Ch-8: Important Terms, Definitions and Formulae

We learnt that an electric current produces a magnetic field and the magnetic field changing with time produces an electric field.

Can an electric field changing with time produces a magnetic field?

James Clerk Maxwell (1831-1879), argued that this was indeed the case-an electric field changing with time produces a magnetic field.

Maxwell noticed that Ampere's circuital law is inconsistent, namely in situations where electric current changes with time. He showed that consistency requires an additional source of magnetic field, this is called displacement current. This made the laws of electricity and magnetism symmetrical.

Electromagnetic waves:

An electromagnetic wave is a wave radiated by an accelerated charge and which propagates through space as coupled electric and magnetic fields, oscillating perpendicular to each other and to the direction of propagating wave.

Q. How does oscillating charge produce EM waves?

Answer:

A moving charge produces a magnetic field and an oscillating magnetic field is produced by an oscillating charge. This gives rise to an oscillating emf which causes an oscillating electric field. , thus, oscillating charge produces EM waves.

Principle of production of electromagnetic waves:

The accelerated charge produces electric and magnetic fields which vary both in space and time. The two oscillating fields act as a source of each other and sustain each other. This results propagation of electromagnetic wave through space.

Maxwell's four set of equations:

a) **Gauss law of electrostatics**-

This law tells that electric flux through a closed surface (or surface integral of electric field around a closed surface) is $1/\varepsilon_0$ times charge enclosed by that surface.

$$\oint \vec{E}.\overrightarrow{dS} = \frac{q_{in}}{\epsilon_0}$$

Charge on an insulated conductor resides only on its outer surface.

b) **Gauss law of magnetism**-

This law tells that magnetic flux through any closed surface is zero.

$$\oint \vec{B}.\overrightarrow{dS} = 0$$

It explains that isolated magnetic poles do not exist.

c) **Faraday's law of electromagnetic induction**-

This law tells that a changing magnetic field induces an electric field. The induced emf set up in a closed circuit is equal to the rate of change of magnetic flux linked with that circuit.

$$e = -\frac{d\varphi_B}{dt} = -\frac{d}{dt}\left(\oint \vec{B}.\overrightarrow{dS}\right) = \oint \vec{E}.\overrightarrow{dl}$$

d) **Modified Ampere's law**-

This law states that line integral of magnetic field around any closed circuit is equal to μ_0 times the total current (the sum of conduction and displacement current) threading the closed circuit.

$$\oint \vec{B}.\vec{dl} = \mu_0[i_C + i_D] = \mu_0\left[i_C + \epsilon_0 \frac{d\varphi_E}{dt}\right]$$

This law implies that not only the conduction current but displacement current also associated with changing electric field, also produces a magnetic field.

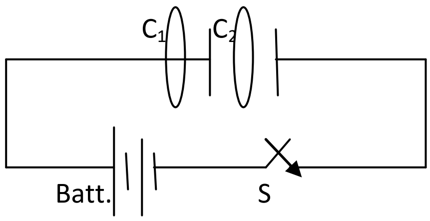
Maxwell's displacement current

Inconsistency of Ampere's circuital law: Conduction and displacement currents are individually discontinuous but their sum is continuous. Why?

Ampere's circuital law states that

$$\oint \vec{B}.\vec{dl} = \mu_0 i_{encl}$$

Maxwell proved this inconsistency by considering a parallel plate capacitor being charged by a battery.



The current flows in the circuit is changing with time. This current produces a magnetic field around the capacitor. It is placed two planar loops C_1 and C_2 with their planes parallel to plates. As C_1 is connected to plate 1, the current i flows through area bounded by loop C_1. So, by Ampere's circuital law,

$$\oint_{C_1} \vec{B}.\vec{dl} = \mu_0 i - - - - - (1)$$

But the area bounded by C_2 lies in the regions between the capacitor plates, so, no current flows through it. Hence,

$$\oint_{C_2} \vec{B}.\vec{dl} = 0 - - - - - (2)$$

Suppose these loops are close to each other, then

$$\oint_{C_1} \vec{B}.\vec{dl} = \oint_{C_2} \vec{B}.\vec{dl} - - - - - -(3)$$

This equation (3) is inconsistent with equation (1) and (2).

