40. Electromagnetic Waves

Short Answer

Answer.1

The food which is being cooked contains water. The microwaves which are directed towards the food has a natural frequency that match with the frequency of water. The water molecules inside the food absorb energy from the microwaves and get heated up causing the food around it to heat up. Due to absorption of energy of the microwaves, the food gets cooked. Whereas the plastic does not have any water molecules which would absorb energy and the frequency also doesn't match with the natural frequency of the microwaves so the plastic container remains unaffected.

Answer.2

The solenoid carrying a high frequency alternating current generates a continuously changing magnetic field across the rod placed along the axis. Due to this varying magnetic field across the rod, eddy currents are generated on the surface of the rod. The resistance of the rod and the eddy currents flowing on the rod are responsible for the generation of heat.

Answer.3

Electromagnetic waves are made up of electric and magnetic fields but not charges. When an electromagnetic wave passes from a region of electric or magnetic field, it will show no deflection as no charge is present which would experience a force due to these fields and be deflected.

Answer.4

Given: Alternating current $i = i_0 \sin(\omega t)$

The current is the rate of flow of charge per unit time. Mathematically $i = \frac{dq}{dt}$

For a time, t, we can assume the charges in the wire are at rest,

then the charge will be given as

$dq = idt = i_0 \sin(\omega t)\, dt$

Similarly, a no. of charges can be assumed to be at rest. These

charges produce a time varying electric field.

Answer.5

Yes, there is a magnetic field between the capacitor plates.

According to Ampere Maxwell's law, the magnetic field in a region is due to the current due to charge carriers and the changing electric field in a region. Mathematical form of the law is

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

where B is the magnetic field, dl is small element of length of an

Amperian loop, μ_0 is the magnetic permeability of free space and its value is $4\pi \times 10^{-7}$ T m A^{-1}, $I_{enclosed}$ is the current due to charge carriers (conduction current) and I_d is the displacement current which

is related to changing electric field.

The displacement current is related to electric field as

$$I_d = \epsilon_0 \left|\frac{d(\phi_E)}{dt}\right|$$

where ϕ_E is the time varying electric flux through the surface

and ϵ_0 is the electric permittivity of free space(vacuum) and is equal

to 8.85×10^{-12} C^2 N^{-1} m^{-2}.

As the capacitor is charging, the charges at different time create a time varying electric field in the space between the capacitor plates.

This time varying electric field further creates an alternating electric flux though a surface present in between the plates.

The time varying electric flux is

$$\phi_E = \oint E(t) dS cos(\theta)$$

According to Gauss's law, the flux at time t is equal to $1/\epsilon_0$ time the

charge enclosed at that time

$$\phi_E = \frac{q_{enclosed}}{\epsilon_0}$$

The charge enclosed at any time t will be

$Q = CV_0 e^{\omega t}$ where C is the capacitance of the capacitor and V_0 is the amplitude of alternating voltage source and ω is the angular frequency of the source.

The magnetic field in between the capacitor plates is given by

$$\oint \vec{B} \cdot \vec{dl} = \mu_0 (I_{enclosed} + \epsilon_0 \left| \frac{d(\frac{CV_0 e^{\omega t}}{\epsilon_0})}{dt} \right|)$$

Answer.6

Electromagnetic waves consist of oscillating electric and magnetic field which are perpendicular to each other and the direction of propagation as well. Thus electromagnetic waves are transverse in nature and can be polarized. Polarization of electromagnetic waves will restrict the vibrations of electric and magnetic field vectors in one direction only.

Answer.7

Explanation: Let us consider an electromagnetic wave traveling

in the z direction. The electric field E of the wave is assumed to be

$$E = E_0 \sin(kz - \omega t)$$

where E_0 is the amplitude of the electric field, k is the wave number

of the wave $(k = \frac{2\pi}{\lambda})$, λ is the wavelength, ω is the angular frequency

of the wave $(\omega = 2\pi\nu)$ and t is the time. The frequency of the wave

is

$$f = \frac{\omega}{2\pi}$$

Now the magnetic field can be considered as

$$B = B_0 \sin(kz - \omega t)$$

where B_0 is the amplitude of the magnetic field, k is the wave

number of the wave $(k = \frac{2\pi}{\lambda})$, λ is the wavelength, ω is the angular

frequency of the wave $(\omega = 2\pi\nu)$ and t is the time. The frequency of

the wave is

$$f = \frac{\omega}{2\pi}$$

The frequencies of electric and magnetic waves are same.

