Electromagnetic Waves

Multiple Choice Questions

Choose and write the correct option(s) in the following questions.

1. **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

2. **A plane electromagnetic wave travelling along X-axis has a wavelength 10.0 mm. The electric field points along Y-direction and has peak value of 30 V/m. Then the magnetic field in terms of x in metre and t in second may be expressed as**

   (a) $30 \sin 200\pi \, (ct - x)$ (b) $10^{-7} \sin 200\pi \, (ct - x)$

   (c) $30 \sin \dfrac{2\pi}{10} (ct - x)$ (d) $10^{-7} \sin \dfrac{2\pi}{10}(ct - x)$

3. **In the process of charging of a capacitor, the current produced between the plates of the capacitor is (where symbols have their usual meanings)**   *[CBSE 2023 (55/1/1)]*

   (a) $\mu_0 \dfrac{d\phi_E}{dt}$ (b) $\dfrac{1}{\mu_0} \dfrac{d\phi_E}{dt}$

   (c) $\varepsilon_0 \dfrac{d\phi_E}{dt}$ (d) $\dfrac{1}{\varepsilon_0} \dfrac{d\phi_E}{dt}$

4. **A linearly polarised electromagnetic wave given as $E = E_0 \hat{i} \cos (kz - \omega t)$ is incident normally on a perfectly reflecting infinite wall at $z = a$. Assuming that the material of the wall is optically inactive, the reflected wave will be given as**   *[NCERT Exemplar]*

   (a) $E_r = -E_0 \hat{i} \cos (kz - \omega t)$ (b) $E_r = E_0 \hat{i} \cos (kz + \omega t)$

   (c) $E_r = -E_0 \hat{i} \cos (kz + \omega t)$ (d) $E_r = E_0 \hat{i} \sin (kz - \omega t)$

16. **An electromagnetic wave of frequency 3.0 MHz passes from vacuum into a dielectric medium with relative permittivity $\varepsilon_r = 4.0$. Then**

   (a) wavelength is doubled and frequency remains unchanged
   (b) wavelength is doubled and frequency becomes half
   (c) wavelength is halved and frequency remains unchanged
   (d) wavelength and frequency both remains unchanged

17. **An electromagnetic wave radiates outwards from a dipole antenna, with E_0 as the amplitude of its electric field vector. The electric field E_0 which transports significant energy from the source falls off as** *[NCERT Exemplar]*

   (a) $\dfrac{1}{r^3}$ (b) $\dfrac{1}{r^2}$ (c) $\dfrac{1}{r}$ (d) remains constant

18. **A plane electromagnetic wave of energy U is reflected from the surface. Then the momentum transferred by electromagnetic wave to the surface is**

   (a) 0   (b) $\dfrac{U}{c}$ (c) $\dfrac{2U}{c}$ (d) $\dfrac{U}{2c}$

19. **The rms value of the electric field of light coming from the sun is 720 N/C. The average total energy density of the electromagnetic wave is**

   (a) 4.58×10^{-6} J/m^3 (b) 6.37×10^{-9} J/m^3
   (c) 1.35×10^{-12} J/m^3 (d) 3.3×10^{-3} J/m^3

20. **A plane electromagnetic wave propagating along x direction can have the following pairs of E and B** *[NCERT Exemplar]*

   (a) E_x, B_y (b) E_y, B_z (c) B_x, E_y (d) E_z, B_y

21. **Electromagnetic waves used as a diagnostic tool in medicine are** *[CBSE 2020 (55/2/1)]*
   (a) X-rays   (b) ultraviolet rays
   (c) infrared radiation   (d) ultrasonic waves

22. **A welder wears special glasses to protect his eyes mostly from the harmful effect of** *[CBSE 2020 (55/2/2)]*

   (a) very intense visible light   (b) infrared radiation
   (c) ultraviolet rays   (d) microwaves

23. **Displacement current exists only when** *[CBSE 2020 (55/2/1)]*
   (a) electric field is changing.   (b) magnetic field is changing.
   (c) electric field is not changing.   (d) magnetic field is not changing.

24. **During the propagation of electromagnetic waves in a medium**
   (a) electric energy density is double of the magnetic energy density.
   (b) electric energy density is half of the magnetic energy density.
   (c) electric energy density is equal to the magnetic energy density.
   (d) both electric and magnetic energy densities are zero.

Answers

1. (c)	2. (b)	3. (c)	4. (b)	5. (b)	6. (a)
7. (d)	8. (d)	9. (b)	10. (c)	11. (c)	12. (a), (b), (c)
13. (c)	14. (a)	15. (b)	16. (c)	17. (c)	18. (c)
19. (a)	20. (b), (d)	21. (a)	22. (c)	23. (a)	24. (c)

Assertion-Reason Questions

In the following questions, a statement of Assertion (A) is followed by a statement of Reason (R). Choose the correct answer out of the following choices.

(a) *Both A and R are true and R is the correct explanation of A.*

(b) *Both A and R are true but R is not the correct explanation of A.*

(c) *A is true but R is false.*

(d) *A is false and R is also false.*

1. **Assertion**(A) : Short wave band is used for transmission of radiowaves to large distances.

   Reason (R) : Short waves are reflected by earth's ionosphere.

2. **Assertion**(A) : Light can travel in vacuum but sound cannot.

   Reason (R) : Light is an electromagnetic wave but sound is a mechanical wave.

3. **Assertion**(A) : If earth's atmosphere disappears the average surface temperature will increase.

   Reason (R) : Without an atmosphere to trap Earth's heat, the temperature will increase.

4. **Assertion**(A) : Gamma rays are more energetic than X-rays.

   Reason (R) : Gamma rays are of nuclear origin while X-rays originate from heavy atoms.

