29. Electric flux through plates of capacitor, $\phi_E = q/\varepsilon_0$

Displacement current,

$$I_D = \varepsilon_0 \frac{d\phi_E}{dt} = \varepsilon_0 \frac{d(q/\varepsilon_0)}{dt} = 0$$

$\because$ The capacitor has been fully charged, thus the charge would be constant.

Conduction current, $I = C\frac{dV}{dt} = 0$, as voltage becomes constant. So, $I = I_D = 0$ for a charged capacitor.

30. The direction of electric field E, direction of magnetic field B and direction of propagation of wave are mutually perpendicular to one another.

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

32. As, directions of electric field, magnetic field and propagation of wave are mutually perpendicular to one another. Thus, the direction of electric and magnetic field vectors are along x and y-directions respectively, as the wave travels in vacuum in z-directions.

33. Radio waves are the electromagnetic waves of frequency ranging from 50 kHz to about 1000 MHz. These waves are produced by oscillating electric circuits having inductor and capacitor.

34. Refer to text on page 228 (Microwaves).

35. Refer to text on page 228 (Infrared waves).

36. Refer to text on page 228 (X-rays).

37. The frequency of electromagnetic waves produced by oscillating charge is equal to the frequency of the oscillating charge only i.e., $\nu_{wave} = 10^5$ Hz.

38. Hot bodies and vibration of atoms or molecules are the sources of infrared waves.

Range of infrared wavelength is 7×10^{-7} m to 10^{-3} m.

39. X-ray has shortest wavelength.

40. The wavelength range of 10^{-10} lies in X-rays. These are used as a diagnostic tool in medicine like in surgeries to detect the fracture, diseased organs, stones in the body etc.

41. Radio wave > Infrared > Blue light > X-ray is the descending order of their wavelength.

42. γ-rays have highest frequency range and hence, highest penetrating power.

43. Ultraviolet ray of electromagnetic spectrum is absorbed from sunlight by ozone layer.

44. Microwaves are used in RADAR system.

45. γ-rays are used to destroy cancer cells and their frequency range is 10^{18} to 10^{22} Hz.

46. Short radio waves of $\lambda > 0.1$ m or $\nu < 3 \times 10^9$ Hz are used in satellite communication.

47. The direction of propagation of electromagnetic waves is along the direction of $\mathbf{E} \times \mathbf{B}$, where $\mathbf{E}$ and $\mathbf{B}$ are electric and magnetic fields.

48. Velocity of propagation of EM wave in terms of peak values of electric field $|\mathbf{E}_0|$ and magnetic field $|\mathbf{B}_0|$ vectors is given as $c = |\mathbf{E}_0|/|\mathbf{B}_0|$.

Since, momentum, $p = \frac{\nu}{c} \Rightarrow p \propto \frac{1}{c}$ ($\because \nu =$ constant)

49. Infrared waves produced from the heat radiating bodies and molecules. Because they have high penetration power. Its frequency range is 3×10^{11} Hz to 4×10^{14} Hz.

Uses of infrared waves are

(a) These are used in satellite for army purpose.

(b) These are used for producing dehydrated fruits.

50. X-rays are produced due to sudden deceleration of fast moving electrons when they collide and interact with target anode.

Uses of X-rays are

(a) They are used in engineering to detect fault, crack on bridge, testing of welds.

(b) These are used in scientific research.

51. According to the question, ultraviolet rays are used to kill germs in water purifier. Its wavelength range is 400 nm to 1 nm.

Uses of ultraviolet rays are

(a) These are used to study molecular structure.

(b) These are used in burglar alarm.

52. Characteristics of an electromagnetic wave are

(a) The electromagnetic waves are produced by accelerated charge.

(b) These waves do not require any material medium of propagation.

Microwaves used in RADAR systems because their frequency lies in the range of 1 GHz to 300 GHz (gigahertz).

53. The electric current due to changing electric field is called displacement current.

$$I_d = \varepsilon_0 \cdot \frac{d\phi_E}{dt}$$

The conduction and displacement currents are individually discontinous but the currents together posses the property of continuity through any closed electric circuit.

Common Mistake Sometimes students think that the displacement current and conventional current both have same nature but displacement current is modification of Ampere's circuital law without using negative sign.

