8 Electromagnetic Waves

Fastrack Revision

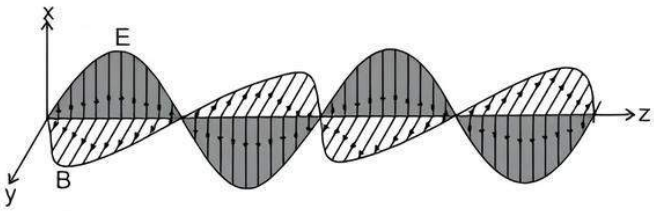
- **Displacement Current:** Displacement current is a quantity appearing in Maxwell's equations. It is defined as the rate of change of the electric displacement.
  It is expressed by the following formula

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

  where, ϕ_E = electric flux.

  SI unit of electric displacement is Ampere and it is a vector quantity.
  It is vital for electromagnetic wave propagation. Maxwell's equation is a good way to explain displacement current.
- **Maxwell's Equations:** There are four Maxwell's equations in vacuum.
  - $\oint \vec{E} \cdot d\vec{A} = Q/\varepsilon_0$ (Gauss's law for electricity)
  - $\oint \vec{B} \cdot d\vec{A} = 0$ (Gauss's law for magnetism)
  - $\oint \vec{E} \cdot d\vec{l} = \frac{-d\phi_B}{dt}$ (Faraday's Law)
  - $\oint \vec{B} \cdot d\vec{l} = \mu_0 i_c + \mu_0 \varepsilon_0 \frac{d\phi_E}{dt}$ (Ampere-Maxwell law)

- **Electromagnetic Waves**
  - Electromagnetic waves are produced only by charges that are accelerating, since acceleration is absolute and not a relative phenomenon.
  - An electric charge oscillating harmonically with frequency ν or f, produces electromagnetic waves of the same frequency ν.
  - An electric dipole is a basic source of electromagnetic waves.
  - Electromagnetic waves with wavelength of the order of a few metres were first produced and detected in the laboratory by Hertz in 1887. He thus verified a basic prediction of Maxwell's equations.
- **Nature of Electromagnetic Waves:** Oscillation of electric and magnetic fields is sinusoidal in space and time in an electromagnetic wave. The oscillating electric and magnetic fields, $\vec{E}$ and $\vec{B}$ are perpendicular to each other and to the direction of propagation of the electromagnetic wave, that is, electromagnetic waves are transverse in nature.
  A linearly polarised electromagnetic wave, propagating in the Z-direction with the oscillating electric field $\vec{E}$ along the X-direction and the oscillating magnetic field B along the Y-direction is show in figure.



- **Characteristics of Electromagnetic Waves**
  - Electromagnetic waves are transverse in nature.
  - No material medium is involved in the vibrations of the electric and magnetic fields.
  - Electromagnetic waves follow the principle of superposition.
  - Electromagnetic waves have constant velocity in vacuum.
  - An electromagnetic waves carries energy and momentum.
  - Electromagnetic wave also exerts pressure called radiation pressure.
  - The oscillation of the electric and magnetic fields are perpendicular to each other and are in same phase.
- **Relation between μ_0 and ε_0:** The speed of electromagnetic wave c in vacuum is related to μ_0 and ε_0 (the free space permeability and permittivity constants respectively) as

$$c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$$

- **Velocity of Light:** The velocity of light or electromagnetic waves in a medium is

$$v = \frac{1}{\sqrt{\mu\varepsilon}}$$

  where, μ and ε are the permeability and permittivity of the medium respectively.
- **Energy per Unit Volume:** If in a region of space in which there exist electric and magnetic fields E and B, there exists energy density (energy per unit volume) associated with these fields is

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

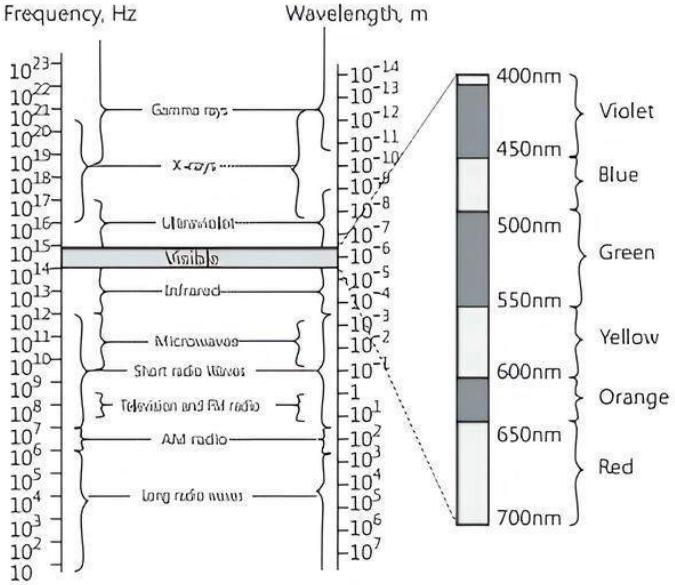
  where we are assuming that the concerned space consists of vacuum only.

▸ **Electromagnetic Spectrum:** The classification of electromagnetic waves according to frequency is called electromagnetic spectrum.

Electromagnetic waves include gamma rays, X-rays, ultraviolet rays, visible rays, infrared rays, microwaves and radio waves in order of increasing wavelength from 10^{-2}Å or 10^{-12} m to 10^{6} m.

There is no sharp division between one kind of wave and the next.

The classification is based roughly on how the waves are produced or detected.



Here, electromagnetic waves are described in order of decreasing wavelengths.

➤ **Radio Waves:**
- These are produced by accelerated motion of charges in conducting wires.
- These are used in radio and television communication systems.
- These are generally in the frequency range from 500 kHz to about 1000 MHz.

➤ **Microwaves:**
- These are short wavelength radio waves with frequencies in the gigahertz range. They are produced by special vacuum tubes.
- Due to their short wavelengths, they are suitable for RADAR systems used in aircraft navigation.
- These are used in microwave ovens for cooking purpose.

➤ **Infrared Rays:**
- These are produced by hot bodies and molecules.
- They lie in the low frequency or long wavelength end of the visible spectrum.
- They are widely used in the remote switches of household electronic system such as TV sets, video recorders etc.

➤ **Visible Rays:**
- It is the most familiar form of EM wave. It is the part of the spectrum that is detected by the human.
- Visible spectrum runs from about 4×10^{14} Hz to about 7×10^{14} Hz.

➤ **Ultraviolet Rays:**
- It covers wavelengths ranging from 400 nm to 0.6 nm.
- It is produced by special lamps and very hot bodies.
- The sun is an important source of UV light.
- UV lamps are used to kill germs in water purifiers.

➤ **X-rays:**
- These cover the range 10 nm to about 10^{-4} nm.
- These are used as a diagnostic tool in medicine and as a treatment for certain forms of cancer.

➤ **Gamma Rays:**
- These lie in the upper frequency range of the spectrum, and have wavelengths in the range 10^{-10} m to less than 10^{-14} m.
- This high frequency radiation is produced in nuclear reactors.
- They are used in medicine to destroy cancer cells.