5. **Assertion**(A) : The speed of electromagnetic waves in free space is maximum for gamma rays and minimum for radiowaves.

   Reason (R) : For waves with same wavelengths this just means that the speed will be equal to c.

6. **Assertion**(A) : In an electromagnetic wave, electric field vector and magnetic field vector are mutually perpendicular.

   Reason (R) : Electromagnetic waves are transverse.

7. **Assertion**(A) : Electromagnetic wave is produced by accelerated charge.

   Reason (R) : An accelerated charge produces both electric and magnetic fields and also radiates them.

8. **Assertion**(A) : Microwaves are better carriers of signals than optical waves.

   Reason (R) : Microwaves move faster than optical waves.

9. **Assertion**(A) : UV radiation causes photo dissociation of ozone into O_2 and O, thus causing damage to the stratospheric ozone layer.

   Reason (R) : Ozone hole is resulting in global warming and climate change. **[AIIMS 2015]**

10. **Assertion**(A) : When a charged particle moves in a circular path, it produces electromagnetic wave.

    Reason (R) : Charged particle has acceleration. **[AIIMS 2016]**

Answers

1. (a)   2. (a)   3. (d)   4. (a)   5. (d)   6. (b)   7. (a)

8. (c)   9. (b)   10. (a)

Case-based/Passage-based Questions

Read the paragraph given below and answer the questions that follow:

Electromagnetic Wave: Maxwell, in 1865, pointed out that when either an electric or a magnetic field is changing with time, a field of the other kind is induced in adjacent regions of space. From this Maxwell concluded that variation of electric and magnetic field vectors perpendicular to each other leads to the production of electromagnetic disturbances which show properties of waves and can travel in space even without any material medium. These waves are called electromagnetic waves.

Electromagnetic waves with macroscopic wavelengths were first produced in the laboratory in 1887 by the German physicist Heinrich Hertz. Seven years after Hertz, Jagdish Chandra Bose, working at Calcutta (now Kolkata) succeeded in producing and observing electromagnetic waves of much shorter wavelength (25 mm to 5 mm). At around the same time, Guglielmo Marconi in Italy followed Hertz's work and succeeded in transmitting electromagnetic waves over distances of many kilometers.

Electromagnetic waves have a broad frequency range 10^3 Hz to 10^{22} Hz. They can travel with speed of light (c) in vacuum. They obey the relation $c = \nu\lambda$, where ν is frequency and λ is wavelength.
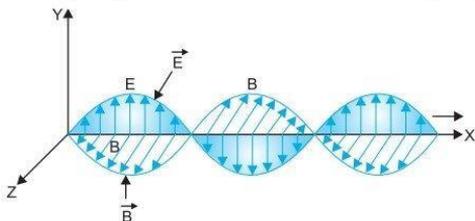
(*i*) **Which of the following electromagnetic wave in order of increasing frequency.**
    (*a*) Microwave < Infrared < Ultraviolet < γ-rays
    (*b*) γ-rays < Ultraviolet < Infrared < Microwave
    (*c*) Ultraviolet < Infrared < Microwave < γ-rays
    (*d*) γ-rays < Microwave < Infrared < Ultraviolet

(*ii*) **Light wave constitutes**
    (*a*) electromagnetic waves   (*b*) longitudinal waves
    (*c*) mechanical waves   (*d*) magnetic waves

(*iii*) **If we want to produce electromagnetic waves of wavelength 500 km by an oscillating charge; then frequency of oscillating charge must be**
    (*a*) 600 Hz   (*b*) 500 Hz   (*c*) 167 Hz   (*d*) 15 Hz

(*iv*) **The angle between $\vec{E}$ and $\vec{B}$ in an electromagnetic wave is**
    (*a*) 180°   (*b*) 120°   (*c*) 90°   (*d*) 45°

OR

The electric field associated with an EM wave in vacuum is given by $\vec{E} = 40 \cos(KZ - 6 \times 10^8\, t)\hat{i}$, where E, Z and t are in volt/m, metre and second respectively. The value of vector K is

    (*a*) 2 m^{-1} (*b*) 0·5 m^{-1} (*c*) 6 m^{-1} (*d*) 3 m^{-1}

Explanations

(i) (a) Microwave < Infrared < Ultraviolet < γ-rays

(ii) (a) electromagnetic waves

(iii) (a) $\nu = \dfrac{c}{\lambda} = \dfrac{3 \times 10^8}{500 \times 10^3} = 600$ Hz

(iv) (c) For EM wave $\vec{B}$ & $\vec{E}$ are mutually perpendicular to each other and to the axis of propagation.

OR

(a) Propagation constant,

$$K = \frac{\omega}{c} = \frac{6 \times 10^8}{3 \times 10^8} = 2 \text{ m}^{-1}$$

CONCEPTUAL QUESTIONS

Q. 1. How is the speed of EM-waves in vacuum determined by the electric and magnetic fields?

[CBSE Delhi 2017]

Ans. Speed of EM waves is determined by the ratio of the peak values of electric field vector and magnetic field vector.

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

Q. 2. Illustrate by giving suitable examples, how you can show that electromagnetic waves carry both energy and momentum. [CBSE 2019 (55/4/1)]

Ans. When EM waves falls on charged particles, they set the charges into motion. This illustrates that the EM waves have energy and momentum. **1**

Alternatively

When the sun shines on your hand, you feel energy being absorbed from the EM waves.

Alternatively

The radio & TV signals carry energy from one place to another (Give full marks if student explains on the basis of any one of above example)

Example – Photo-electric effect

[CBSE Marking Scheme 2019 (55/4/1)]

Q. 3. In which situation is there a displacement current but no conduction current?

[CBSE South 2016]

Ans. During charging or discharging there is a displacement current but no conduction current between plates of capacitor.