54. Refer to solution 53 on page 236.

55. (i) 10^{-12} m $- 10^{-8}$ m $= 0.01$ Å $- 100$ Å

The wave is identify as X-ray

It is used in crystallography.

(ii) 10^{-3} m $- 10^{-1}$ m $= 0.1$ cm $- 10$ cm

The waves is identify as radio wave

It is used in radio communication.

56. Refer to text given on page 228.

57. (i) Radiation re-radiated by the earth's surface has greater wavelength.

(ii) Tanning effect is significant for direct UV radiation, it is negligible for radiation coming through the glass window.

58. Ampere's circuital law was modified to

$$\oint \mathbf{B} \cdot d\mathbf{l} = \mu_0 (I_c + I_d)$$

where, I_c = conduction current
and I_d = displacement current.

$$\Rightarrow \quad \oint \mathbf{B} \cdot d\mathbf{l} = \mu_0 \left(I_c + \varepsilon_0 \frac{d\phi_E}{dt} \right)$$

In order to overcome the inconsistency of this law. Maxwell introduced a term, i.e., displacement current to make it logically consistent.

Displacement current is that current which comes into play in the region in which the electric field and electric flux is changing with time.

59. Refer to text on page 226 (Electromagnetic waves).

Electric and magnetic fields are the sources of energy associated with EM waves.

60. Let the alternating emf charging the plates of capacitor be $V = V_0 \sin \omega t$ ...(i)

Charge on the capacitor, $q = CV = CV_0 \sin \omega t$ [from Eq.(i)]

and instantaneous current,

$$I = \frac{dq}{dt} = \frac{d}{dt}(CV_0 \sin \omega t)$$
$$= \omega CV_0 \cos \omega t = I_0 \cos \omega t$$

where, $I_0 = \omega CV_0$

Displacement current, $I_d = \varepsilon_0 \frac{d\phi_E}{dt}$

$$\Rightarrow \quad \varepsilon_0 A \frac{d(E)}{dt} = \varepsilon_0 A \frac{d}{dt}\left(\frac{q}{\varepsilon_0 A} \right)$$
$$= \varepsilon_0 A \frac{d}{dt}\left(\frac{CV_0 \sin \omega t}{\varepsilon_0 A} \right)$$
$$= \frac{d}{dt}(CV_0 \sin \omega t)$$
$$= \omega CV_0 \cos \omega t = I_0 \cos \omega t$$

Thus, the displacement current inside the capacitor is the same as the current charging the capacitor.

61. (i) Infrared waves have frequencies lower than those of visible light, vibrate not only the electrons, but also the entire atoms or molecules in the structure of the substance they encountered.
This vibration increases the internal energy and hence the temperature of the structure, that is why infrared waves are often called heat waves.

(ii) Electromagnetic wave transports linear momentum as it travels through space. If an electromagnetic wave transfer a total energy U to a completely absorbing surface in time t, then total linear momentum delivered to that surface is given as

$$p = \frac{U}{c}$$

where, c is the speed of electromagnetic wave.

62. (i) Electromagnetic radiations obtained in nuclear disintegrations are used to study the structure of atomic nucleus.

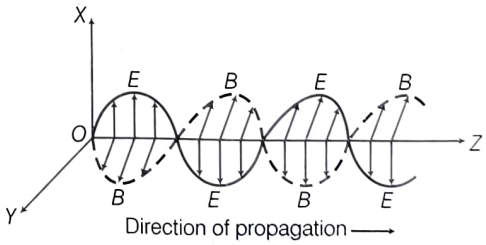
(ii) (a) Current in between capacitor's plates, is only displacement current, but no conduction current.
(b) Current flowing through a metallic wire is conduction current, but no displacement current.

63. (i) 10^{-12} m - 10^{-8} m = .01 Å - 100 Å — X-ray.
It is used in crystallography.

(ii) 10^{-3} m - 10^{-1} m = 0.1 cm - 10 cm —Microwaves.
It is used in microwave oven for cooking purpose.

64. (i) The oscillating charge produces an oscillating electric field and an oscillating electric field produces magnetic field which is then produces an oscillating emf. An oscillating voltage (emf) produces an oscillating magnetic field and so on. This in turn produces an oscillating electric fields and so on. This oscillating electric and magnetic fields regenerate each other as the wave propagates through space. In this way, the oscillating charges produce an electromagnetic waves.