Hence (a) and (b) oscillate with the same frequency.

Now the electric field energy density of the electromagnetic wave is

given by the relation

$$U_{de} = \frac{1}{2}\epsilon_0 E^2$$

where ϵ_0 is the electric permittivity of free space(vacuum) and is equal to 8.85 × 10^{-12} C^2 N^{-1} m^{-2} and U_{de} is the energy density of electric field. Now the energy of the wave over small volume V of the region is the product of energy density and the small volume V. The energy of the electric field is

$$U_E = U_{de} \times V = \frac{1}{2}\, \epsilon_0 E^2 \times V$$

$$U_E = \frac{1}{2}\, \epsilon_0 (E_0 \sin(kz - \omega t))^2 \times V = \frac{1}{2} \epsilon_0 E_0^2 sin^2(kz - \omega t) \times V$$

$$= \frac{1}{2} \epsilon_0 E_0^2 \left(\frac{1 - cos2(kz - \omega t)}{2}\right) \times V = \frac{1}{4} \epsilon_0 E_0^2 \big(1 - cos2(kz - \omega t)\big) \times V$$

$$U_E = \frac{1}{4} \epsilon_0 E_0^2 \big(1 - cos2(kz - \omega t)\big) \times V$$

The energy of the electric field is $\frac{1}{4} \epsilon_0 E_0^2 \big(1 - cos2(kz - \omega t)\big) \times V$.

The angular frequency of the energy of the wave is 2ω, the

Corresponding frequency will be

$$f' = \frac{2\omega}{2\pi}$$

Now the magnetic field energy density of the electromagnetic wave

is given by the relation

$$U_{db} = \frac{1}{2} \frac{B^2}{\mu_0}$$

where μ_0 is the magnetic permeability of free space and its value is

$4\pi \times 10^{-7}$ T m A^{-1}, U_{db} is the magnetic field energy density. Now the energy of the wave over small volume V of the region is the product of energy density and the small volume V. The energy of the magnetic field is

$$U_B = U_{db} \times V = \frac{1}{2} \frac{B^2}{\mu_0} \times V$$

$$U_B = \frac{1}{2\mu_0}\, (B_0 \sin(kz - \omega t))^2 \times V = \frac{1}{2\mu_0} B_0^2 sin^2(kz - \omega t) \times V$$

$$= \frac{1}{2\mu_0} B_0^2 \left(\frac{1 - cos2(kz - \omega t)}{2}\right) \times V = \frac{1}{4\mu_0} B_0^2 \big(1 - cos2(kz - \omega t)\big) \times V$$

$$U_B = \frac{1}{4\mu_0} B_0^2 \big(1 - cos2(kz - \omega t)\big) \times V$$

The energy of the magnetic field is $\frac{1}{4\mu_0} B_0^2 \big(1 - cos2(kz - \omega t)\big) \times V$.

The angular frequency of the energy of the wave is 2ω, the

Corresponding frequency will be

$f' = \frac{2\omega}{2\pi}$

The electric field energy and magnetic field energy have the same

frequencies of oscillation.

So (c) and (d) form a pair.

Objective I

Answer.1

Explanation: A magnetic current can be produced by a moving

charge. If the charge is moving uniformly, it will generate a constant

current. If we assume a constant current is flowing through a

conductor of length L, the magnetic field due to it at a distance R

from it is given by Biot-Savart law. The field would be

$$\underset{B}{\rightarrow} = \frac{\mu_0}{4\pi} \times i \times \frac{(\underset{L}{\rightarrow} \times \underset{R}{\rightarrow})}{R^3}$$

where i is the constant current and μ_0 is the magnetic permeability

of free space and its value is $4\pi \times 10^{-7}$ T m A^{-1}. So A. is correct.

A changing electric field can also generate a magnetic field around it. According to Ampere-Maxwell law, the total magnetic field around a region is due to flow of charge carriers (called as conduction current)

and the time varying electric flux. Mathematically

$\oint \underset{B}{\rightarrow} . \underset{dl}{\rightarrow} = \mu_0 (I_{enclosed} + I_d)$ ...(i)

where B is the magnetic field, dl is small element of length of an

Amperian loop, μ_0 is the magnetic permeability of free space and its value is $4\pi \times 10^{-7}$ T m A^{-1}, $I_{enclosed}$ is the current due to charge carriers (conduction current) and I_d is the displacement current which

is related to changing electric field.