Q. 4. The charging current for a capacitor is 0.25 A. What is the displacement current across its plates? [CBSE (F) 2016]

Ans. The displacement current is equal to the charging current. So, displacement current is also 0.25 A.

Q. 5. In which directions do the electric and magnetic field vectors oscillate in an electromagnetic wave propagating along the *x*-axis? [*CBSE (AI) 2017*]

Ans.

Electric and magnetic field vectors are perpendicular to the direction of propagation of the wave.

The electric field vector is along positive Y-axis and the magnetic field is oscillating along the positive z-axis. So that $(\vec{E} \times \vec{B})$ = $\vec{E}\vec{B}\hat{i}$. The wave is propagating along the +ve x-axis.

[*Topper's Answer 2017*]

Q. 6. How is displacement current produced between the plates of a parallel plate capacitor during charging? [*CBSE 2020 (55/1/2)*]

Ans. With the change in charge on the capacitor plates electric field/electric flux changes. Hence displacement current is produced./ $I_d = \varepsilon_0 \dfrac{d\phi_E}{dt}$ **1**

[*CBSE Marking Scheme 2020 (55/1/2)*]

Q. 7. Differentiate between conduction current and displacement current. [*CBSE 2020 (55/1/3)*]

Ans. Conduction current is due to the flow of charges whereas the displacement current due to the change of electric field/ flux between the capacitor plates or due to changing electric field/ flux. **1**

[*CBSE Marking Scheme 2020 (55/1/3)*]

Q. 8. Why are infra-red radiations referred to as heat waves? Name the radiations which are next to these radiations in the electromagnetic spectrum having (*i*) shorter wavelength (*ii*) longer wavelength. [*CBSE (F) 2013*]

Ans. Infrared waves are produced by hot bodies and molecules, so are referred to as heat waves.

(*i*) Electromagnetic wave having short wavelength than infrared waves are visible, UV, X-rays and γ-rays.

(*ii*) Electromagnetic wave having longer wavelength than infrared waves are microwaves, radio waves.

Q. 9. The amplitude of the magnetic field of a harmonic electromagnetic wave in vacuum is $B_0 = 510$ nT. What is the amplitude of the electric field part of the wave? [*NCERT*]

Ans. The relation between magnitudes of magnetic and electric field vectors in vacuum is

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

Here, $B_0 = 510\,\text{nT} = 510 \times 10^{-9}\,\text{T}, c = 3 \times 10^8\,\text{ms}^{-1}$

$E_0 = 510 \times 10^{-9} \times 3 \times 10^8 = \textbf{153 N/C.}$

Q. 10. Name the electromagnetic radiations used for (*a*) water purification, and (*b*) eye surgery. [*CBSE 2018*]

Ans. (*a*) Ultraviolet rays

(*b*) Ultraviolet rays/laser

Q. 11. How are electromagnetic waves produced by accelerating charges? *[CBSE 2019 (55/2/1)]*

Ans. Accelerated charge produces an oscillating electric field which produces an oscillating magnetic filed, which is a source of oscillating electric field, and so on. Thus electromagnetic waves are produced. 1

[CBSE Marking Scheme 2019 (55/2/1)]

Q. 12. Why is the orientation of the portable radio with respect to broadcasting station important? *[NCERT Exemplar] [HOTS]*

Ans. As electromagnetic waves are plane polarised, so the receiving antenna should be parallel to electric/magnetic part of the wave.

Q. 13. The charge on a parallel plate capacitor varies as $q = q_0 \cos 2\pi\nu t$. The plates are very large and close together (area = A, separation = d). Neglecting the edge effects, find the displacement current through the capacitor? *[NCERT Exemplar] [HOTS]*

Ans. Conduction current I_C = Displacement current I_D

$$I_C = I_D = \frac{dq}{dt} = \frac{d}{dt}(q_0 \cos 2\pi\nu t) = -2\pi q_0 \nu \sin 2\pi\nu t$$

Q. 14. A variable frequency ac source is connected to a capacitor. How will the displacement current change with decrease in frequency? *[NCERT Exemplar] [HOTS]*

Ans. On decreasing the frequency, reactance $X_C = \frac{1}{\omega C}$ will increase which will lead to decrease in conduction current. In this case $I_D = I_C$, hence displacement current will decrease.

Q. 15. Professor C.V. Raman surprised his students by suspending freely a tiny light ball in a transparent vacuum chamber by shining a laser beam on it. Which property of em waves was he exhibiting? Give one more example of this property. *[NCERT Exemplar] [HOTS]*

Ans. Electromagnetic waves exert radiation pressure. Tails of comets are due to solar radiation.

Very Short Answer Questions

Each of the following questions are of 2 marks.

Q. 1. Consider an induced magnetic field due to changing electric field and an induced electric field due to changing magnetic field. Which one is more easily observed? Justify your answer. *[CBSE 2023 (55/1/1)]*

Ans. Electric field which is easily observed because an *a.c.* circuit displacement current can be increased by increasing the angular frequency of current. The electric field increase due to changing magnetic field can be increased by taking more no. of turns of the coil. But magnetic field set up due to this displacement current is very small so it can easily observed.

Q. 2. Suppose that the electric field amplitude of an electromagnetic wave is $E_0 = 120$ N/C and that its frequency $\nu = 50.0$ MHz. (*a*) Determine B_0, ω, k and λ (*b*) Find expressions for $\vec{E}$ and $\vec{B}$. *[NCERT]*

Ans. (*a*) We have $\dfrac{E_0}{B_0} = c \implies B_0 = \dfrac{E_0}{c} = \dfrac{120}{3 \times 10^8} = 4 \times 10^{-7}\,\text{T}$

$$\omega = 2\pi\nu = 2 \times 3.14 \times 50 \times 10^6 = 3.14 \times 10^8\,\text{rads}^{-1}$$

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

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

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

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

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

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

$$= (4 \times 10^{-7}) \sin(1.05\,x - 3.14 \times 10^8 t)\hat{k} \text{ tesla.}$$

Q. 3. Write the generalised expression for the Ampere's circuital law in terms of the conduction current and the displacement current. Mention the situation when there is:

(i) only conduction current and no displacement current.