(ii) The propagation of electromagnetic wave is shown in figure below.



65. (i) Refer to Sol. 64(i) on pages 237.

(ii) According to the quantum theory, electromagnetic radiation is made up of massless particles called photons. Momentum of the photon is expressed as $p = E/c$

where, p = momentum of photon, E = energy
and c = speed of light of photon.

Thus, I am convinced that electromagnetic waves carry energy and momentum.

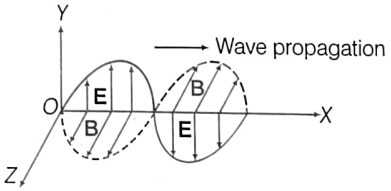
66. (i) The decreasing order of wavelengths of electromagnetic waves is

Microwaves > Infrared > Ultraviolet > γ-rays

(ii) **Microwaves** They are used in RADAR devices.

γ-rays It is used in radio therapy.

67. (i) Given that, velocity, $\mathbf{v} = v\,\hat{\mathbf{i}}$, this means electric field **E** will be along *Y*-axis and magnetic field **B** will be along *Z*-axis, because the two fields are perpendicular to each other and perpendicular to the direction of propagation of wave.



(ii) Speed of electromagnetic wave can be given as $c = E_0/B_0 = E/B$

where, E_0 and B_0 = peak value of **E** and **B**, E and B are instantaneous value of **E** and **B**.

68. The ammeter will show the momentary deflection during charging only, after that the current in the circuit becomes zero.

This momentary deflection occurs due to the fact that the conduction current flows through connecting wires during the charging of capacitor. This leads to gathering of charge at two plates and hence varying electric field of increasing nature is produced between the plates which in turn produces displacement current in space between two plates. Thus, maintains the continuity with the conduction current.

The current inside the capacitor, $I_C = I_D$

where, I_D is displacement current, $I_D = \varepsilon_0 \dfrac{d\phi_E}{dt}$

69. An ideal capacitor offers infinite resistance for an DC source. Thus, no current flows.

On the other hand, when AC source is connected to a capacitor, a conduction current continuously flows through the connecting wire to charge the capacitor. Due to this changing current, accumulation of the charges at the two plates changes. Due to this, a varying electric field of increasing nature is produced between the plates. This in turn produces a displacement current in between the plates. To maintain this continuity, this conduction current will be equal to the displacement current flowing, i.e.

Conduction current = Displacement current and $I_D = \varepsilon_0 (d\phi_E/dt)$

70. **For production of electromagnetic waves**

Refer to Sol. 64 (i) on page 237.

The frequency of the electromagnetic waves naturally equals the frequency of oscillation of the charge.

71. (i) Microwaves are used for aircraft navigation and their frequency range is 10^9 Hz to 10^{11} Hz.

(ii) X-rays are used to study crystal structure and their frequency range is 10^{16} Hz to 10^{21} Hz.

72. The direction of propagation of electromagnetic wave is perpendicular to both electric field vector **E** and magnetic field vector **B**, i.e. in the direction of $\mathbf{E} \times \mathbf{B}$. For figure refer to Sol. 64 (ii) on page 237.

Here, electromagnetic wave is along the *z*-direction which is given by the cross product of **E** and **B**.

73. Ascending order of the frequencies of electromagnetic waves is radio waves < microwaves < X-rays < γ-rays.

Uses of X-rays. Refer to text on page 228.

74. X-rays can be produced by colliding fast moving electron beam on metal target.

For Uses Refer to text on page 228.

75. Infrared waves are produced by hot objects and vibration of atoms and molecules.

For Uses Refer to text on page 228.

76. Microwaves are produced by oscillating current in vacuum tubes like klystrons, magnetrons.

For Uses Refer to text on page 228.

77. (i) λ_1 is microwave which is suitable for RADAR systems used in aircraft navigation.

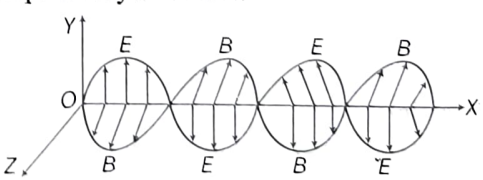
(ii) λ_2 is ultraviolet which used to kill germs in water purifiers.