The displacement current is related to electric field as

$I_d = \epsilon_0 \left|\frac{d(\phi_E)}{dt}\right|$ ...(ii)

where ϕ_E is the time varying electric flux through the surface

and ϵ_0 is the electric permittivity of free space(vacuum) and is equal

to $8.85 \times 10^{-12}\ C^2\ N^{-1}\ m^{-2}$.

The electric flux is the amount of electric field lines passing

through a surface normally. Mathematically

$\phi_E = \oint E(t) dS cos(\theta)$ .... (iii)

where E(t) is the time varying electric field, dS are a small area

element on the surface and θ is the angle between the electric field

vector and area vector (if the field lines are not falling normally).

From (ii) and (iii)

$$\oint_{\vec{B}} \cdot_{\vec{dl}} = \mu_0 (I_{enclosed} + \epsilon_0 \left|\frac{d(\oint E(t) dS cos(\theta))}{dt}\right|)$$

If the conduction current is zero, so the magnetic field will entirely be

produced by the changing electric field and would be produced by it.

Hence B. is correct

Hence D. is correct

Answer.2

deflects and gradually comes to the original position

in a time, which is large compared to the time constant.

Explanation: The deflection in a compass needle are because of

magnetic field around the region of the compass. The magnetic field

arises due to charging of the capacitor which creates a varying

electric field. This varying electric field produces a changing electric

field through the capacitor plates. Due to this changing electric flux, a current called the displacement current arises in the capacitor. The

current I_d is related to the electric flux as

$$I_d = \epsilon_0 \left|\frac{d(\phi_E)}{dt}\right| \text{ .... (i)}$$

where ϕ_E is the time varying electric flux through the plane surface

and ϵ_0 is the electric permittivity of free space(vacuum) and is equal

to $8.85 \times 10^{-12}\ C^2\ N^{-1}\ m^{-2}$.

According to Ampere-Maxwell's law of electromagnetism, the total

magnetic field is due to current due to charge carriers and the

current due to time varying electric flux. Ampere-Maxwell law is the

extension of Ampere Circuital Law. The mathematical relation

is

$$\oint \vec{B} . \vec{dl} = \mu_0 (I_{enclosed} + I_d) \text{ ...(ii)}$$

where B is the magnetic field, dl is small element of length of an

Amperian loop, μ_0 is the magnetic permeability of free space and its value is $4\pi \times 10^{-7}$ T m A^{-1}, and $I_{enclosed}$ is the current due to charge carriers.

From (i) and (ii)

$$\oint \vec{B}.\vec{dl} = \mu_0 \left(I_{enclosed} + \epsilon_0 \left|\frac{d(\phi_E)}{dt}\right|\right) \text{ ...(iii)}$$

According to Gauss's Law of electrostatics, the electric flux through

a surface is equal to $1/\epsilon_0$ times the charge enclosed by it.

$$\phi_E = \frac{q_{enclosed}}{\epsilon_0}$$

The charge enclosed by the capacitor plates is changing with time as the capacitor is charging. The charge is given as

$$Q = CV(1 - e^{\frac{-t}{RC}})$$

where

C=capacitance of the capacitor

V=potential of the battery

R=resistance of the resistor connected in series

Using the above two relations in (iii)

$$\oint \vec{B} . \vec{dl} = \mu_0 (I_{enclosed} + \epsilon_0 \left| \frac{d(\frac{CV(1 - e^{\frac{-t}{RC}})}{\epsilon_0})}{dt} \right|) = \mu_0 (I_{enclosed} + \left| \frac{d(CV(1 - e^{\frac{-t}{RC}}))}{dt} \right|$$

So the magnetic field depends on the charge of the capacitor. The needle will show deflection till the capacitor gets charged to a specific value at a time τ called the time constant. $\tau = RC$ is the time constant of the capacitor. Charging after this time will be gradual so the needle will come to its original position.

Answer.3

Explanation: The electrical permittivity of free space and magnetic permeability of free space is related with the speed of light in vacuum as

$$C = \frac{1}{\sqrt{\epsilon_0 \mu_0}}$$

squaring the above relation

$$C^2 = \frac{1}{\epsilon_0 \mu_0}$$

The dimension of $\frac{1}{\epsilon_0 \mu_0}$ will be the dimension of C^2.