(ii) only displacement current and no conduction current. **[CBSE (F) 2013]**

Ans. Generalised Ampere's circuital Law—

$$\oint \vec{B} \cdot \vec{dl} = \mu_0 I_C + \mu_0 \varepsilon_0 \frac{d\phi_E}{dt}$$

Line integral of magnetic field over closed loop is equal to μ_0 times sum of conduction current and displacement current.

(i) In case of steady electric field in a conducting wire, electric field does not change with time, conduction current exists in the wire but displacement current may be zero. So,
$$\oint \vec{B} \cdot \vec{dl} = \mu_0 I_C.$$

(ii) In large region of space, where there is no conduction current, but there is only a displacement current due to time varying electric field (or flux). So, $\oint \vec{B} \cdot \vec{dl} = \mu_0 \varepsilon_0 \dfrac{d\phi_E}{dt}$.

Q. 4. (a) How does oscillating charge produce electromagnetic waves?

(b) Sketch a schematic diagram depicting oscillating electric and magnetic fields of an em wave propagating along + z-direction. **[CBSE (F) 2014, Delhi 2016]**

Ans. (a) An oscillating charge produces an oscillating electric field in space, which produces an oscillating magnetic field. The oscillating electric and magnetic fields regenerate each other, and this results in the production of em waves in space.

(b) Electric field is along x-axis and magnetic field is along y-axis.
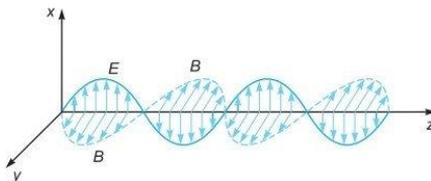
Q. 5. (a) An EM wave is travelling in a medium with a velocity $\vec{v} = v\hat{i}$. Draw a sketch showing the propagation of the EM wave, indicating the direction of the oscillating electric and magnetic fields.

(b) How are the magnitudes of the electric and magnetic fields related to the velocity of the EM wave? **[CBSE Delhi 2013]**

Ans. The direction of propagation of electromagnetic wave is given by $\vec{E} \times \vec{B}$

(a) $\hat{i} = \hat{j} \times \hat{k}$.
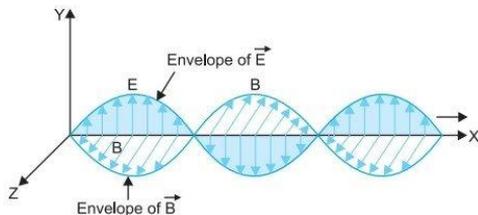
(b) The speed of electromagnetic wave $|c| = \dfrac{|E_0|}{|B_0|}$

Q. 6. Which of the following electromagnetic waves has (a) minimum wavelength, and (b) minimum frequency? Write one use of each of these two waves.

Infrared waves, Microwaves, γ-rays and X-rays **[CBSE 2020 (55/2/1)]**

Ans.

The electromagnetic wave having :-
(a) minimum wavelength is — γ-rays. ½
(b) minimum frequency is — Microwaves. ½

Use :- (a) γ-rays :- γ-ray is used to treat cancer ½
(b) Microwave :- It is used to heat food in microwave oven. ½

[Topper's Answer 2020]

Q. 7. (i) How are infrared waves produced? Write their one important use.

(ii) The thin ozone layer on top of the stratosphere is crucial for human survival. Why? **[CBSE East 2016; 2019 (55/4/1)]**

Ans. (i) Infrared waves are produced by hot bodies and molecules.
Important use:

(a) To treat muscular strains (b) To reveal the secret writings on the ancient walls (c) For producing dehydrated fruits (d) Solar heater (e) Solar cooker (*Any one*)

(ii) Ozone layer protects us from harmful UV rays.

Q. 8. (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? **[CBSE (F) 2016]**

Ans. (i) Gamma rays have the highest frequency. These are produced during nuclear reactions and also emitted by radioactive nuclei. They are used in medicine to destroy cancer cells.

(ii) Ultraviolet rays lie near the high frequency end of visible part of EM spectrum. They are used to sterilise drinking water and surgical instruments. Exposure to UV radiation induces the production of more melanin, causing tanning of the skin.

Q. 9. **How does an oscillating charge radiate an electromagnetic wave? Give the relation between the frequency of radiated wave and the frequency of oscillating charge.** *[CBSE 2020 (55/3/1)]*

Ans. An oscillating charge produces an oscillating electric field in space, which produces an oscillating magnetic field, which in turn, is a source of oscillating electric field, and so on. The oscillating electric and magnetic fields thus regenerate each other, as the wave propagates through the space. **1**

The frequency of the electromagnetic wave equals the frequency of oscillation of the charge. **1**

[CBSE Marking Scheme 2020 (55/3/1)]

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 (55/2/1)]*

Ans. Infrared waves are produced by hot bodies and vibrations of molecules. They are referred as heat waves because they are rapidly absorbed by water molecules and increase their thermal energy and heat them.

Uses:

   (*i*) Dehydration of fruits.

   (*ii*) In greenhouse Effect.