(iii) λ_3 is infrared which used to improve visibility in runways during fog and mist condition.

Arrangement in ascending order of their magnitude.

$$\lambda_2 < \lambda_3 < \lambda_1$$

78. (i) As wave is propagating along *X*-axis, so electric field and magnetic field are along *Y*-axis and *Z*-axis respectively as shown



The expressions of oscillating electric and magnetic field are

$$\mathbf{E} = E_0 \sin(kx - \omega t)\hat{\mathbf{j}}$$

$$\mathbf{B} = B_0 \sin(kx - \omega t)\hat{\mathbf{k}}$$

(ii) Refer to text on page 227.

(Important characteristics of electromagnetic waves).

79. (i) In RADAR system → Microwaves
In water purifiers → Ultraviolet rays
In remote switches of TV → Infrared waves

(ii) Microwaves — Klystron valve
UV rays — Inner shell electrons in atoms moving from one energy level to a lower level.
Infrared waves — Vibration of atoms and molecules.

80. (i) γ-rays are produced by radio active decay of nucleus. These are used in radiotherapy for treatment of tumour and cancer.
(ii) Ultraviolet rays (UV rays) are produced by the welding arcs. These rays are used in burglar alarm.
(iii) Infrared rays are produced by hot bodies. These are used in remote control of TV.

81. (i) Gamma rays 3×10^{18} Hz to 5×10^{22} Hz
(ii) Ultraviolet rays 10^{14} Hz to 10^{16} Hz
(iii) Radio waves 54 MHz to 890 MHz

82. (i) (a) Microwave - 1 GHz to 300 GHz.
(b) Ultraviolet (by LASIK eye surgery) - 10^{14} Hz to 10^{16} Hz.

(ii) The energy density (energy per unit volume) in an electric field **E** in vacuum is $\frac{1}{2}\varepsilon_0 E^2 (U_e)$ and that in magnetic field **B** is $\frac{B^2}{2\mu_0}(U_m)$.

∴Energy associated with an electromagnetic wave is given by, $U = \frac{1}{2}\varepsilon_0 E^2 + \frac{1}{2}\cdot\frac{B^2}{\mu_0}$

Also, average energy density,

$$u_{av} = \frac{1}{4}\varepsilon_0 E_0^2 + \frac{1}{4}\frac{B_0^2}{\mu_0}$$

Since, we know that the energy in electromagnetic waves is divided, on an average, equally between electric and magnetic fields.

$$U_e = U_m$$

So, $u_{av} = \frac{1}{2}\varepsilon_0 E_0^2 = \frac{B_0^2}{2\mu_0}$

83. Given that,

$$B_y = 12 \times 10^{-8} \sin(1.20 \times 10^7 z + 3.60 \times 10^{15} t)$$

$$B_0 = 12 \times 10^{-8}$$

$$E_0 = c \times B_0 = 3 \times 10^8 \times 12 \times 10^{-8}$$

$$E_0 = 36 \text{ N/C} \quad \ldots(i)$$

(i) Energy density, $U = \frac{1}{2}\varepsilon_0 E_0^2$ ...(ii)

Putting value of Eq. (i) in Eq. (ii),

$$U = \frac{1}{2} \times 8.85 \times 10^{-12} \times (36)^2$$

$$= 5.74 \times 10^{-15} \text{ J/m}^2$$

(ii) Speed of the wave,

$$B_y = 12 \times 10^{-8} \sin(1.20 \times 10^7 z + 3.60 \times 10^{15} t)$$

$$k = 1.20 \times 10^7$$

$$\omega = 3.6 \times 10^{15}$$

Speed of the wave $= \frac{\omega}{k} = \frac{3.6 \times 10^{15}}{1.20 \times 10^7} = 3 \times 10^8$ m/s

84. Refer to Sol. 64 (i) on page 237.

An oscillating *L-C* circuit can produce electromagnetic waves of frequency as charge oscillates across the capacitor's plates in this circuit. The frequency of oscillation is given by

$$\nu = 1/2\pi\sqrt{LC}$$

This frequency is equal to the frequency of EM waves.

For figure Refer to Sol. 64 (ii) on page 237.

In this diagram, we see that permanent curve shows electric field **E** and dotted curve shows magnetic field **B**. They change continuously. Electromagnetic waves so produced have the direction perpendicular to **E** and **B**.