The dimension of C is $[L\,T^{-1}]$, so the dimension of C^2 will be $[L\,T^{-1}]^2$

$$[L\,T^{-1}]^2 = [L^2 T^{-2}]$$

Therefore C. is the only correct option.

Answer.4

Explanation: An accelerating charge produces a changing electric field which in turn produces a magnetic field. These alternatively changing magnetic and electric fields give rise to electromagnetic waves. A static charge gives rise to only an electric field and a moving charge creates a magnetic field so A. and B. are incorrect.

Answer.5

Explanation: The amplitudes of the electric and magnetic fields are

related as

$\frac{E_0}{B_0} = c$ ...(i)

where c is the speed of wave and E_0 and B_0 are the amplitudes of the fields.

The speed of wave is related with its frequency and wavenumber as

$\frac{\omega}{k} = c$ ...(ii)

where ω is the angular frequency of the wave $(\omega = 2\pi\nu)$ and k is the wavenumber $(k = \frac{2\pi}{\lambda})$ and ν is the frequency and λ is the wavelength of the wave.

From (i) and (ii)

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

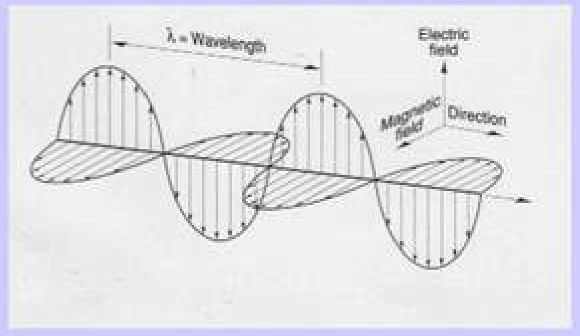
$\frac{\omega}{k} = \frac{E_0}{B_0} \rightarrow E_0 k = B_0 \omega$ so A. is correct.

B. and C. are invalid relations. Only A. is the correct option.

Answer.6

Explanation: There exists a mode of propagation of electromagnetic wave called the Transverse Electric and Magnetic (TEM) mode where both electric and magnetic field are moving tranverse to the direction of propagation of wave. The fields are not in the direction of propagation.

It is possible that an electromagnetic wave may exist when electric and magnetic fields are not perpendicular to each other.



Answer.7

Explanation: Let us assume the linearly polarized plan wave travels in z direction so the electric and magnetic fields of the wave are given by

$E_x \ = E_0 \sin(kz - \omega t)$

$B_Y \ = B_0 \sin(kz - \omega t)$

Their average values over one cycle would be the average from time t=0 to t=T.

Average of electric field

$$\langle E_x \rangle = \frac{\int_0^T E_x dt}{\int_0^T dt} = \frac{\int_0^T E_0 \sin(\mathrm{kz} - \omega \mathrm{t}) dt}{\int_0^T dt}$$

$$= \frac{1}{T} \ E_0 \int_0^T \sin(\mathrm{kz} - \omega \mathrm{t}) dt = \frac{E_0}{T} \left[\frac{\cos(kz - \omega t)}{\omega} \right] \begin{matrix} T \\ 0 \end{matrix}$$

$$= \frac{E_0}{T \times \frac{2\pi}{T}} \left[\cos\left(kz - \frac{2\pi}{T} T \right) - \cos\left(kz - \frac{2\pi}{T} 0 \right) \right]$$

$$= \frac{E_0}{T \times \frac{2\pi}{T}}[\cos(kz - 2\pi) - \cos(kz)] == \frac{E_0}{T \times \frac{2\pi}{T}}[\cos(kz) - \cos(kz)] = 0$$

(because $\omega = \frac{2\pi}{T}$ and $\cos(\theta - 2\pi) = \cos(\theta)$)

Therefore, the average of electric field is zero.