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

How does these observation lead to modify the Ampere's circuital law? Hence write the generalised expression of Ampere's law.

Answer:

During charging or discharging a capacitor, displacement current is developed across the plates. The circuit becomes completes and galvanometer shows a momentary deflection.

According to Ampere's circuital law, the line integral of magnetic field around any closed loop is equals to μ_0 times the net current i threading through the area enclosed by the loop.

Mathematically,

$$\oint \vec{B}.\overrightarrow{dl} = \mu_0 i_{net} - - - - - (1)$$

Maxwell in 1864 showed the logical inconsistency of equation (1) when applied to the charging or discharging of a capacitor. He suggested that during the charging of capacitor, a changing electric field exists in the region between the plates of a capacitor which produces the same magnetic effect as does the conduction current, called displacement current. Hence, during charging of a capacitor, the conduction current flows through wires and displacement current exists in the region between the plates of the capacitor, fulfilling the condition of continuity of current.

Let q be the charge on capacitor plate at any instant. Then the instantaneous electric field between the plates will be

$E = \frac{\sigma}{\epsilon_0} = \frac{q}{\epsilon_0 A}$, where, A is the area of each plate.

By differentiating, we get

$$\frac{dE}{dt} = \left(\frac{1}{\epsilon_0 A}\right)\frac{dq}{dt} = \frac{i}{\epsilon_0 A}$$

Therefore, $i = \epsilon_0 A \frac{dE}{dt} = \epsilon_0 \frac{dEA}{dt} = \epsilon_0 \frac{d\varphi_E}{dt} = i_d$, Where, $\varphi_E = EA = Electric\ flux$

Thus, modified Ampere's circuital law can be stated as $\oint \vec{B}.\overrightarrow{dl} = \mu_0(i_c + i_d) = \mu_0\left(i_c + \epsilon_0 \frac{d\varphi_E}{dt}\right)$

The displacement current between the plates is exactly equal to conduction current in the connecting wires. The conduction current and displacement current are individually are discontinuous, but their sum is continuous.

Definition of displacement current:

Displacement current (i_D): It arises due to changing electric field between the capacitor plates. Electric field changes due to variation of charge on capacitor plates. This way rate of flow of charge is the cause of conduction current and rate of variation of charge or changing electric field is the factor producing displacement current. $i_D = \epsilon_0 \frac{d\varphi_E}{dt}$

Consistency of modified Ampere's law-

The total current across the closed loop is, $i = i_C + i_D = i_C + \epsilon_0 \frac{d\varphi_E}{dt}$

Hence, modified form of Ampere's law is,$\oint \vec{B}.\overrightarrow{dl} = \mu_0(i) = \mu_0(i_C + i_D) = \mu_0 i_C + \mu_0 i_D = \mu_0 i_C + \mu_0 \epsilon_0 \frac{d\varphi_E}{dt}$

For loop C_1, conduction current is i but flux ϕ_E is zero (electric field is zero), so, $\oint \vec{B}.\overrightarrow{dl} = \mu_0 i_C$

For loop C_2, conduction current is zero (no conduction current flows between plates as two plates are not wired to each other), but displacement current is not zero, as time varying electric field exists between the plates. Hence, $\oint \vec{B}.\overrightarrow{dl} = \mu_0 \epsilon_0 \frac{d\varphi_E}{dt}$

Electric field between the plates (if charge is q, area of plate is A) is, $E = \frac{\sigma}{\epsilon_0} = \frac{q}{A\epsilon_0} \Rightarrow EA = \frac{q}{\epsilon_0} = \varphi_E$

So, $\oint \vec{B}.\overrightarrow{dl} = \mu_0 \epsilon_0 \frac{d\varphi_E}{dt} = \mu_0 \epsilon_0 \frac{d}{dt}\left(\frac{q}{\epsilon_0}\right) = \frac{\mu_0 \epsilon_0}{\epsilon_0}\left(\frac{dq}{dt}\right) = \mu_0 i_C$

Equation (5) and equation (7) are same and consistent with equation (4).