   (*iii*) In remote switches. *[any two]*

Q. 11. **(*a*) Explain briefly the fact that electromagnetic waves carry energy.**

    (*b*) Why do we not, feel the pressure due to sunshine? *[CBSE 2020 (55/3/1)]*

Ans. (*a*) Consider a plane perpendicular to the direction of propagation of the electromagnetic wave. If there are, on this plane, electric charges, they will be set and sustained in motion by the electric and magnetic fields of the electromagnetic wave. The charges thus acquire energy and momentum from the waves. **1**

   (*b*) When the sun shines on your hand, you feel the energy being absorbed from the electromagnetic waves (your hands get warm). Electromagnetic waves also transfer momentum to your hand but because c is very large, the amount of momentum transferred is extremely small and you do not feel the pressure. **1**

[For any other alternative correct explanation also, award full 2 marks]

[CBSE Marking Scheme 2020 (55/3/1)]

Q. 12. **How are X-rays produced? Give any two uses of these.** *[CBSE 2023 (55/2/1)]*

Ans. When fast moving electrons strike a heavy target like tungsten, X-rays are produced.

Uses:

   (*i*) Used as a diagnostic tool in medicine.

   (*ii*) Treatment for certain forms of cancer.

   (*iii*) To study crystal structure. *[any two]*

Q. 13. **What is a displacement current? How is it different from a conduction current?**

[CBSE 2023 (55/3/1), (55/4/1)]

Ans. During charging, electric flux between the plates of capacitors keeps on charging; this results in the production of a displacement current between the plates.

Mathematically, $I_d = \varepsilon_0 \left(\dfrac{d\phi_E}{dt} \right)$

Conduction current is established by actual movement of free electrons through a metallic conductor while displacement current is established by polarisation of molecules of a dielectric under the influence of an external electric field.

Q. 14. Write any two characteristics of an electromagnetic wave. Why are microwaves used in radar systems? [*CBSE 2023 (55/4/1)*]

Ans. Characteristics property of EM wave:

(*i*) Transverse nature

(*ii*) Does not get deflected by electric or magnetic fields

(*iii*) Same speed in vacuum for all waves

(*iv*) No material medium required for propagation

(*v*) They get refracted, diffracted and polarised [*any two*]

Due to high wavelength and low energy dispersion during long distance communication.

Thus they are used in radar system.

Short Answer Questions

Each of the following questions are of 3 marks.

Q. 1. How are electromagnetic waves produced? What is the source of energy of these waves? Write mathematical expressions for electric and magnetic fields of an electromagnetic wave propagating along the z-axis. Write any two important properties of electromagnetic waves. [*CBSE North 2016*]

Ans. EM waves are produced by oscillating charged particle.

Mathematical expression for electromagnetic waves travelling along z-axis:

$E_x = E_0 \sin (kz - \omega t)$ and [For electric field]

$B_y = B_0 \sin (kz - \omega t)$ [For magnetic field]

Properties

(*i*) Electromagnetic waves have oscillating electric and magnetic fields along mutually perpendicular directions.

(*ii*) They have transverse nature.

Q. 2. Arrange the following electromagnetic waves in the order of their increasing wavelength:

(*a*) γ-rays (*b*) Microwaves

(*c*) X-rays (*d*) Radiowaves

How are infra-red waves produced? What role does infra-red radiation play in (*i*) maintaining the earth's warmth and (*ii*) physical therapy? [*CBSE Panchkula 2015*]

Ans. γ-rays < X-rays < Microwaves < Radiowaves

Infra-red waves are produced by the vibration of atoms and molecules.

(*i*) **Maintaining Earth's Warmth:** Infrared rays are absorbed by the earth's surface and reradiated as longer wave length infrared rays. These radiations are trapped by green house gases such as CO_2 and maintain earth's warmth.

(*ii*) **Physical Therapy:** Infrared rays are easily absorbed by water molecules present in body. After absorption, their thermal motion increases causing heating which is used as physical therapy.

Q. 3. 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? [*CBSE Delhi 2012*]

Ans. When an ideal capacitor is charged by *dc* battery, charge flows (momentarily) till the capacitor gets fully charged.

When an *ac* source is connected then conduction current $I_c = \dfrac{dq}{dt}$ keep on flowing in the connecting wire. Due to changing current, charge deposited on the plates of the capacitor changes with time. This causes change in electric field between the plates of the capacitor which causes the electric flux to change and gives rise to a displacement current in the region between the plates of the capacitor.

As we know, displacement current

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

and $\quad\quad\quad I_d = I_c$ at all instants.

Q. 4. Why does a galvanometer when connected in series with a capacitor show a momentary deflection, when it is being charged or discharged?

How does this observation lead to modifying the Ampere's circuital law? Hence write the generalised expression of Ampere's law. [*CBSE (F) 2015*]

Ans. During charging or discharging of the capacitor, displacement current between the plates is produced. Hence, circuit becomes complete and galvanometer shows momentary deflection.
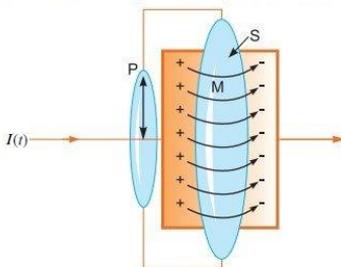
According to Ampere's circuital Law

$$\oint \vec{B} \cdot \vec{dl} = \mu_0 I$$

At surface P, $\quad \oint \vec{B} \cdot \vec{dl} = \mu_0 I_c$

At surface S, $\quad \oint \vec{B} \cdot \vec{dl} = 0$

$\therefore \quad\quad \oint_p \vec{B} \cdot \vec{dl} \neq \oint_s \vec{B} \cdot \vec{dl}$

This contradicts Ampere's circuital law. This law must be missing something. Hence the law needs modification.