Similarly average of magnetic field is also zero as

$$\langle B_y \rangle = \frac{\int_0^T B_y\, dt}{\int_0^T dt} = \frac{\int_0^T B_0 \sin(\mathrm{kz} - \omega t)\, dt}{\int_0^T dt}$$

$$= \frac{1}{T} B_0 \int_0^T \sin(\mathrm{kz} - \omega t)\, dt = \frac{B_0}{T}\left[\frac{\cos(kz - \omega t)}{\omega}\right]_0^T$$

$$= \frac{B_0}{T \times \frac{2\pi}{T}}\left[\cos\left(kz - \frac{2\pi}{T}T\right) - \cos\left(kz - \frac{2\pi}{T}0\right)\right]$$

$$= \frac{B_0}{T \times \frac{2\pi}{T}}[\cos(kz - 2\pi) - \cos(kz)] == \frac{B_0}{T \times \frac{2\pi}{T}}[\cos(kz) - \cos(kz)] = 0$$

So electric and magnetic field have their average value zero.

Therefore (A) is correct.

Now the electric energy associated with the electric field is given by

$U_{de} = \frac{1}{2}\, \epsilon_0 E^2$ ...(i)

where ϵ_0 is the electric permittivity of free space(vacuum) and is equal to $8.85 \times 10^{-12}\ C^2\ N^{-1}\ m^{-2}$ and U_{de} is the energy density of electric field.

Similarly, the magnetic energy associated with the magnetic field is given by

$U_{db} = \frac{1}{2}\frac{B^2}{\mu_0}$ ...(ii)

where μ_0 is the magnetic permeability of free space and its value is $4\pi \times 10^{-7}\ T\ m\ A^{-1}$, U_{db} is the magnetic field energy density.

Also the amplitudes of electric and magnetic fields are related as

$\frac{E_0}{B_0} = C$ ...(iii)

where C is the speed of light in vacuum.

$U_{de} = \frac{1}{2}\,\epsilon_0 E_0^2 sin^2(kz - \omega t)$ and $U_{db} = \frac{1}{2\mu_0}\,(B_0 \sin(kz - \omega t))^2$

Using (iii) in (i)

$U_{de} = \frac{\epsilon_0 B_0^2 C^2}{2} sin^2(kz - \omega t)$ .... (iv)

The electrical permittivity and magnetic permeability of free space

related as

$C = \frac{1}{\sqrt{\epsilon_0 \mu_0}} \Rightarrow C^2 = \frac{1}{\epsilon_0 \mu_0}$ .... (v)

Using (v) in (iv)

$$U_{de} = \frac{\epsilon_0 B_0^2 C^2}{2} sin^2(kz - \omega t) = \frac{\epsilon_0 B_0^2}{2\epsilon_0 \mu_0} sin^2(kz - \omega t) = \frac{1}{2\mu_0}\,(B_0 \sin(kz - \omega t))^2$$

$U_{de} = U_{db}$

Therefore, the electric and magnetic energy densities are same in

magnitude and so their average values will be same.

Average of electric energy over one cycle will be

$$\langle U_{de} \rangle = \frac{\int_0^T \frac{1}{2}\,\epsilon_0 E_0^2 sin^2(kz - \omega t)\, dt}{\int_0^T dt} = \frac{1}{2T}\epsilon_0 E_0^2 \int_0^T \left(\frac{1 - cos2(kz - \omega t)}{2}\right) dt$$

$$= \frac{1}{4T}\epsilon_0 E_0^2 \int_0^T \left(1 - cos(2kz - 2\omega t)\right) dt = \frac{1}{4T}\epsilon_0 E_0^2 [t - \frac{\sin(2kz - 2\omega t)}{2\omega}]_0^T$$

$$= \frac{1}{4T}\epsilon_0 E_0^2 [(T - 0) - \frac{1}{2\omega}[(\sin(2kz - \frac{4\pi}{T} T) - (\sin\left(2kz - \frac{4\pi}{T} 0\right)]]$$

$$= \frac{1}{4T}\epsilon_0 E_0^2 [T - \frac{1}{2\omega}[\sin(2kz - 4\pi) - \sin(2kz)]]$$

$$= \frac{1}{4T}\epsilon_0 E_0^2 \left[T - \frac{1}{2\omega}[\sin(2kz) - \sin(2kz)]\right] = \frac{1}{4}\epsilon_0 E_0^2 \neq 0$$

So electric and magnetic energy and have non zero average values.

Therefore (B) is also correct.

Answer.8

Explanation: A particle placed in and electromagnetic wave moving

with velocity v experiences a force called Lorentz's force due to the

electric and magnetic fields. The force is given as

$$\vec{F} = q(\vec{E} + \vec{v}\times\vec{B})$$

where q is the charge of the particle, E is the electric field, v is the

velocity of the particle and B is the magnetic field.