Different Types of Electromagnetic Waves

Type	Wavelength range	Production	Detection
Radio	> 0.1 m	Rapid acceleration and decelerations of electrons in aerials	Receiver's aerials.
Microwave	0.1 m to 1 mm	Klystron valve or magnetron valve	Point contact diodes
Infrared	1mm to 700nm	Vibration of atoms and molecules	Thermopile Bolometer, Infrared photographic film
Light	700 nm to 400 nm	Electrons in atoms emit light when they move from one energy level to a lower energy level	The eye photocells photographic film.
Ultraviolet	400 nm to 0.6 nm	Inner shell electrons in atoms moving from one energy level to a lower level	Photocells Photographic film
X-rays	10 nm to 10^{-4} nm	X-ray tubes or inner shell electrons	Photographic film Geiger tubes Ionisation chamber
Gamma rays	< 10^{-5}nm	Radioactive decay of the nucleus	Photographic film Geiger tubes Ionisation chamber

Practice Exercise

Multiple Choice Questions

Q 1. Displacement current depends on:
a. moving charges
b. change in time
c. Both a. and b.
d. Neither moving charges nor changes in time.

Q 2. What is the unit of displacement current?
a. Coulomb b. Metre
c. Ampere d. Ampere/coulomb.

Q 3. Which of the following formula is correct for displacement current?
a. $\oint \vec{B} \cdot ds$ b. $\mu_0 \varepsilon_0 \frac{d\phi}{dt}$ c. $\mu_0 \varepsilon_0$ d. $\varepsilon_0 \frac{d\phi}{dt}$

Q 4. Identify the expression of Ampere-Maxwell's circuital law:
a. $\oint \vec{B} \cdot d\vec{l} = \mu_0 i_c + \mu_0 \varepsilon_0 \frac{d\phi_E}{dt}$
b. $\oint \vec{B} \cdot d\vec{l} = \mu_0 i_c - \mu_0 \varepsilon_0 \frac{d\phi_E}{dt}$
c. $\oint \vec{B} \cdot d\vec{l} = (\mu_0 i_c) \times \left(\mu_0 \varepsilon_0 \frac{d\phi_E}{dt}\right)$
d. None of the above

Q 5. Which of the following is true in regards to the Maxwell's equations?
a. The total current has the same value of current for all surfaces
b. The most important prediction to emerge from Maxwell's equations is the existence of magnetic waves
c. Maxwell's equations involves only electric and magnetic field
d. None of the above

Q 6. EM waves can be produced by:
a. an accelerated charged particle
b. a charged particle moving with constant speed
c. a particle at rest
d. a particle which is either at rest or moving with constant velocity

Q 7. Electromagnetic waves of wavelength of the order of a few meters were first produced and detected in the laboratory by: *(CBSE 2023)*
a. J.C. Maxwell b. J.C. Bose
c. H.R. Hertz d. G. Marconi

Q 8. The diagram below shows the electric field $(\vec{E})$ and magnetic field $(\vec{B})$ components of an electromagnetic wave at a certain time and location.

The direction of the propagation of the electromagnetic wave is: *(CBSE SQP 2023-24)*
a. perpendicular to $\vec{E}$ and $\vec{B}$ and out of plane of the paper
b. perpendicular to $\vec{E}$ and $\vec{B}$ and into the plane of the paper
c. parallel and in the same direction as $\vec{E}$
d. parallel and in the same direction as $\vec{B}$

Q 9. What is wavelength of signal weather frequency of 300 MHz?
a. 2 m b. 20 m c. 10 m d. 1 m

Q 10. EM waves transport:
a. Charge and momentum
b. Frequency and wavelength
c. Energy and momentum
d. Wavelength and energy

Q 11. If $\vec{E}$ and $\vec{B}$ represent electric and magnetic field vectors of the electromagnetic wave, the direction of propagation of electromagnetic wave is along: *(NCERT EXEMPLAR)*
a. $\vec{E}$ b. $\vec{B}$ c. $\vec{B} \times \vec{E}$ d. $\vec{E} \times \vec{B}$

Q 12. Electromagnetic wave consists of periodically oscillating electric and magnetic field vectors:
a. in mutually perpendicular planes but vibrating with a phase difference of π.
b. in mutually perpendicular planes but vibrating with a phase difference of $\frac{\pi}{2}$
c. in randomly oriented planes but vibrating in phase.
d. in mutually perpendicular planes but vibrating in phase.

Q 13. If *E* and *B* denote electric and magnetic fields respectively, which of the following is dimensionless?
a. $\sqrt{\mu_0 \varepsilon_0} \frac{E}{B}$ b. $\mu_0 \varepsilon_0 \frac{E}{B}$
c. $\mu_0 \varepsilon_0 \left(\frac{B}{E}\right)^2$ d. $\frac{E}{\varepsilon_0} \frac{\mu_0}{B}$

Q 14. Which of the following has/have zero average value in a plane electromagnetic wave?
a. Both magnetic and electric fields.
b. Electric field only
c. Magnetic field only
d. None of the above

Q 15. The photon energy in units of eV for electromagnetic waves of wavelength 2 cm is:
a. 2.5×10^{-19} b. 5.2×10^{16}
c. 3.2×10^{-16} d. 6.2×10^{-5}

Q 16. A plane electromagnetic wave travels in free space along *X*-direction. If the value of $\vec{B}$ (in Tesla) at a particular point in space and time is $1.2 \times 10^{-8}\ \hat{k}$, the value of $\vec{E}$ (in V m^{-1}) at that point is:
a. $1.2\ \hat{j}$ b. $3.6\ \hat{k}$ c. $1.2\ \hat{k}$ d. $3.6\ \hat{j}$

Q 17. Which of the following is not true for electromagnetic waves?

a. These transport energy
b. These have momentum
c. These travel at different speeds in air depending on their frequency
d. These travel at different speeds in medium depending on their frequency

Q 18. Which of the following rays is not an electromagnetic wave?

a. X-rays b. γ-rays
c. β-rays d. Heat rays

Q 19. Which one of the following electromagnetic radiation has the least wavelength? *(CBSE 2023)*

a. Gamma rays b. Microwaves
c. Visible light d. X-rays

Q 20. 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

Q 21. If λ_x, λ_m and λ_v represents wavelength of X-rays, microwaves and visible rays respectively, then:

a. $\lambda_m > \lambda_x > \lambda_v$ b. $\lambda_m > \lambda_v > \lambda_x$
c. $\lambda_v > \lambda_x > \lambda_m$ d. $\lambda_v > \lambda_m > \lambda_x$

Q 22. The ultra high frequency band of radio waves in electromagnetic wave is used as in:

a. television waves
b. cellular phone communication
c. commercial FM radio
d. Both a. and c.