Maxwell's prediction of electromagnetic waves and mathematical representation of electromagnetic waves:

Maxwell's prediction of electromagnetic waves-

a) A time varying magnetic field is a source of changing electric field.

b) A time varying electric field is a source of changing magnetic field.

1. Electromagnetic waves consist of oscillating electric and magnetic fields.
2. The various possible frequencies of electromagnetic waves form a spectrum, a small part of which is visible light.
3. An electromagnetic wave travelling along an x-axis has an electric field $\vec{E}$ and a magnetic field $\vec{B}$ with magnitude that depends on x and t:
   $E = E_m \sin(kx - \omega t)$ and $B = B_m \sin(kx - \omega t)$
   E_m and B_m are amplitude of the field, k wave number and ωthe angular frequency.
4. The speed of any electromagnetic magnetic wave in vacuum is c,
   $$c = \frac{1}{\sqrt{\mu_0 \epsilon_0}}$$
   $$\left[v = \frac{E}{B} = \frac{\frac{q}{4\pi\varepsilon_0 r^2}}{\frac{\mu_0 v r \sin\theta}{4\pi \quad r^3}} = \frac{\frac{q}{4\pi\varepsilon_0 r^2}}{\frac{\mu_0 q v}{4\pi r^2}} = \frac{1}{\mu_0 \epsilon_0 v} \Rightarrow v^2 = \frac{1}{\mu_0 \epsilon_0} \Rightarrow v = \frac{1}{\sqrt{\mu_0 \epsilon_0}} = c\right]$$
5. Electric and magnetic field $\vec{E}$ and $\vec{B}$ are always perpendicular to the direction in which the wave travelling. Thus wave is a transverse wave.
6. Electric field is always perpendicular to the magnetic field.
7. The cross product $\vec{E}x\vec{B}$ always gives the direction in which the wave travels.
8. The field always vary sinusoidally and with same frequency and in phase with each other.
9. All electromagnetic waves including visible light (700 nm to 400 nm), have the same speed c in vacuum.
10. Amplitude ratio $= \frac{E_m}{B_m} = c$ and magnitude ratio $= \frac{E}{B}$

Maxwell's law of induction: A changing electric flux induces a magnetic field $\vec{B}$. Maxwell's law of induction $\oint \vec{B}.\overrightarrow{dl} = \mu_0 \epsilon_0 \frac{d\varphi_E}{dt}$ relates the magnetic field induced along a closed loop to the changing electric flux ϕ_E through the loop.

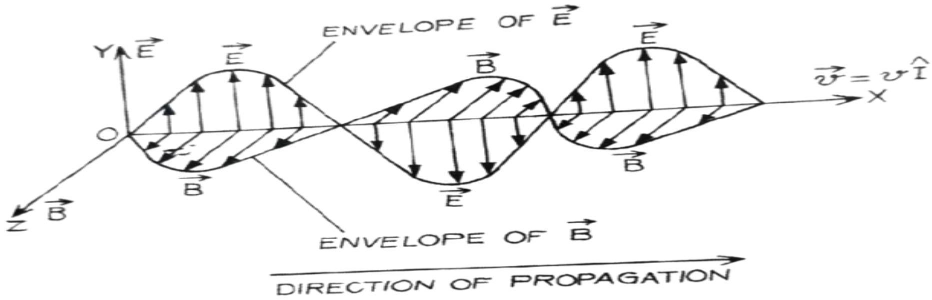
Faraday's law of induction: A changing magnetic flux induces an electric field $\oint \vec{E}.\overrightarrow{dl} = -\frac{d\varphi_B}{dt}$

Ampere's law: It gives the magnetic field generated by the current i_{enc} encircled by a closed loop.