An electron at rest is placed in the path of a plane electromagnetic wave. The Lorentz force acting on the electron will be

$$\vec{F} = q(\vec{E} + 0\times\vec{B})$$

where e is the charge of the electron. As the electron is at rest so the velocity will be 0. The net Lorentz's force will be

$$\vec{F} = q\vec{E}$$

The electron will move in the direction of the field.

Answer.9

Explanation: An electromagnetic wave striking a material surface

delivers both energy and momentum to the surface.

If the frequency of the wave is ν then the energy imparted will be

$E = h\nu$ .... (i)

where h is the Planck's constant.$(h = 6.63 \times 10^{-34} J\, s^{-1})$

The energy is also related to the speed of the wave as

$E = pc$ .... (ii)

where p is the momentum and c is the speed of the wave.

From (i) and (ii)

$$E = h\nu = pc$$

$$p = \frac{h\nu}{c} = \frac{E}{c}$$

The energy and momentum both are non zero.

We can also define a quantity known as *radiation pressure* which is the pressure the radiation exerts on the material surface is strikes.

The radiation pressure is given as

$Pressure(P) = \frac{force(F)}{area(A)}$ .... (iii)

Also the electromagnetic wave has energy so there is an intensity related to it given by

$Intensity(I) = \frac{Energy(E)}{area(A) \times time(t)}$ .... (iv)

From (iii) and (iv)

$$I = \frac{E}{\frac{F}{P} \times t} = \frac{Power}{\frac{F}{P}} = \frac{velocity(c)}{1/P}$$

(because energy dissipated per unit time is the power and power = force × velocity)

So $P = \frac{I}{c}$ is the radiation pressure.

Objective II

Answer.1

Explanation:

Given: The equation of an electromagnetic wave is given as

$E = E_0 sin(\kappa x - \omega t)$

where E_0 is the amplitude of the electric field, k is the wave number of the wave $(k = \frac{2\pi}{\lambda})$, λ is the wavelength, ω is the angular frequency of the wave $(\omega = 2\pi\nu)$ and t is the time. The frequency of the wave is $\nu = \frac{\omega}{2\pi}$.

A. is k which is equal to $\frac{2\pi}{\lambda}$ and is dependent on λ so A. is incorrect.

B is ω which is $2\pi\nu$. If the speed of the wave is c, then $c = \nu \times \lambda$, so ω becomes $\frac{2\pi c}{\lambda}$, hence B. in incorrect.

C. is $\frac{\omega}{k}$, substituting the values of ω and k we get $\frac{k}{\omega} = \frac{\frac{2\pi}{\lambda}}{\frac{2\pi c}{\lambda}} = \frac{1}{c}$=which is independent of wavelength so C. in correct.

D. is kω, using the values of k and ω, $k\omega = \frac{2\pi}{\lambda} \times \frac{2\pi c}{\lambda}$ which is dependent on wavelength so D. is in incorrect.

Answer.2

Explanation: The displacement current depends on the changing electric flux across the capacitor plates. Due to the charging of the capacitor, the charge varies on the capacitor plates with time. Due to this, the electric flux also varies with time. The relation between the displacement current and the electric flux is given as

$$I_d = \epsilon_0 \frac{d(\phi_E)}{dt}$$

where ϕ_E is the time varying electric flux through the plane surface, ϵ_0 is the electric permittivity of free space(vacuum) and is equal to 8.85×10^{-12} C^2 N^{-1} m^{-2} and I_d is the displacement current.

The electric flux is given by Gauss's law as

$$\phi_E = \frac{q_{enclosed}}{\epsilon_0}$$

The displacement current then becomes

$$I_d = \epsilon_0 \times \frac{d(\frac{q_{enclosed}}{\epsilon_0})}{dt} = \epsilon_0 \times \frac{1}{\epsilon_0} \times \frac{dq_{enclosed}}{dt} = \frac{d(q_{enclosed})}{dt}$$

$$I_d = \frac{d(q_{enclosed})}{dt}$$

which is dependent on charge. If the charge is zero, then the R.H.S would be zero so D. is incorrect. If the charge doesn't change with time so its derivative w.r.t time will be zero and so will be the current, so C. is zero. For R.H.S to be non-zero, the charge must vary with time i.e. increase or decrease, hence A. and B. are correct.