Q 23. An electromagnetic radiation has wavelength 1 Å, this radiation belongs to the region of:

a. visible light b. ultraviolet
c. infrared d. X-rays

Q 24. X-rays, gamma rays and microwaves travelling in vacuum have:

a. same wavelength but different velocities
b. same frequency but different velocities
c. same velocity but different wavelength
d. same velocity and same frequency

Q 25. One requires 11 eV of energy to dissociate a carbon monoxide molecule into carbon and oxygen atoms. The minimum frequency of the appropriate electromagnetic radiation to achieve the dissociation lies in: *(NCERT EXEMPLAR)*

a. visible region
b. infrared region
c. ultraviolet region
d. microwave region

Assertion & Reason Type Questions

Directions (Q.Nos. 26-37): *In the following questions, a statement of Assertion (A) is followed by a statement of Reason (R). Mark the correct choice as:*

a. Both Assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of Assertion (A).
b. Both Assertion (A) and Reason (R) are true but Reason (R) is not the correct explanation of Assertion (A).
c. Assertion (A) is true but Reason (R) is false.
d. Both Assertion (A) and Reason (R) are false.

Q 26. Assertion (A): Displacement current goes through the gap between the plates of a capacitor does not change.
Reason (R): The displacement current arises in the region in which the electric field and hence the electric flux does not change with time.

Q 27. Assertion (A): Different electromagnetic waves differ considerably in their mode of interaction with matter.
Reason (R): Different electromagnetic waves have different wavelength or frequency.

Q 28. Assertion (A): All electromagnetic waves travel through vacuum with same speed but they have different wavelength or frequency.
Reason (R): The wavelength of the electromagnetic waves is often correlated with the characteristic size of the system that produces and radiates them.

Q 29. Assertion (A): High frequency electromagnetic waves are detected by some means based on the physical effects produce on interacting with matter.
Reason (R): The oscillating fields of an electromagnetic wave can accelerate charges and can produce oscillating currents therefore, an apparatus designed to detect EM waves is based on this fact.

Q 30. Assertion (A): In an EM wave the magnitude of the electric field vector is more than the magnitude of the magnetic field vector.
Reason (R): Energy of the EM wave is shared equally between the electric and magnetic fields.

Q 31. Assertion (A): Long distance radio broadcasts use short-wave bands.
Reason (R): Ionosphere reflects waves in these bands.

Q 32. Assertion (A): If the earth did not have an atmosphere, its average surface temperature would have been lower.
Reason (R): In the absence of atmosphere, the green house effect will be absent.

Q 33. Assertion (A): Radio waves are diffracted by buildings.
Reason (R): Radio waves are high energy waves.

Q 34. **Assertion (A): Microwaves are better carrier of signals than optical waves.**
Reason (R): Microwaves move faster than optical waves.

Q 35. **Assertion (A): Infrared waves are often called heat waves.**
Reason (R): Infrared waves vibrate not only the electrons, but entire atoms or molecules of a substance which increases the internal energy and temperature of the substance.

Q 36. **Assertion (A): It is necessary to use satellites for long distance TV transmission.**
Reason (R): Television signals are not properly reflected by the ionosphere therefore, reflection is affected by satellites.

Q 37. **Assertion (A): Optical and radio telescopes are built on the ground but X-ray astronomy is possible only from satellites orbiting the earth.**
Reason (R): Atmosphere absorbs X-rays, while visible and radio waves can penetrate it.

Fill in the Blanks Type Questions

Q 38. **The current due to the changing ..... is called displacement current.**

Q 39. **EM waves are produced by ..... charges.**

Q 40. **Shorter the wavelength of an electromagnetic waves, ... energy it carries.**

Q 41. **For an EM wave propagating along *X*-axis E_{max} = 30 V/m, the maximum value of magnetic field is .....**

Q 42. **Waves used to transmit cellular telephone message are .....**

Q 43. **Human eye can detect ..... part of electromagnetic spectrum.**

Q 44. **During the propagation of an EM wave in a medium electrical energy density is ..... to magnetic energy density.**

Q 45. **To study structure of crystals ..... are used.**

Q 46. **Gamma rays lie in the ..... frequency range of the spectrum.**

Answers

1. (b) change in time
Displacement current is the current which arise due to variations in the field. Hence, it does not depend on the moving charges but it change with time which causes variation in the field.

2. (c) Ampere

3. (d) $\varepsilon_0 \frac{d\phi}{dt}$

4. (a) $\oint \vec{B} \cdot d\vec{l} = \mu_0 i_c + \mu_0 \varepsilon_0 \frac{d\phi_E}{dt}$

5. (a) The total current has the same value of current for all surfaces.

6. (a) an accelerated charged particle

7. (c) H.R. Hertz
Electromagnetic waves with wavelength of the order of a few meters were first produced and detected in the laboratory by Hertz in 1887. He thus verified a basics prediction of Maxwell's equations.

8. (a) Perpendicular to $\vec{E}$ and $\vec{B}$ and out of plane of the paper.

9. (d) 1 m

$$\text{wavelength, } \lambda = \frac{c}{v} = \frac{3 \times 10^8}{300 \times 10^6} = 1\,\text{m}$$

10. (c) Energy and momentum

11. (d) $\vec{E} \times \vec{B}$
The direction of propagation of electromagnetic wave is perpendicular to both electric field vector $\vec{E}$ and magnetic field vector $\vec{B}$ *i.e.*, in the direction of $\vec{E} \times \vec{B}$.

12. (d) in mutually perpendicular planes but vibrating in phase.
Electromagnetic wave consists of periodically oscillating electric and magnetic field vectors in mutually perpendicular planes but vibrating in phase.

13. (a) $\sqrt{\mu_0 \varepsilon_0}\,\frac{E}{B}$

$$\text{Speed of light, } c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}; \text{ Also, } \frac{E}{B} = c$$

Therefore, $\sqrt{\mu_0 \varepsilon_0}\,\frac{E}{B}$ is dimensionless.

14. (a) Both magnetic and electric fields.

15. (d) 6.2×10^{-5} eV
Given, $\lambda = 2\text{cm} = 2 \times 10^{-2}\text{m}$

$$\therefore \quad E = \frac{hc}{\lambda}$$

$$= \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{2 \times 10^{-2}} = 9.9 \times 10^{-24}\,\text{J}$$

$$= \frac{9.9 \times 10^{-24}}{1.6 \times 10^{-19}}\,\text{eV} = 6.2 \times 10^{-5}\,\text{eV}$$

16. (d) $3.6\,\hat{j}$

The magnitude of $\vec{E}$ is $E = Bc$

$$= (1.2 \times 10^{-8}\,\text{T})\,(3 \times 10^8\,\text{ms}^{-1})$$
$$= 3.6\,\text{Vm}^{-1}$$

$\vec{B}$ is along *Z*-direction and the wave propagates along *X*-direction. Therefore $\vec{E}$ should be in a direction perpendicular to both *X* and *Z*-axes. Using vector algebra $\vec{E} \times \vec{B}$ should be along *X*-direction.

Since $(+\hat{k}) \times (+\hat{i}) = \hat{j}$, $\vec{E}$ is along the *Y*-direction.

Thus, $\vec{E} = 3.6\hat{j}\ Vm^{-1}$.

17. (c) These travel at different speeds in air depending on their frequency.

18. (c) β-rays

X-rays, γ-rays, heat rays are the form of EM waves but β-rays are not EM waves because they are charged particles and are capable of getting deflected by the magnetic field.

19. (a) Gamma rays

20. (d) Ultraviolet rays

Ultraviolet water purification is the most effective method for disinfecting bacteria from the water.