Ampere's law and Maxwell's law can be written as single equation $\oint \vec{B}.\overrightarrow{dl} = \mu_0 \epsilon_0 \frac{d\varphi_E}{dt} + \mu_0 i_{enc}$

Mathematical representation of electromagnetic waves:

A linearly polarized electromagnetic wave is propagating in the x-direction with the oscillating electric field $\vec{E}$ along the y-direction and the oscillating magnetic field $\vec{B}$ along the z-direction.



A plane EM wave travelling along X-axis. The electric field $\vec{E}$ oscillates along Y-axis while the magnetic field $\vec{B}$ oscillates along Z-axis.

$\vec{E} = E_y\hat{j} = E_0 \sin(kx - \omega t)\hat{j} = E_0 \sin\left[2\pi\left(\frac{x}{\lambda} - ft\right)\right]\hat{j} = E_0 \sin\left[2\pi\left(\frac{x}{\lambda} - \frac{t}{T}\right)\right]\hat{j}$

Where, $k = \frac{2\pi}{\lambda} = propogation\ constant\ of\ the\ wave$ and ω=2πf=angular frequency

Here, $E_x = 0, E_z = 0$

Likewise, $\vec{B} = B_z\hat{k} = B_0 \sin(kx - \omega t)\hat{k}$ and $B_x = B_y = 0$

$k = \frac{2\pi}{\lambda} = \frac{2\pi f}{f\lambda} = \frac{\omega}{c}$ =propagation constant or wave number

The direction of EM wave can be determined by th equation as:

$$\vec{E} \times \vec{B} = \vec{v}$$

The $\vec{E}$ represents in which direction the electric field oscillates. The $\vec{B}$ represents in which direction the magnetic field oscillates. The $\vec{v}$ represents in which direction the wave is propagating.

Suppose, the wave is propagating in positive x –direction, so, it is in $\hat{\imath}$ direction. Now, to find the direction of oscillations of Electric and Magnetic field. By applying as: $\vec{E} \times \vec{B} = \vec{v}$

$$\boxed{\hat{j}} \times \boxed{\hat{k}} = \boxed{\hat{\imath}}$$

Hence, electric field will oscillate in y-direction and magnetic field will oscillate in z-direction.

Hertz's experiment: In 1888, Hertz succeeded in experimentally confirming the existence of EM wave. By using oscillatory L-C circuit, he not only produced and detected electromagnetic waves, but also demonstrated their properties of reflection, refraction, interference and polarisation and established that light radiation has wave nature. He was able to produce EM wave of around 6 m.

Contribution of J. C. Bose and Marconi: In 1895, Sir J. C. Bose succeeded in producing and observing EM wave of much shorter wave length (25 mm t0 5 mm).

In 1896, Marconi succeeded in transmitting EM waves over distance of many kilometres. His experiments marked the beginning of radio communication.

Basic properties of EM waves:

1. The EM waves are produced by accelerated charge and do not require any medium for propagation.
2. The oscillations of $\vec{E}$ and $\vec{B}$ fields are perpendicular to each other and also both are perpendicular to the direction of propagation of wave. So, EM waves are transverse in nature.
3. The oscillations of $\vec{E}$ and $\vec{B}$ fields are same phase.
4. All EM waves travel in free space with the speed of light c and is given by $c = \frac{1}{\sqrt{\mu_0\epsilon_0}}$ = 3 x 10^8 m/s

   In a material medium of refractive index n, the speed of EM wave is given by $v = \frac{1}{\sqrt{\mu\varepsilon}} = \frac{1}{\sqrt{\mu_0\mu_r\epsilon_0\epsilon_r}} = \frac{c}{n}$
5. The ratio of the amplitude of electric and magnetic field is $\frac{E_0}{B_0} = c = \frac{1}{\sqrt{\mu_0\epsilon_0}}$

6. The EM wave carry energy as they travel through space and this energy is shared equally by the electric and magnetic fields. The average energy density of EM wave is $u = u_E + u_B = \frac{1}{2}\epsilon_0 {E_0}^2 + \frac{1}{2}\frac{{B_0}^2}{\mu_0}$
7. Linear momentum of an EM wave: $p = \frac{U}{c}$
   The EM waves transport linear momentum as they travel through space.
8. Intensity of EM wave: $Intensity = \frac{\frac{Energy}{time}}{Area} = \frac{Power}{Area}$
9. The EM waves are not deflected by electric and magnetic fields.
10. The EM waves obey the principle of superposition. They show the properties of reflection, refraction, interference, diffraction and polarisation.
11. The electric field of an EM wave is responsible for its optical effects, because $E_0 >> B_0$.