Modified form of Ampere's circuital law

$$\oint \vec{B} \cdot \vec{dl} = \mu_0 \left[I_c + \varepsilon_0 \frac{d}{dt} \phi_E \right]$$

Q. 5. A capacitor, made of two parallel plates each of plate area A and separation d, is being charged by an external ac source. Show that the displacement current inside the capacitor is the same as the current charging the capacitor. [*CBSE (AI) 2013*]

Ans.
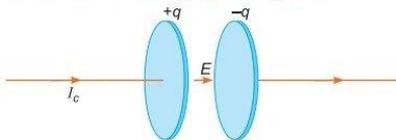
In Fig. conduction current is flowing in the wires, causes charge on the plates

So, $\qquad I_c = \dfrac{dq}{dt}$ $\qquad\qquad$ ...(i)

According to Maxwell, displacement current between plates,

$$I_d = \varepsilon_0 \dfrac{d\phi_E}{dt}, \text{ where } \phi_E = \text{Electric flux} \qquad ...(ii)$$

Using Gauss's theorem, if one of the plate is inside the tiffin type Gaussian surface, then

$$\phi_E = \dfrac{q}{\varepsilon_0}$$

So $\qquad I_d = \varepsilon_0 \dfrac{d}{dt}\left(\dfrac{q}{\varepsilon_0}\right) \implies I_d = \dfrac{dq}{dt}$ $\qquad$ ...(iii)

From equation (i) and (iii),

Both conduction current and displacement current are equal.

Q. 6. **Write the expression for the generalised form of Ampere's circuital law. Discuss its significance and describe briefly how the concept of displacement current is explained through charging/discharging of a capacitor in an electric circuit.** $\qquad$ **[CBSE Allahabad 2015]**

Ans. The generalisation in Ampere's circuital law was modified by Maxwell, as

$$\oint \vec{B}.\vec{dl} = \mu_0(I_c + I_d)$$

$$= \mu_0 I_c + \mu_0 I_d = \mu_0 I_c + \mu_0 \varepsilon_0 \dfrac{d\phi_E}{dt}$$

where $I_d = \varepsilon_0 \dfrac{d\phi_E}{dt}$ is displacement current.

Significance: This expression signifies that the source of magnetic field is not just due to the conduction current in the metallic conductors, but also due to the time rate of change of electric flux called displacement current.

During charging and discharging of a capacitor, electric field between the plates will change. Hence there will be a change in electric flux, called displacement current, between the plates.
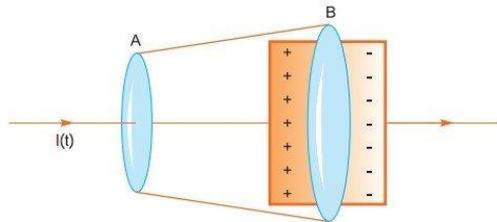
Q. 7. **Considering the case of a parallel plate capacitor being charged, show how one is required to generalise Ampere's circuital law to include the term due to displacement current.**

$\qquad$ **[CBSE (AI) 2014]**

Ans.
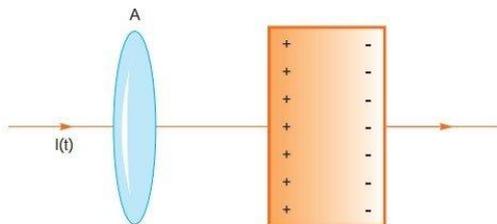
During charging capacitor C, a time varying current $I(t)$ flows through the conducting wire, so on applying Ampere's circuital law (for loop A) $\oint \vec{B}.\vec{dl} = \mu_0 I(t)$ $\qquad$ ...(i)

Now we consider a pot like surface enclosing the positively charged plate and nowhere touches the conducting wire,

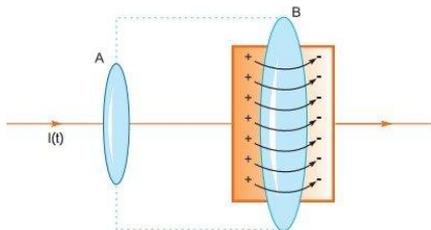$$\oint \vec{B}.\vec{dl} = 0 \qquad \qquad \ldots(ii)$$

From equation (i) and (ii), we have a contradiction

If surfaces A and B forms a tiffin box, and electric field $\vec{E}$ is passing through the surface (B); constitute an electric flux

$$\phi = EA = \frac{\sigma A}{\varepsilon_0} = \frac{QA}{A\varepsilon_0} = \frac{Q}{\varepsilon_0} \qquad \qquad \ldots(iii)$$

If the charge on the plate in the tiffin box is changing with time, there must be a current between the plates.

From equation (iii)

$$I = \frac{dQ}{dt} = \frac{d}{dt}(\varepsilon_0 \phi) = \varepsilon_0 \frac{d\phi}{dt}$$

This is the missing term in Ampere's circuital law.

The inconsistency may disappear if displacement current is included between the plates.

So generalised Ampere's circuital law can be given as

$$\oint \vec{B}.\vec{dl} = \mu_0 I_c + \mu_0 I_d = \mu_0 I_c + \mu_0 \varepsilon_0 \frac{d\phi}{dt}$$

Q. 8. (a) **Which one of the following electromagnetic radiations has least frequency: UV radiations, X-rays, Microwaves?**

(b) **How do you show that electromagnetic waves carry energy and momentum?**

(c) **Write the expression for the energy density of an electromagnetic wave propagating in free space.** [*CBSE Bhubaneswar 2015*]

Ans. (a) Microwave

(b) When a charge oscillates with some frequency. It produces an oscillating electric field and magnetic field in space. So, an electromagnetic wave is produced.

The frequency of the EM wave is equal to the frequency of oscillation of the charge.

Hence energy associated with the EM wave comes at the expense of the energy of the source.