21. (b) $\lambda_m > \lambda_v > \lambda_x$

22. (b) cellular phone communication

23. (d) X-rays

X-rays cover wavelengths ranging from about 10^{-8} m (100 Å) to 10^{-13} m (10^{-3} Å).

24. (c) Same velocity but different wavelengths.

In vacuum X-rays, gamma rays and microwaves travel with same velocity *i.e.*, with the velocity of light ($c = 3 \times 10^8\ ms^{-1}$) but have different wavelengths.

25. (c) ultraviolet region

Here, $E = 11\ eV = 11 \times 1.6 \times 10^{-19}\ J = h\nu$

$$\therefore\ \nu = \frac{11 \times 1.6 \times 10^{-19}}{h}$$

$$= \frac{11 \times 1.6 \times 10^{-19}}{6.62 \times 10^{-34}} = 2.6 \times 10^{15} Hz$$

This frequency belongs to ultraviolet region.

26. (d) Displacement current arises when electric field in a region is changing with time and given by

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

It will be so if the charge on a capacitor is not constant but changing with time.

27. (b) Mode of interaction is not interrelated with wavelength or frequency.

28. (a) Both Assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of Assertion (A).

29. (a) Both Assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of Assertion (A).

30. (b) Both Assertion (A) and Reason (R) are true but Reason (R) is not correct explanation of Assertion (A).

31. (a) Both Assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of Assertion (A).

32. (a) Both Assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of Assertion (A).

33. (c) Radio waves are electromagnetic waves having **low energy**. A low energy wave has a low frequency and consequently a large wavelength. Diffraction of waves takes place when the obstacles in the path are of a size comparable to the wavelength of the wave. For some radio waves whose wavelength is comparable to the size of the building gets diffracted by the building.

34. (d) The optical waves used in optical fibre communication are better carrier of signals than microwaves. The speed of microwave and optical wave is same in vacuum.

35. (a) Both Assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of Assertion (A).

36. (a) Both Assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of Assertion (A).

37. (a) Both Assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of Assertion (A).

38. electric field **39.** accelerated/oscillated

40. more **41.** 10^{-7} T **42.** microwaves

43. visible **44.** equal **45.** X-rays

46. upper

Case Study Based Questions

Case Study 1

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.

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 is about 300 crore hertz, which is 3 gigahertz (GHz). If water receives microwaves of this frequency, its molecules absorb this 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 not 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 heated 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 way energy is not wasted in heating up the vessel. 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.

Read the given passage carefully and give the answer of the following questions:

Q 1. Which of the following electromagnetic radiations have the longest wavelength?

a. X-rays b. γ-rays
c. Microwaves d. Radio waves

Q 2. Why does a microwave oven heat up a food item containing water molecules most efficiently?

a. Microwaves are heat waves, so always produce heat.
b. Infrared waves produce heating in a microwave oven.
c. Energy from the microwaves is transferred efficiently to the kinetic energy of water molecules at their resonant frequency.
d. The frequency of microwaves has no relation with natural frequency of water molecules.

Q 3. Microwaves are:

a. transverse electromagnetic waves
b. longitudinal electromagnetic waves
c. stationary waves
d. None of the above

Q 4. Microwaves are used in:

a. RADAR system for aircraft navigation
b. long-distance communication systems *via* geostationary satellites
c. microwave ovens
d. All of the above

Answers

1. (d) Radio waves
2. (c) Energy from the microwaves is transferred efficiently to the kinetic energy of water molecules at their resonant frequency.
3. (a) transverse electromagnetic waves
4. (d) All of the above

Case Study 2

A major report on mobile phones and health advises limits of their use by children, the BBC understands.

While the Stewart Report has found no clear evidence that mobiles can damage the health of either adults or children, scientists suggest that there may be some effect on the human body.

Children may be advised to cut phone use

And it recommends that mobile phone companies should not aim their advertising at children. The report was commissioned in response to fears that mobile use could be linked to memory loss, and even Alzheimer's disease.

Some studies have suggested that children are more vulnerable to the effects of microwave radiation emissions because their nervous systems are not fully developed and their skull is thinner than adults, providing less protection.

"A growing number of children have access to mobile phones, and they are a great source of comfort and security for parents, knowing they can find out where their children are and can keep in touch with them."

The radiation emitted by mobile phones is not X-ray radiation, but microwave radiation, and some scientists were concerned that it might actually be heating and damaging brain cells because the phone is held so close to the head.

Read the given passage carefully and give the answer of the following questions:

Q 1. What type of electromagnetic waves do mobile phones emit?

a. Heat waves b. X-rays
c. UV rays d. Microwaves

Q 2. Why are mobile phones more likely to cause damage to young people's brain cells?

a. Because they don't know, how to use mobile phones properly
b. Because they use mobile phones for longer time
c. Because their nervous system is not fully developed and their skull is thinner than adults.
d. Because mobile phone causes memory loss in young people

Q 3. Which of the following are fundamentally different from the others?

a. Gamma rays b. Microwaves
c. Sound waves d. Light waves

Q 4. The main difference between microwaves and light waves is:

a. speed b. wavelength
c. nature d. None of these

Answers

1. (d) Microwaves
2. (c) Because their nervous system is not fully developed and their skull is thinner than adults.
3. (c) Sound waves
4. (b) wavelength

Case Study 3

The beauty of a coral reef, the warm radiance of sunshine, the sting of sunburn, the X-ray revealing a broken bone, even microwave popcorn, all are brought to us by electromagnetic waves.

It is worth noting at the outset that the general phenomenon of electromagnetic waves was predicted by theory before it was realised that light is a form of electromagnetic wave. The prediction was made by James Clerk Maxwell in the mid-19th century when he formulated a single theory combining all the electric and magnetic effects known by scientists at that time. "Electromagnetic waves" was the name he gave to the phenomena he predicted.

An electromagnetic wave has a frequency 'ν' and a wavelength 'λ' associated with it and travels at the speed of light 'c'. The relationship among these wave characteristics is

$$c = \nu\lambda.$$

Thus, for all electromagnetic waves, the greater the frequency, the smaller the wavelength. Electromagnetic waves are classified into categories such as radio waves, infrared rays, ultraviolet rays, and so on, so that we can understand some of their similarities as well as some of their differences.

Read the given passage carefully and give the answer of the following questions:

Q 1. Which of the following electromagnetic radiations have the shortest wavelength?

a. X-rays b. β-rays
c. Microwaves d. Gamma rays

Q 2. If a source is transmitting electromagnetic waves of frequency 8.2×10^6 Hz, the wavelength of electromagnetic wave transmitted from the source is:

a. 36.5 m b. 18.8 m c. 42.8 m d. 58 m

Q 3. Light can travel in vacuum due to its:

a. transverse nature b. electromagnetic nature
c. longitudinal nature d. Both a. and c.