Electromagnetic spectrum:

The orderly distribution of EM waves in accordance with their wave length or frequency in order to distinct groups having widely differing properties is called EM spectrum.

Uses of EM spectrum-

EM spectrum	Uses
1.Radio waves	In radio and communication systems
	In radio astronomy

Some important wireless communication bands:

Frequency Bands	Service
540-1600 kHz	Medium wave AM band
3-30 MHz	Short wave AM band
88-108 Mhz	FM broadcast
54-890 Mhz	TV waves
840-935 MHz	Cellular mobile radio

EM spectrum	Uses
2.Microwaves (or short wavelength of radio waves)	A.In radar systems for aircraft navigation
	B.In microwave ovens
	C.In long distance communication system via geostationary satellites
3.Infrared waves (or heat waves)	A.In green house to keep the plant warm
	B.In knowing the molecular structure
	C.In reading the secret writing on the ancient walls
	D.Infrared lamps to treat muscular complaints
	E.To keep the earth warmth
4.Visible light	A.It provides us information of the world around us.
	B.It can cause chemical reactions

Visible Spectrum:

Colour	Wavelength range (Ǎ)	Colour	Wavelength range (Ǎ)
Violet, Indigo	4000-4500	Yellow	5700-5900
Blue	4500-5000	Orange	5900-6200
Green	5000-5700	Red	6200-7500

EM spectrum	Uses
5.Ultraviolet Light	A.In food preservation
	B.In the study of invisible writing, forged documents and finger print
6.X-rays	A.In radiotherapy to cure untraceable skin diseases
	B.In the study of crystal structure as X-rays can be reflected and diffracted by crystals
	C.In detective departments to detect explosives, diamonds, gold
	D.In medical diagnosis because X-rays can pass through flesh but not through bones

7.Gamma Rays	A.To initiate some nuclear reactions
	B.In the manufacture of polyethylene from ethylene
	C.In radiotherapy for treatment of malignant tumours
	D.To preserve food stuff for a long time

Wave length and frequency of spectrum:

Spectrum	Wave length decreasing order	Frequency (Hz) increasing order
Radio Waves	600 m to 0.1 m (>0.1 m)	10^4 to 10^8
Microwaves	0.3 m to 3 x 10^{-3} m (0.1 m to 1 mm)	10^8 to 10^{12}
Infrared	5 x 10^{-3} m to 10^{-6} m (1 mm to 700 nm)	10^{11} to 5 x 10^{14}
Visible light	8 x 10^{-7} m to 4 x 10^{-7} m (700 nm to 400 nm)	4 x 10^{14} to 7 x 10^{14}
Ultraviolet	3.5 x 10^{-7} m to 1.5 x 10^{-7} m (400 nm to 1 nm)	10^{16} to 10^{17}
X-rays	100 Ă to 0.1 Ă (1 nm to 10^{-3} nm)	10^{18} to 10^{20}
Gamma rays	10^{-14} m to 10^{-10} m (< 10^{-3} m)	10^{18} to 10^{22}

Sources of EM waves:

1. An accelerating charge produces electric and magnetic fields changing both with time and space sinusoidally.
2. An L-C circuit can produce EM waves of frequency $f = \frac{1}{\sqrt{LC}}$ as charge oscillates across capacitor plates in this circuit.
3. When fast moving electrons are suddenly stopped by metal target of high atomic number, EM waves are also produced. These EM waves are called X-rays.
   The physical properties of EM waves are determined by their frequency and not by the mode of their production.