Answer.3

Explanation: The speed of electromagnetic waves is given by

$$c = \nu \times \lambda$$

where ν is the frequency and λ is the wavelength. Thus the speed

will be not same for all frequencies and wavelengths so A. and D.

are incorrect. Also as wave travels from one medium to another, the

speed changes so B. is incorrect. The relation between speed and

intensity of a wave is given by

$$I = \tfrac{1}{2}\, \epsilon_0\, E_0^2 c$$

where ϵ_0 is the electric permittivity of free space(vacuum) and is equal to $8.85 \times 10^{-12}\ C^2\ N^{-1}\ m^{-2}$, c is the speed of wave and E_0 is the amplitude of electric field. The speed will be same for all intensities in a given medium will be same so C. is correct.

Answer.4

Explanation: Let us assume the wave travels in z direction so the

electric and magnetic fields of the wave are given by

$$E_x = E_0 \sin(kz - \omega t)$$

$$B_Y = B_0 \sin(kz - \omega t)$$

Their average values over one cycle would be the average from time

t=0 to t=T.

Average of electric field

$$\langle E_x \rangle = \frac{\int_0^T E_x dt}{\int_0^T dt} = \frac{\int_0^T E_0 \sin(\mathrm{kz} - \omega \mathrm{t}) dt}{\int_0^T dt}$$

$$= \frac{1}{T} E_0 \int_0^T \sin(\mathrm{kz} - \omega \mathrm{t}) dt = \frac{E_0}{T} \left[\frac{\cos(kz - \omega t)}{\omega} \right]_0^T$$

$$= \frac{E_0}{T \times \frac{2\pi}{T}} \left[\cos\left(kz - \frac{2\pi}{T} T\right) - \cos\left(kz - \frac{2\pi}{T} 0\right) \right]$$

$$= \frac{E_0}{T \times \frac{2\pi}{T}} [\cos(kz - 2\pi) - \cos(kz)] == \frac{E_0}{T \times \frac{2\pi}{T}} [\cos(kz) - \cos(kz)] = 0$$

(because $\omega = \frac{2\pi}{T}$ and $\cos(\theta - 2\pi) = \cos(\theta)$)

Therefore, the average of electric field is zero.

Similarly average of magnetic field is also zero as

$$\langle B_y \rangle = \frac{\int_0^T B_y dt}{\int_0^T dt} = \frac{\int_0^T B_0 \sin(\mathrm{kz} - \omega \mathrm{t}) dt}{\int_0^T dt}$$

$$= \frac{1}{T} B_0 \int_0^T \sin(\mathrm{kz} - \omega \mathrm{t}) dt = \frac{B_0}{T} \left[\frac{\cos(kz - \omega t)}{\omega} \right]_0^T$$

$$= \frac{B_0}{T \times \frac{2\pi}{T}} \left[\cos\left(kz - \frac{2\pi}{T} T\right) - \cos\left(kz - \frac{2\pi}{T} 0\right) \right]$$

$$= \frac{B_0}{T \times \frac{2\pi}{T}} [\cos(kz - 2\pi) - \cos(kz)] == \frac{B_0}{T \times \frac{2\pi}{T}} [\cos(kz) - \cos(kz)] = 0$$

So electric and magnetic field have their average value zero.

Now the electric energy associated with the electric field is given by

$U_{de} = \frac{1}{2} \epsilon_0 E^2$ ...(i)

where ϵ_0 is the electric permittivity of free space(vacuum) and is

equal to 8.85 × 10^{-12} C^2 N^{-1} m^{-2} and U_{de} is the energy density of

electric field.

Similarly, the magnetic energy associated with the magnetic field is

given by

$U_{db} = \frac{1}{2}\frac{B^2}{\mu_0}$ ...(ii)

where μ_0 is the magnetic permeability of free space and its value is

$4\pi \times 10^{-7}$ T m A^{-1}, U_{db} is the magnetic field energy density.

Also the amplitudes of electric and magnetic fields are related as

$\frac{E_0}{B_0} = C$ ...(iii)

where C is the speed of light in vacuum.