Q 4. We consider the radiation emitted by the human body. Which one of the following statements is true?

a. The radiation emitted is in the infrared region
b. The radiation emitted only during the day
c. The radiation is emitted during the summers and absorbed during winters
d. The radiation emitted lies in the ultraviolet region and hence is not visible

Answers

1. (d) Gamma rays
2. (a) 36.5 m

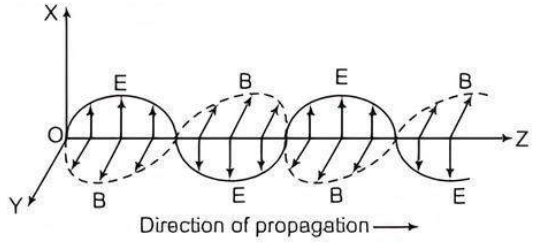
   Given, frequency, $\nu = 8.2 \times 10^6$ Hz

   Wavelength, $\lambda = \frac{c}{\nu} = \frac{3 \times 10^8}{8.2 \times 10^6}$

   $= 36.5$ m
3. (b) electromagnetic nature
4. (a) The radiation emitted is in the infrared region

Case Study 4

A stationary charge produces only an electrostatic field while a charge in uniform motion produces a magnetic field, that does not change with time. An oscillating charge is an example of accelerating charge. It 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.



Read the given passage carefully and give the answer of the following questions:

Q 1. Magnetic field in a plane electromagnetic wave is given by $\vec{B} = B_0 \sin(kx + \omega t)\,\hat{j}\,T$. What will be the expression for corresponding electric field?

Q 2. The electric field component of monochromatic radiation is given by $\vec{E} = 2E_0\, k \sin kz \cdot \cos \omega t$. What will be its magnetic field component?

Q 3. A plane electromagnetic wave of frequency 25 MHz travels in a free space along *X*-direction. At a particular point in space and time, $E = (6.3\,\hat{j})$ V/m. What is magnetic field at that time?

Q 4. A plane electromagnetic wave travelling along the *X*-direction has a wavelength of 3 mm. The variation in the electric field occurs in the *Y*-direction with an amplitude 66 V m^{-1}. Write the equations for the electric and magnetic fields as a function of *x* and *t*.

Answers

1. Given, $\vec{B} = B_0 \sin(kx + \omega t)\hat{j}$ T

The relation between electric and magnetic fields is,

$C = \frac{E}{B}$ or $E = cB$

The electric field component is perpendicular to the direction of propagation and the direction of magnetic field. Therefore, the electric field component along Z-axis is obtained as $\vec{E} = cB_0 \sin(kx + \omega t)\hat{k}$ kV/m.

2. Since, $\frac{dE}{dz} = -\frac{dB}{dt}$

$\frac{dE}{dz} = -2E_0 k \sin kz \cos \omega t = -\frac{dB}{dt}$

$dB = +2E_0 k \sin kz \cos \omega t\, dt$

$B = +2E_0 k \sin kz \int \cos \omega t\, dt = +2E_0 \frac{k}{\omega} \sin kz \sin \omega t$

$\because \frac{E_0}{B_0} = \frac{\omega}{k} = c$

$\therefore \quad B = \frac{2E_0}{c} \sin kz \sin \omega t$

Thus, magnetic field component,

$$\vec{B} = \frac{2E_0}{c} \sin kz \sin \omega t\, \hat{j}$$

3. Given, $E = 6.3\ \hat{j}$ V/m, $c = 3 \times 10^8$ m/s

The magnitude of magnetic field,

$$B_z = \frac{E}{c} = \frac{6.3}{3 \times 10^8} = 2.1 \times 10^{-8}\ \text{T} = 0.021\ \mu\text{T}$$

4. Given, $E_0 = 66\ \text{Vm}^{-1}$, $E_y = 66 \cos \omega \left(t - \frac{x}{c}\right)$,

$\lambda = 3\ \text{mm} = 3 \times 10^{-3}$ m, $k = \frac{2\pi}{\lambda}$

$\frac{\omega}{k} = c \Rightarrow \omega = ck = 3 \times 10^8 \times \frac{2\pi}{3 \times 10^{-3}}$

or $\omega = 2\pi \times 10^{11}$ rad/s

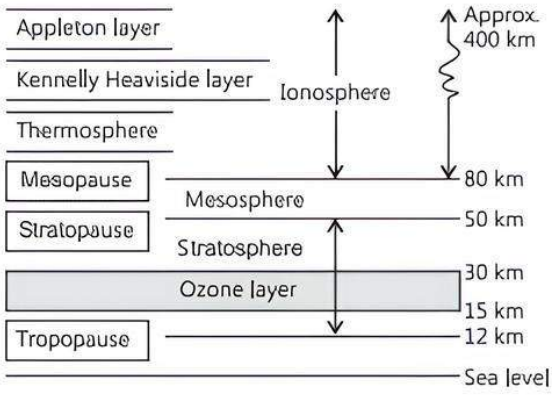
$\therefore \quad E_y = 66 \cos 2\pi \times 10^{11} \left(t - \frac{x}{c}\right)$

$B_z = \frac{E_y}{c} = \left(\frac{66}{3 \times 10^8}\right) \cos 2\pi \times 10^{11} \left(t - \frac{x}{c}\right)$

$= 2.2 \times 10^{-7} \cos 2\pi \times 10^{11} \left(t - \frac{x}{c}\right)$

Case Study 5

Radio waves are produced by the accelerated motion of charges in conducting wires. Microwaves are produced by special vacuum tubes. Infrared waves are produced by hot bodies and molecules and also known as heat waves. UV rays are produced by special lamps and very hot bodies like sun.



Read the given passage carefully and give the answer of the following questions:

Q 1. What is the cause of greenhouse effect?

Q 2. Ozone is present in which layer?

Q 3. What is the biological importance of ozone layer?

Q 4. Earth's atmosphere is richest in which radiation?

Answers

1. Greenhouse effect is due to infrared rays.
2. Ozone lies in stratosphere.
3. Ozone layer absorbs the harmful ultraviolet radiations coming from the sun.
4. Earth's atmosphere is richest in infrared radiations. The earth emits huge amount of infrared radiation and thereby makes the atmosphere richest in infrared rays.

Very Short Answer Type Questions

Q 1. Why was the concept of displacement current introduced?

Ans. 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.

Q 2. When can a charged particle acts as a source of EM wave?

Ans. When charged particle is either accelerated or oscillating.

Q 3. What oscillates in electromagnetic waves?

Ans. Electric and magnetic fields oscillate in electromagnetic waves.

Q 4. What is the phase relationship between oscillating electric and magnetic fields in an EM wave?

Ans. They are in the same phase.

Q 5. Write the relation for the speed of electromagnetic waves in terms of the amplitudes of electric and magnetic fields.

Ans. Speed of EM waves (c) is given by the ratio of the amplitudes of electric and magnetic field vectors *i.e.*,

$$c = \frac{E_0}{B_0}$$

TiP

E_0 and B_0 are maximum electric field and magnetic field component respectively of EM waves.

Q 6. What is the wavelength of light wave if its frequency is 5.0×10^{14} Hz?

Sol. Given, frequency $f = 5.0 \times 10^{14}$ Hz

Wavelength, $\lambda = \frac{c}{f} = \frac{3 \times 10^8}{5.0 \times 10^{14}}$

$= 0.6 \times 10^{-6}$ m $= 6.0\,\mu$m

Q 7. What is meant by the transverse nature of electromagnetic waves? *(CBSE 2016, 15)*

Ans. Transverse nature means, $\vec{E}$ and $\vec{B}$ are perpendicular to each other as well as perpendicular to the direction of propagation of the wave.