Production of EM Waves:

Radio waves: These waves are produced by rapid acceleration and deceleration of the electrons in conducting wires.

Microwaves: These are produced by special vacuum tubes like klystrons, magnetrons and gunn diodes.

IR radiations (infrared radiation): These are produced by vibration of atoms and molecules.

X-rays: These are produced by bombarding a metal target by high energy electrons.

Visible spectrum (VIBGYOR) wave length:

Visible Spectrum	Wave length (nm)
Violet, Indigo	400 - 450
Blue	450 - 500
Green	500 -550
Yellow	550 -600
Orange	600 -650
Red	6650 -700

The orderly arrangement of EM wave in increasing or decreasing order of wavelength or frequency is called EM spectrum. The range varies from 10^4 m to 10^{-12} m from radio waves to Gamma rays.
Decreasing order of Wavelength:
Radio waves > Microwaves > Infrared > Visible > Ultraviolet > X-rays > γ rays
Increasing order of frequency:
Radio waves < Microwaves < Infrared < Visible < Ultra violet < X rays < γrays

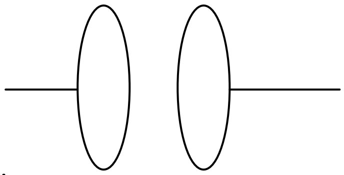
Order	Radio waves	Microwaves	Infrared	Visible	Ultraviolet	X ray	γray
Wavelength	>0.1 m	0.1 m to 1 mm	0.1 mm to 700 nm	700 nm to 400 nm	400 nm to 1 nm	1 nm to 10^{-3} nm	< 10^{-3} nm

Ch-8: Questions bank on Electromagnetic waves

1. A capacitor has been charged to a dc source. What are the magnitudes of conduction and displacement current, when it is fully charged? [Delhi 2013]
   [Ans. Conduction current and displacement current both are zero.]
2. What are the direction of electric and magnetic field vectors relative to each other and relative to the direction of propagation of EM waves. [Ans. mutually perpendicular]
3. Which part of EM spectrum has largest penetrating power? [Ans. γ -rays]
4. Which part of EM spectrum is absorbed from sunlight by ozone layer? [D 2010]
   [Ans. Ultraviolet rays]
5. Speed of an EM wave in a material medium is given by $v = \frac{1}{\sqrt{\mu\epsilon}}$. How does its frequency change? [AI 2012] [Ans. It will remain same.]
6. Name the EM waves which (i) maintains the earth's warmth and (ii) are used in aircraft navigation. [F 2012] [Ans. (i) Infrared, (ii) Microwaves]
7. Arrange the following EM waves in order of increasing frequency: Gamma rays, Ultraviolet rays, microwaves, infrared [F 2014] [Ans. Gamma rays> ultraviolet> Infrared> microwaves]
8. What oscillates in EM waves? Are these waves transverse or longitudinal?[CBSE Sample paper 2011] [Ans. Electric and magnetic fields, transverse]
9. Name EM radiations used for detecting fake currency notes. [Ans. UV radiations]
10. Why are microwaves used in radar? [Ans. Microwaves have the wave length of order of few millimetres. Due to their short wave length, they are not diffracted easily and can travel longer distances.]
11. For which frequency of light, the human eyes are most sensitive? [Ans. The human eyes are most sensitive for wavelength $\boldsymbol{\lambda}$ = 555 nm, so its frequency is $f = \frac{c}{\lambda} = \frac{3x10^8}{555x10^{-9}} = 5.405x10^{14}$ Hz.]
12. What is the time period of visible light for which human eye is most sensitive? [Ans. 1.85 x 10^{-15} s]
13. Which of the following can act as a source of EM waves?
    a) A charge moving with a constant velocity
    b) A charge is at rest
    c) A charge moving in a circular orbit

    [Ans. (c) as in (a) acceleration is zero, in (b) force is zero]

14. What evidence is there that sound is not EM in nature? [Ans. Sound wave requires an inertial medium for their propagation which shows that sound is not EM in nature.]
15. A capacitor made of two circular plates each of radius 12 cm and separated by 5 cm. The capacitor is being charged by an external source. The charging current is constant and equals to 0.15 A.
    a) Calculate the capacitance and rate of change of potential difference between the plates.
    b) Obtain the displacement current across the plates.
    c) Is Kirchhoff's first rule (Junction rule) valid at each plate of the capacitor? Explain.