85. (i) (a) Microwaves are suitable for RADAR system used in aircraft navigation.
(b) X-rays are produced by bombarding a metal target by high speed electrons.

(ii) During charging and discharging of capacitor, a conduction current is produced due to the flow of charges from battery to the plates, *vice versa* connecting wires. Due to this, galvanometer shows a momentary deflection. Now, when the capacitor is fully charged, the conduction current stops flowing. Also during charging and discharging, there is zero conduction current between the plates. But, it was found that an electric field exist inside the plates, therefore indicating existence of magnetic field which leads to inconsistency in the

Ampere's circuital law. To account this problem, the concept of displacement current was introduced by Maxwell. He changed the Ampere's circuital law, ($\oint \mathbf{B} \cdot d\mathbf{l} = \mu_0 I$) to a modified form which is given as $\oint \mathbf{B} \cdot d\mathbf{l} = \mu_0 (I_C + I_D)$

where, I_D is the displacement current.

86. (i) Gamma rays has the highest frequency in the electromagnetic waves. These rays are of the nuclear origin and are produced in the disintegration of radioactive atomic nuclei and in the decay of certain subatomic particles. They are used in the treatment of cancer and tumours.

(ii) Ultraviolet rays lie near the high frequency end of visible part of EM spectrum. These rays are used to preserve food stuff. The harmful effect from exposure to ultraviolet (UV) radiation can be life threatening, and include premature aging of the skin, suppression of the immune systems, damage to the eyes and skin cancer.

87. (i) The EM waves suitable for RADAR system is microwaves.

These rays are produced by special vacuum tubes, namely klystrons, magnetrons and gunn diodes.

(ii) Infrared waves are used to treat muscular strain. These rays are produced by hot bodies and vibration of molecules and atoms.

(iii) X-rays are used a diagnostic tool in medicine. These rays are produced when high energy electrons are stopped suddenly on a metal surface of high atomic number.

88. (i) γ-rays are produced during radioactive decay of a nucleus. Its frequency range is from 3×10^{18} Hz to 5×10^{22} Hz.

(ii) Refer to Sol. 28 on page 235.

(iii) Infrared rays are called heat waves, because they cause the atoms and molecules to vibrate when they encounter a substance.

This increases the internal energy of atoms and molecules. Thereby, increasing the temperature of the substance.

They are used in physical therapy and weather forecasting.

89. (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 is only possible if EM wave constitutes momentum and energy. Thus, this illustrates that EM waves carry energy and 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 increase the kinetic energy of the molecules. Thus, facilitating the food to cook properly.

(iii) Refer to text on page 228 (Infrared waves).

90. In microwave oven, the frequency of the microwaves is selected to match the resonant frequency of water molecules. This leads to the vibrations of these molecules. As these vibrations increase with time, the temperature increases leading to production of heat and this is the heat which is responsible for the cooking of food in the oven.

As, microwaves are short wavelength radio waves, with frequency of order of 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 systems used in aircraft navigation.

91. (i) Refer to Sol. 64 (i) on page 237 (For electromagnetic waves).

(ii) Refer to text on page 228 (Uses of electromagnetic waves).

92. (i) (d) Electromagnetic waves are neither deflected by magnetic field nor by electric field.

(ii) (d) Total energy density of electromagnetic waves in vacuum is equal to sum of energy density of electric field E and magnetic field B.

i.e. $u = u_E + u_B = \frac{1}{2}\varepsilon_0 E^2 + \frac{B^2}{2\mu_0}$

(iii) (c) Since, radiations from γ-rays to radio waves, all belong in category of electromagnetic wave, hence speed of all waves remains same as 3×10^8 m/s.

(iv) (a) Solar radiation is transverse electromagnetic wave because its electric and magnetic field vector vibrate perpendicular to each other and also perpendicular to direction of propagation of wave.

(v) (a) Given, $\mathbf{E} = 6.3\hat{\mathbf{j}}$ V/m

We know that, the magnetic field intensity due to the wave is

$$\mathbf{B} = \frac{\mathbf{E}}{c} = \frac{6.3}{3 \times 10^8} = 2.1 \times 10^{-8}\ \hat{\mathbf{k}}\ \text{T}$$