Q 8. Do electromagnetic waves carry energy and momentum? *(CBSE 2017)*

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

Q 9. What is the frequency of EM waves produced by oscillating charge of frequency ν? *(CBSE 2015)*

Ans. Frequency of EM wave = frequency of oscillating charge = ν.

Q 10. Name the electromagnetic radiations used for
(i) water purification, and
(ii) eye surgery. *(CBSE 2018)*

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

TiP

Learn uses of electromagnetic radiations using table and mind maps.

Q 11. In which directions of the electric and magnetic field vectors oscillate in an electromagnetic wave propagating along the *X*-axis? *(CBSE 2017)*

Ans. Electric field vector $\vec{E}$ and magnetic field vector $\vec{B}$ are always perpendicular to each other and to direction of propagation of light. Also, direction of propagation is parallel to $\vec{E} \times \vec{B}$. As, the wave is propagating along *X*-axis, hence, $\vec{E}$ is along + *Y*-axis and $\vec{B}$ is along + *Z*-axis.

(Alternatively $\vec{E}$ along *Z*-axis and $\vec{B}$ along *Y*-axis).

Q 12. Why are infrared waves often called as heat waves? Explain. *(CBSE 2018)*

Ans. Infrared rays are readily absorbed by the water molecules in most of the substances and hence increases their thermal motion that is why it is called heat wave.

Q 13. To which part of the electromagnetic spectrum does a wave of frequency 5×10^{19} Hz belong?

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

Q 14. Name the electromagnetic waves which:
(i) maintain the earth's warmth and
(ii) are used in aircraft navigation.

Ans. (i) Infrared rays maintain the earth's warmth.
(ii) Microwaves are used in aircraft navigation.

Q 15. Which part of electromagnetic spectrum has largest penetrating power?

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

Q 16. Arrange the following in descending order of wavelength. X-rays, radio waves, blue light, infrared rays.

Ans. Radio waves > Infrared rays > Blue light > X-rays is the descending order of wavelength.

Short Answer Type-I Questions

Q 1. What is meant by the term 'displacement current'? Briefly explain how this current is different from a conduction current. *(CBSE 2023)*

Ans. Displacement current is a quantity appearing in Maxwell's equations. It is defined as the rate of change of the electric displacement. It SI unit is Ampere.

Difference between Displacement Current and Conduction Current:

The current due to changing electric field is called displacement current while the current carried by conductors due to flow of charges is called conduction current. Conduction current obeys Ohm's law but displacement does not.

Q 2. (i) How are electromagnetic waves produced? Explain. *(CBSE 2017, 16, 15)*
(ii) What is the source of energy of these waves?

Ans. (i) **Production of EM Waves:** EM waves are produced by accelerated/oscillating charged particles.

When a charged particle moves with acceleration, both the magnetic and electric fields change continuously. This change produces electromagnetic waves.

(ii) Source of energy of EM waves is the energy of accelerated/oscillating charged particles.

Q 3. How are electromagnetic waves produced? Write their two characteristics. *(CBSE 2023)*

Ans. **Production of EM Waves:** EM waves are produced by accelerated/oscillating charged particles.

When a charged particle moves with acceleration, both the magnetic and electric fields change continuously. This change produces electromagnetic waves.

Characteristics of Electromagnetic waves:

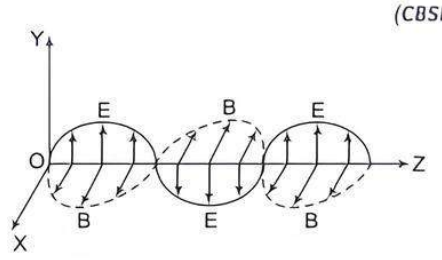
(i) Electromagnetic waves are transverse in nature.

(ii) Electromagnetic waves travel through vacuum with speed 3×10^8 m/s, *i.e.* speed of light.

Q 4. Draw a sketch of linearly polarised EM waves propagating in the *Z*-direction. Indicate the directions of the oscillating electric and magnetic fields.

(CBSE 2016, 15)

Ans.



⟵ Direction of Propagation ⟶

TiP

We are taking direction of electric field (E) and magnetic field (B) in such a way that these are follow the right handed system of axes.

Q 5. In a plane electromagnetic wave, the electric field oscillates sinusoidally with a frequency of 2.0×10^{10} Hz and amplitude 48 Vm^{-1}.

(i) What is the wavelength of the wave?

(ii) What is the amplitude of the oscillating magnetic field? *(NCERT EXERCISE)*

Sol. (i) The wavelength is

$$\lambda = \frac{c}{\nu} = \frac{3 \times 10^8 \text{ ms}^{-1}}{2.0 \times 10^{10} \text{ s}^{-1}}$$

$$= 1.5 \times 10^{-2} \text{ m}$$

(ii) If E_0 and B_0 be the amplitudes of the oscillating electric and magnetic fields respectively, then we have

$$\frac{E_0}{B_0} = c$$

$$\therefore B_0 = \frac{E_0}{c} = \frac{48 \text{ Vm}^{-1}}{3 \times 10^8 \text{ ms}^{-1}}$$

$$= 1.6 \times 10^{-7} \text{ NA}^{-1} \text{ m}^{-1}$$

Q 6. Electromagnetic waves with wavelength:

(i) λ_1 is suitable for RADAR systems used in aircraft navigation. *(CBSE SQP 2023)*

(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.

Ans. (i) λ_1 = Microwave

(ii) λ_2 = Ultraviolet

(iii) λ_3 = Infrared

Ascending order of wavelengths– $\lambda_2 < \lambda_3 < \lambda_1$.

Q 7. (i) Give one use of electromagnetic radiations obtained in nuclear disintegrations.

(ii) Arrange the following electromagnetic radiations in ascending order of their frequencies.

(a) Microwaves (b) Radio waves

(c) X-rays (d) γ-rays.

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

(ii) Ascending order of the frequencies of electromagnetic waves is

Radio waves < Microwaves < X-rays < γ-rays.

Q 8. How are X-rays produced? Write their two important uses.

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

Uses of X-rays:

(i) In medical diagnosis as these can pass through the muscles but not through the bones.

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

Q 9. How are microwaves produced? Write their two important uses.

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

Uses of Microwaves:

(i) In RADAR communication.

(ii) In analysis of molecular and atomic structure or in microwave oven for cooking food.

Q 10. Identify the electromagnetic waves whose wavelength vary as given and also write one use for each. *(CBSE 2017)*

(i) $10^{-12} \text{ m} < \lambda < 10^{-8} \text{ m}$

(ii) $10^{-3} \text{ m} < \lambda < 10^{-1} \text{ m}$

Ans. (i) X-rays/γ-rays: used for medical purposes/nuclear reactions.

(ii) Microwaves: used for RADAR systems.

TiP

The velocity differs when medium is present or absent. The frequency of a particular wave is constant, only the wavelength changes when enters a medium from the vacuum.

Q 11. Name the following constituent radiations of electromagnetic spectrum which:

(i) are adjacent to the low frequency end of electromagnetic spectrum.

(ii) produced by nuclear reactions/used to destroy cancer cells/treatment of cancer.