If the em wave of energy U strikes on a surface and gets completely absorbed, total momentum delivery to the surface is $p = \dfrac{U}{E}$.

Hence em wave also carry momentum.

(c) The EM wave consists of oscillating electric and magnetic fields, So net energy density of EM wave is

$$U = U_E + U_B$$

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

Q. 9. (a) **How are electromagnetic waves produced by oscillating charges?**

(b) **State clearly how a microwave oven works to heat up a food item containing water molecules.**

(c) **Why are microwaves found useful for the radar systems in aircraft navigation?**

[CBSE (F) 2013]

Ans. (a) If a charge particle oscillates with some frequency, produces an oscillating electric field in space, which produces an oscillating magnetic field, which inturn, is a source of electric field, and so on. Thus oscillating electric fields and magnetic fields regenerate each other, and an electromagnetic wave propagates in the space.

(b) In microwave oven, the frequency of the microwaves is selected to match the resonant frequency of water molecules so that energy from the waves get transferred efficiently to the kinetic energy of the molecules. This kinetic energy raises the temperature of any food containing water.

(c) Microwaves are short wavelength radio waves, with frequency of order of few 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. 10. 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 (55/3/1), Term-2]

Ans. (i) (a) Radar Systems – Microwave

(b) Water purifiers – Ultra Violet (UV)

(c) Remote switches of TV–Infrared (IR)

(ii)

EM-Waves	Source
(a) Microwave	Magnetrons or Gunn diodes
(b) Ultra violet (UV)	Inner shell electrons in atoms moving from one energy level to another
(c) Infrared (IR)	Hot bodies and molecules.

Q. 11. (a) **Name the e.m. waves which are suitable for radar systems used in aircraft navigation. Write the range of frequency of these waves.**

(b) **If the Earth did not have atmosphere, would its average surface temperature be higher or lower than what it is now? Explain.**

(c) **An e.m. wave exerts pressure on the surface on which it is incident. Justify.**

[CBSE Sample Paper-2022, Term-2]

Ans. (a) Microwaves are suitable for the radar system used in aircraft navigation.

Range of frequency of microwaves is 10^8 Hz to 10^{11} Hz.

(b) 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.

(c) An e.m. wave carries momentum with itself and given by

$$P = \text{Energy of wave } (U) \,/\, \text{Speed of the wave } (c)$$
$$= U/c$$

when it is incident upon a surface it exerts pressure on it.

Q. 12. **Answer the following questions:**

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

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

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

[CBSE Delhi 2014]

Ans. (a) EM waves : γ-rays

Range : 10^{19} Hz to 10^{23} Hz

(b) This is because the special glass goggles protect the eyes from large amount of UV radiations produced by welding arcs.

(c) Infrared waves are called heat waves because water molecules present in the materials readily absorb the infrared rays and get heated up.

Application: They are used in green houses to warm the plants.

Q. 13. **Answer the following:**

(a) **Name the EM waves which are used for the treatment of certain forms of cancer. Write their frequency range.**

(b) **Thin ozone layer on top of stratosphere is crucial for human survival. Why?**

(c) **Why is the amount of the momentum transferred by the em waves incident on the surface so small?** *[CBSE Delhi 2014]*

Ans. (a) X-rays or γ–rays

Range: 10^{18} Hz to 10^{22} Hz.

(b) Ozone layer absorbs the ultraviolet radiations from the sun and prevents it from reaching the earth's surface.

(c) Momentum transferred, $p = \dfrac{U}{c}$

where U = energy transferred, and c = speed of light

Due to the large value of speed of light (c), the amount of momentum transferred by the em waves incident on the surface is small.

Q. 14. **Electromagnetic waves with wavelength**

(i) **λ_1 is used in satellite communication.**

(ii) **λ_2 is used to kill germs in water purifier.**

(iii) **λ_3 is used to detect leakage of oil in underground pipelines.**

(iv) **λ_4 is used to improve visibility in runways during fog and mist conditions.**

(a) **Identify and name the part of electromagnetic spectrum to which these radiations belong.**

(b) **Arrange these wavelengths in ascending order of their magnitude.**

(c) **Write one more application of each.** *[NCERT Exemplar]*

Ans. (a) $\lambda_1 \to$ Microwave, $\qquad \lambda_2 \to$ UV

$\qquad \lambda_3 \to$ X-rays, $\qquad\qquad \lambda_4 \to$ Infrared

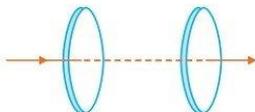(b) $\lambda_3 < \lambda_2 < \lambda_4 < \lambda_1$

(c) Microwave – RADAR

UV – LASIK eye surgery

X-ray – Bone fracture identification (bone scanning)

Infrared – Optical communication

Q. 15. Figure shows a capacitor made of two circular plates each of radius 12 cm and separated by 5.0 mm. The capacitor is being charged by an external source (not shown in the figure). The charging current is constant and equal to 0.15 A.

(a) Calculate the capacitance and the rate of change of potential difference between the plates.

(b) Obtain the displacement current across the plates.

(c) Is Kirchhoff's first rule function rule valid at each plate of the capacitor? Explain.