Answer:

Given, Radius R = 12 cm = 12 x 10^{-2} m, separation d = 5 cm = 5 x 10^{-2} m, I = 0.15 A, $\mathcal{E}_0$ = 8.85 x 10^{-12} C^2/N-m^2, Current I = 0.15 A

$$C = \frac{\epsilon_0 A}{d} = \frac{8.85\ x\ 10^{-12} x\ \pi(12\ x\ 10^{-2})^2}{5\ x\ 10^{-2}} = 80\ pF$$

$$V = \frac{q}{C} \Rightarrow \frac{dV}{dt} = \frac{1}{C}\left(\frac{dq}{dt}\right) = \frac{I}{C} = \frac{0.15}{80} = 1.87\ x\ 10^9\ V/s$$

Displacement current across the plate = Conduction current = 0.15 A

16. A parallel plate capacitor made of circular plates each of radius R = 6 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.
    a) What is the rms value of conduction current?
    b) Is the conduction current equals to the displacement current?
    c) Determine the amplitude of B at a point 3 cm from the axis between the plates.

    Given, radius of each plate R = 6 cm = 6 x 10^{-2} m, Capacitance C = 100 pF = 100 x 10^{-12} F, Supply voltage V_{rms} = 230 V, angular frequency ω = 300 rad/s

    $$I_{rms} = \frac{V_{rms}}{X_C} = \omega C V_{rms} = 300\ x\ 100\ x\ 10^{-12} x\ 230 = 69\ x\ 10^{-7} = 6.9\ \mu A$$

    Yes, conduction current = displacement current

    Magnetic field (B)

    $$B = \frac{\mu_0 I_0 r}{2\pi R^2} = \frac{4\pi\ x\ 10^{-7} x\ I_{rms}\sqrt{2}\ x\ 3\ x\ 10^{-2}}{2\pi(6\ x\ 10^{-2})^2} = 1.63\ x\ 10^{-11}\ \text{T}$$

17. Write Maxwell's generalization of Ampere's circuital law. Show that in the process of charging a capacitor, the current produced within the plates of the capacitor is

    $$i = \epsilon_0 \frac{d\varphi_E}{dt}$$

18. Mention situations when there is : [F 2013]
    a) Only conduction current and no displacement current
    b) Displacement current and no conduction current

    [Ans. When a steady current passes through a conductor, there is no displacement current. When there is electric potential difference is infinity, there is no conduction current.]

19. Suppose that the electric field amplitude of an em wave is E_0 = 120 N/C and its frequency is f = 50 Mhz. Determine B_0, ωk, and $\boldsymbol{\lambda}$, (b) Find expression for vector E and vector B.

[Ans. (a) 100 nT, 3.14×10^8 rad/s, 1.04 rad/s, 6 m, (b) $\vec{E} = 120\sin(1.05\,x - 3.14\,x\,10^8 t)\,\hat{j}$
$\vec{B} = 400\sin(1.05\,x - 3.14\,x\,10^8 t)\,\hat{j}$]

20. Suppose that the electric field part of an em wave in vacuum is
$\vec{E} = (3.1\,N/C)\cos[(1.8\,rad/m)y + (5.4\,x\,10^6\,rad/s)t]\hat{\imath}$
    a) What is the direction of propagation? [Ans. –ve y-direction]
    b) What is the wavelength? [Ans. 3.5 m]
    c) What is the frequency? [Ans. 0.86 Mhz]
    d) What is the amplitude of magnetic field part of the wave?[1.03×10^{-8} T]
    e) What is the expression for the magnetic field part of the wave? [$\vec{B} = B_0\cos(kz + \omega t)$