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

(iv) maintains the earth's warmth/used in remote sensing.

Ans. (i) Microwaves

(ii) γ-rays

(iii) X-rays

(iv) Infrared rays.

Q 12. Which constituent radiations of electromagnetic spectrum is used:
(i) in RADAR
(ii) in photographs of internal parts of human body/ as a diagnostic tool in medicine. *(CBSE 2015)*
(iii) for taking photographs of sky, during night and fog conditions.
(iv) has the largest penetrating power
Give reason for your answer in each case.

Ans. (i) Microwaves; because these go straight and are not absorbed by the atmosphere.
(ii) X-rays; because these can penetrate light elements (flesh).
(iii) Infrared rays; because these penetrate fog and are not absorbed by the atmosphere.
(iv) γ-rays; because these have the highest frequency and hence highest energy.

TiP

Learn uses of electromagnetic radiations using table and mind maps.

Short Answer Type-II Questions

Q 1. A parallel plate capacitor with plate area *A* and separation between the plates *d*, is charged by a constant current *I*. Consider a plane surface of area *A*/2 parallel to the plates and drawn between the plates. What will be the displacement current through the area?

Sol. Let, charge on capacitor plates at time *t*, $q = It$

$\therefore$ Electric field between plates.

$$E = \frac{q}{AE_0} = \frac{It}{AE_0}$$

or $$AE = \frac{It}{E_0}$$

Now, electric flux through the area $\frac{A}{2}$.

$$\phi_E = \frac{A}{2} \times E = \frac{It}{2\varepsilon_0}$$

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

$$= \varepsilon_0 \frac{d}{dt}\left(\frac{It}{2\varepsilon_0}\right)$$

$$= \frac{I}{2}$$

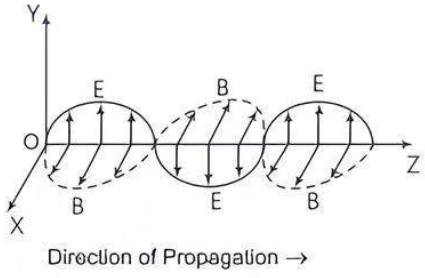
Q 2. How are electromagnetic waves produced by oscillating charges?
Draw a sketch of linearly polarised electromagnetic waves propagating in the *Z*-direction. Indicate the directions of the oscillating electric and magnetic fields. *(CBSE 2016)*

Ans. 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.

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. The sketch of linearly polarised EM wave propagating in *Z*-direction is shown in figure.



A plane electromagnetic wave travelling along Z-axis

In this figure, we see that dark line curve shows electric field $\vec{E}$ and dotted curve shows magnetic field $\vec{B}$. These change continuously. Electromagnetic waves is produced have the direction perpendicular to $\vec{E}$ and $\vec{B}$.

Q 3. (i) Write the expression for the speed of light in a material medium of relative permittivity ε_r and relative magnetic permeability μ_r.
(ii) Write the wavelength range and name of the electromagnetic waves which are used in (a) RADAR systems for aircraft navigation and (b) Earth satellites to observe the growth of the crops. *(CBSE 2020)*

Ans. (i) The speed of electromagnetic waves in a material medium is given by

$$v = \frac{1}{\sqrt{\mu\varepsilon}} = \frac{1}{\sqrt{\mu_0\mu_r\varepsilon_0\varepsilon_r}}$$

(ii) (a) Microwaves, range 0.1 m to 1 mm.
(b) Infrared rays, range 1 mm to 700 nm.

Q 4. (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. *(CBSE 2019)*

Ans. (i) (a) Microwave: 1 GHz to 300 GHz.
(b) Ultraviolet rays: 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 $E = Bc$ and $c = \frac{1}{\sqrt{\varepsilon_0 \mu_0}}$

$$\therefore \quad U_E = \frac{1}{2}\varepsilon_0 \times B^2 \times \left(\frac{1}{\sqrt{\varepsilon_0 \mu_0}}\right)^2 = \frac{1}{2\mu_0} B^2$$

Thus, $U_E = U_M$

Q 5. (i) Name the EM waves which are suitable for RADAR systems used in aircraft navigation. Write the range of frequency of these waves.
(ii) If the Earth did not have atmosphere, would its average surface temperature be higher or lower than what it is now? Explain.
(iii) An EM wave exerts pressure on the surface on which it is incident. Justify.

(CBSE SQP 2022, Term-2)

Ans. (i) Microwave are suitable for RADAR system used in aircraft navigation. Range of frequency of microwaves is from 10^9 Hz to 10^{11} Hz.

(ii) If the earth did not have atmosphere, then there would be absence of greenhouse effect of the atmosphere. Due to this reason, the temperature of the earth would be lower than what it is now.

(iii) An EM wave exerts pressure on the surface on which it is incident because these waves carry both energy and momentum.

Q 6. (i) Which segment of electromagnetic waves have 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? *(CBSE 2016)*

Ans. (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. These are used in the treatment of cancer and tumors.

(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.

Q 7. Gamma rays and radio waves travel with the same velocity in free space. Distinguish between them in terms of origin and the main application.

Ans.

S. No.	Basis of Difference	Gamma rays	Radio waves
1.	Origin	From hottest and most energetic objects in the universe, such as neutron stars, pulsars, supernova, explosions and regions around black holes.	From broadcast radio towers, cell phones and RADAR.
2.	Main Applications	In radio therapy, sterilisation and disinfection.	In fixed and mobile radio communication, radar and other navigation systems, communication satellites, computer networks.

Q 8. (i) State clearly how a microwave oven works to heat up a food item containing water molecules.
(ii) Why are microwaves found useful for the raw systems in aircraft navigation?

Ans. (i) In microwave oven, the frequency of the microwave 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 food in the oven.

(ii) 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.

Q 9. Answer the following questions:
(i) Name the EM waves which are used for the treatment of certain forms of cancer. Write their frequency range.
(ii) Thin ozone layer on top of stratosphere is crucial for human survival. Why?
(iii) Why is the amount of the momentum transferred by the EM waves incident on the surface so small?

Ans. (i) γ-rays are used for the treatment of certain forms of cancer. Its frequency range is 3×10^{19} Hz to 5×10^{24} Hz.

COMMON ERROR
Several students did not know the correct ranges of wavelength in different radiations.

(ii) The thin ozone layer on top of stratosphere absorbs most of the harmful ultraviolet rays

coming from the sun towards the earth surface. Ultraviolet rays include UVA, UVB and UVC radiations, which can destroy the life system on the earth surface.

Hence, this layer is crucial for human survival.

(iii) An electromagnetic wave transports linear momentum as it travels through space. If an electromagnetic wave transfers a total energy U to a totally absorbing surface in time t, then total linear momentum delivered to the surface is $p = \frac{U}{c} \Rightarrow p = \frac{h\nu}{c}$

This means, the momentum range of EM waves is 10^{-19} to 10^{-41}. Thus, the amount of momentum transferred by the EM waves incident on the surface is very small.

Q 10. Identify the part of the electromagnetic spectrum which:
(a) produces heating effect,
(b) is absorbed by the ozone layer in the atmosphere,
(c) is used for studying crystal structure.
Write any one method of the production of each of the above radiations. *(CBSE SQP 2023-24)*

Ans. (a) Infrared, (b) Ultraviolet, (c) X-rays.