<div align="right">[<i>NCERT</i>]</div>

Ans. Here, $\quad I = 0.15$ A

$\qquad r = 12$ cm $= 12 \times 10^{-2}$ m

$\qquad d = 5.0$ mm $= 5 \times 10^{-3}$ m

$\qquad A = \pi r^2$

(a) Capacitance

$$C = \frac{\varepsilon_0 A}{d} = \frac{\varepsilon_0 \pi r^2}{d}$$

$$= \frac{8.85 \times 10^{-12} \times 22 \times (12 \times 10^{-2})^2}{7 \times 5 \times 10^{-3}}$$

$$= \frac{28036.8 \times 10^{-16}}{35 \times 10^{-3}} = 801.05 \times 10^{-13} \text{ F}$$

$$= 80.1 \times 10^{-12} \text{ F} = \textbf{80.1 pF}$$

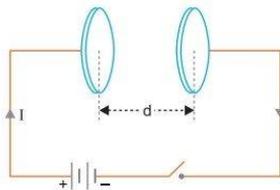Let C be the capacitance of capacitor and q the instantaneous charge on plates, then

$$q = CV$$

$\therefore \qquad \dfrac{dq}{dt} = C\dfrac{dV}{dt} \qquad \Rightarrow \qquad \dfrac{dV}{dt} = \dfrac{I}{C}$

$\therefore \qquad \dfrac{dV}{dt} = \dfrac{0.15}{80.1 \times 10^{-12}} = 0.00187 \times 10^{12} \text{ Vs}^{-1} = \textbf{1.87} \times \textbf{10}^9 \textbf{ Vs}^{-1}$

(b) Displacement current $I_d = \varepsilon_0 A\dfrac{dE}{dt} = \varepsilon_0 A\dfrac{I}{\varepsilon_0 A} = I =$ conduction current $= \textbf{0.15 A.}$

(c) Yes, Kirchhoff's law holds at each plate of capacitor since displacement current is equal to conduction current.

1. **Choose and write the correct option in the following questions.**

   (i) The electromagnetic radiations used to kill germs in water purifiers are called
   [CBSE 2023 (55/3/1)]

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

   (ii) The quantity $\sqrt{\mu_0 \varepsilon_0}$ represents

   (a) speed of sound   (b) speed of light in vacuum
   (c) speed of electromagnetic waves   (d) inverse of speed of light in vacuum

   (iii) The ratio of amplitude of magnetic field to the amplitude of electric field for an electromagnetic wave propagating in vacuum is equal to

   (a) the speed of light in vacuum
   (b) reciprocal of speed of light in vacuum
   (c) the ratio of magnetic permeability to the electric susceptibility of vacuum
   (d) unity

   (iv) Microwave oven acts on the principle of

   (a) giving rotational energy to water molecules
   (b) giving vibrational energy to water molecules
   (c) giving translational energy to water molecules
   (d) transferring electrons from lower to higher energy levels in water molecule

   (v) In a travelling plane electromagnetic wave, which of the following have zero average value?
   [CBSE 2020 (55/2/3)]

   (a) Magnetic energy and electric energy   (b) Magnetic field and electric field
   (c) Magnetic energy and magnetic field   (d) Electric energy and electric field

2. **In the following questions, a statement of Assertion (A) is followed by a statement of Reason (R). Choose the correct answer out of the following choices.**

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

   Assertion (A) : When a charged particle moves in a circular path, it produces electromagnetic wave.

   Reason (R) : Charged particle has acceleration.

3. Give the ratio of velocity of the two light waves of wavelengths 4000 Å and 8000 Å travelling in vacuum. [CBSE Sample Paper-2021)]

4. Name the electromagnetic radiation which can be produced by klystron or a magnetron valve.

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

   $$E_y = 30 \sin(2 \times 10^{11} t + 300\pi x)\, \text{V m}^{-1}$$

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

6. How does an oscillating charge radiate an electromagnetic wave? Give the relation between the frequency of radiated wave and the frequency of oscillating charge. [CBSE 2020 (55/3/1)]

7. Gamma rays and radio waves travel with the same velocity in free space. Distinguish between them in terms of their origin and the main application. [CBSE 2020 (55/5/1)]

8. Answer the following questions:

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

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

9. 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.

10. (a) Write the expression for the speed of light in a material medium of relative permittivity ε_r and relative magnetic permeability μ_r.

   (b) Write the wavelength range and name of the electromagnetic waves which are used in (*i*) radar systems for aircraft navigation, and (*ii*) earth satellites to observe the growth of the crops. [*CBSE 2020 (55/1/1)*]

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

   (a) What is the wavelength of a wave?

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

   (c) Show that the average energy density of the electric field equals the average energy density of the B field. [$c = 3 \times 10^8$ ms^{-1}]

12. (a) Identify the part of the electromagnetic spectrum used in (*i*) radar and (*ii*) eye surgery. Write their frequency range.

   (b) Prove that the average energy density of the oscillating electric field is equal to that of the oscillating magnetic field.

13. (a) A parallel plate capacitor is being charged by a time varying current. Explain briefly how Ampere's circuital law is generalized to incorporate the effect due to the displacement current.

   (b) Find the wavelength of electromagnetic waves of frequency 6×10^{12} Hz in free space. Give its two applications.

14. A parallel plate capacitor (fig.) made of circular plates each of radius $R = 6.0$ cm has a capacitance $C = 100$ pF. The capacitor is connected to a 230 V ac supply with an angular frequency of 300 rad/s. [*NCERT*]
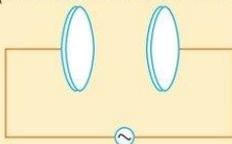
   (a) What is the rms value of the conduction current?

   (b) Is conduction current equal to the displacement current?

   (c) Determine the amplitude of magnetic field induction B at a point 3.0 cm from the axis between the plates.

Answers

1. (*i*) (*d*) (*ii*) (*d*) (*iii*) (*b*) (*iv*) (*b*) (*v*) (*b*)

2. (*a*) 3. 1 : 1 5. (*a*) 6.67×10^{-3} m (*b*) $10^{-7} \sin (2 \times 10^{11}t + 300\pi x)$ T

11. (*a*) 1.5×10^{-2} m (*b*) 1.6×10^{-7} T 14. (*a*) 6.9 µA (*b*) 1.63×10^{11} T