Method of Production:

(i) Infrared: Vibration of atoms and molecules

(ii) Ultraviolet: Inner shell electrons in atoms moving from one energy level to a lower level.

(iii) X-rays: X-ray tubes or inner shell electrons.

Long Answer Type Questions

Q 1. Suppose that the electric field amplitudes of an electromagnetic wave is $E_0 = 120$ N/C and that its frequency is $\nu = 50.0$ MHz.
(i) Determine B_0, ω, k and λ,
(ii) Find expressions for $\vec{E}$ and $\vec{B}$. *(NCERT EXERCISE)*

Sol. Given, $E_0 = 120$ N/C and $\nu = 50.0$ MHz

(i) We have, $\frac{E_0}{B_0} = c$ or $B_0 = \frac{E_0}{c} = \frac{120}{3 \times 10^8}$

$= 4 \times 10^{-7}$ T.

Angular frequency,

$\omega = 2\pi\nu = 2 \times 3.14 \times 50 \times 10^6$

$= 3.14 \times 10^8$ rad s^{-1}.

Propagation constant,

$k = \frac{\omega}{c} = \frac{3.14 \times 10^8}{3 \times 10^8} = 1.05$ rad m^{-1}.

Wavelength, $\lambda = \frac{c}{\nu} = \frac{3 \times 10^8}{50.0 \times 10^6} = 6.00$ m.

(ii) If wave is propagating along X-axis, electric field will be along Y-axis and magnetic field along Z-axis.

$\vec{E} = E_0 \sin(kx - \omega t)\hat{j}$, where x is in m and t in s.

$\vec{E} = 120 \sin(1.05x - 3.14 \times 10^8 t)\hat{j}$ N/C

and $\vec{B} = B_0 \sin(kx - \Omega t)\hat{k}$

$= (4 \times 10^{-7}) \sin(1.05x - 3.14 \times 10^8 t)$ T

Q 2. (i) What are electromagnetic waves? Are these waves transverse or longitudinal?
(ii) Name the parts of the electromagnetic spectrum which is:
(a) suitable for RADAR systems in aircraft navigations.
(b) used to treat muscular strain.
(c) used as a diagnostic tool in medicine.
Write in brief, how these waves can be produced. *(CBSE 2015)*

Ans. (i) The waves produced by accelerated charged particles, in which there are sinusoidal variations of electric and magnetic field vectors at right angles to each other as well as at right angles to the direction of propagation of wave, are called electromagnetic waves or EM waves. EM waves are transverse in nature.

(ii) (a) The EM waves suitable for RADAR system is microwaves.

These waves are produced by special vacuum tubes, namely klystrons, magnetrons and Gunn diodes.

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

TiP

Infrared rays are also called the heat rays.

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

Chapter Test

Multiple Choice Questions

Q 1. $\vec{E}$ and $\vec{B}$ represent the electric and the magnetic fields of an electromagnetic wave respectively. The direction of propagation of the wave is along. *(CBSE 2023)*

a. $\vec{B}$ b. $\vec{E}$ c. $\vec{E} \times \vec{B}$ d. $\vec{B} \times \vec{E}$

Q 2. The crystal structure can be studied by using:

a. UV rays

b. X-rays

c. IR radiation

d. microwaves

Assertion and Reason Type Questions

Directions (Q.Nos. 3 and 4): *In the following questions a statement of Assertion (A) is followed by a statement of Reason (R). Mark the correct choice as:*

a. Both Assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of Assertion (A).
b. Both Assertion (A) and Reason (R) are true but Reason (R) is not the correct explanation of Assertion (A).
c. Assertion (A) is true but Reason (R) is false.
d. Both Assertion (A) but Reason (R) false.

Q 3. Assertion (A): The electromagnetic wave is transverse in nature.
Reason (R): Electromagnetic wave propagates parallel to the direction of electric and magnetic fields.

Q 4. Assertion (A): One should not use metal containers in a microwave oven.
Reason (R): Only because metal may melt from heating.

Fill in the blanks

Q 5. The SI unit of displacement current is .....

Q 6. To treat cancer and tumor in radiography ..... are used.

Case Study Based Question

Q 7. All the known radiations from a big family of electromagnetic waves which stretch over a large range of wavelengths. Electromagnetic wave include radio waves, microwaves, visible light waves, infrared rays, UV rays, X-rays and gamma rays. The orderly distribution of the electromagnetic waves in accordance with their wavelength or frequency into distinct groups having widely differing properties is electromagnetic spectrum.

Read the given passage carefully and give the answer of the following questions:

(i) Which of the following electromagnetic radiations have the longest wavelength?
a. X-rays b. γ-rays
c. Microwaves d. Radio waves

(ii) Which one of the following is not electromagnetic in nature?
a. X-rays b. Gamma rays
c. Cathode rays d. Infrared rays

(iii) Which of the following has minimum wavelength?
a. X-rays b. Ultraviolet rays
c. γ-rays d. Cosmic rays

(iv) The decreasing order of wavelength of infrared, microwave, ultraviolet and gamma rays is:
a. microwaves, infrared rays, ultraviolet rays, gamma rays
b. gamma rays, ultraviolet rays, infrared rays, microwaves
c. microwaves, gamma rays, infrared rays, ultraviolet rays
d. infrared rays, microwaves, ultraviolet rays, gamma rays

Very Short Answer Type Questions

Q 8. How does the displacement current arise?

Q 9. Write any two equation of Maxwell in vacuum.

Short Answer Type-I Questions

Q 10. How are infrared waves produced? Why are these waves referred to as heat waves? Give any two uses of infrared waves. *(CBSE 2023)*

Q 11. A plane electromagnetic wave of frequency 25 MHz travels in free space along the *X*-direction. At a particular point in space and time, $E = 6.3\hat{j}$ V/m. What is *B* at this point?

Q 12. How are X-rays produced? Give any two uses of these. *(CBSE 2023)*

Short Answer Type-II Questions

Q 13. The magnetic field in a plane electromagnetic wave is given by $= (2 \times 10^{-7})$T $\sin(0.5 \times 10^{3}x + 1.5 \times 10^{11}t)$.
(i) What is the wavelength and frequency of the wave?
(ii) Write an expression for the electric field.

Q 14. A plane electromagnetic wave travels in free space along *X*-axis. At a particular point in space, the electric field along *Y*-axis is 9.3 Vm^{-1}. What is the magnetic induction (*B*) along *Z*-axis?

Q 15. Gamma rays and radio waves travel with the same velocity in free space. Distinguish between them in terms of origin and the main application.

Long Answer Type Questions

Q 16. Calculate the electric and magnetic fields produced by the radiation coming from a 100 W bulb at a distance of 3 m. Assume that the efficiency of the bulb is 2.5% and it is a point source.

Q 17. (i) What are electromagnetic waves? Are these waves transverse or longitudinal?
(ii) Name the parts of the electromagnetic spectrum which is:
(a) suitable for RADAR systems in aircraft navigations.
(b) used to treat muscular strain.
(c) used as a diagnostic tool in medicine.
Write in brief, how these waves can be produced?