$U_{de} = \frac{1}{2}\,\epsilon_0 E_0^2 sin^2(kz - \omega t)$ and $U_{db} = \frac{1}{2\mu_0}\,(B_0 \sin(kz - \omega t))^2$

Using (iii) in (i)

$U_{de} = \frac{\epsilon_0 B_0^2 C^2}{2} sin^2(kz - \omega t)$ .... (iv)

The electrical permittivity and magnetic permeability of free space

related as

$C = \frac{1}{\sqrt{\epsilon_0 \mu_0}} \Rightarrow C^2 = \frac{1}{\epsilon_0 \mu_0}$ .... (v)

Using (v) in (iv)

$$U_{de} = \frac{\epsilon_0 B_0^2 C^2}{2} sin^2(kz - \omega t) = \frac{\epsilon_0 B_0^2}{2\epsilon_0 \mu_0} sin^2(kz - \omega t) = \frac{1}{2\mu_0}\,(B_0 \sin(kz - \omega t))^2$$

$U_{de} = U_{db}$

Therefore, the electric and magnetic energy densities are same in

magnitude and so their average values will be same.

Average of electric energy over one cycle will be

$$\langle U_{de} \rangle = \frac{\int_0^T \frac{1}{2}\,\epsilon_0 E_0^2 sin^2(kz - \omega t)\,dt}{\int_0^T dt} = \frac{1}{2T}\epsilon_0 E_0^2 \int_0^T \left(\frac{1 - cos2(kz - \omega t)}{2}\right) dt$$

$$= \frac{1}{4T}\epsilon_0 E_0^2 \int_0^T (1 - cos(2kz - 2\omega t))dt = \frac{1}{4T}\epsilon_0 E_0^2 [t - \frac{\sin(2kz - 2\omega t)}{2\omega}]_0^T$$

$$= \frac{1}{4T}\epsilon_0 E_0^2 [(T - 0) - \frac{1}{2\omega}[(\sin(2kz - \frac{4\pi}{T}T) - (\sin\left(2kz - \frac{4\pi}{T}0\right)]]$$

$$= \frac{1}{4T}\epsilon_0 E_0^2 [T - \frac{1}{2\omega}[\sin(2kz - 4\pi) - \sin(2kz)]]$$

$$= \frac{1}{4T} \epsilon_0 E_0^2 \left[T - \frac{1}{2\omega} [\sin(2kz) - \sin(2kz)] \right] = \frac{1}{4} \epsilon_0 E_0^2 \neq 0$$

So electric and magnetic energy and have non zero average values.

Answer.5

Explanation: Let us consider an electromagnetic wave traveling

in the z direction. The electric field E of the wave is assumed to be

$$E = E_0 \sin(kz - \omega t)$$

where E_0 is the amplitude of the electric field, k is the wave number

of the wave $(k = \frac{2\pi}{\lambda})$, λ is the wavelength, ω is the angular frequency

of the wave $(\omega = 2\pi\nu)$ and t is the time. The frequency of the wave

is

$$f = \frac{\omega}{2\pi}$$

Now the electric field energy density of the electromagnetic wave is

given by the relation

$$U_{de} = \frac{1}{2} \epsilon_0 E^2$$

where ϵ_0 is the electric permittivity of free space(vacuum) and is equal to 8.85 × 10^{-12} C^2 N^{-1} m^{-2} and U_{de} is the energy density of electric field. Now the energy of the wave over volume V of the region is the product of energy density and the volume V. The energy of the electric field is

$$U_E = U_{de} \times V = \frac{1}{2} \epsilon_0 E^2 \times V$$

$$U_E = \frac{1}{2} \epsilon_0 (E_0 \sin(kz - \omega t))^2 \times V = \frac{1}{2} \epsilon_0 E_0^2 sin^2(kz - \omega t) \times V$$

$$= \frac{1}{2}\epsilon_0 E_0^2 \left(\frac{1 - cos2(kz - \omega t)}{2}\right) \times V = \frac{1}{4}\epsilon_0 E_0^2 \big(1 - cos2(kz - \omega t)\big) \times V$$

$$U_E = \frac{1}{4}\epsilon_0 E_0^2 \big(1 - cos2(kz - \omega t)\big) \times V$$

The energy of the electric field is $\frac{1}{4}\epsilon_0 E_0^2 \big(1 - cos2(kz - \omega t)\big) \times V$.

The angular frequency of the energy of the wave is 2ω, the

Corresponding frequency will be

$$f' = \frac{2\omega}{2\pi}$$

This frequency f' is twice of f, $f' = 2f$.

Now the magnetic field can be considered as

$$B = B_0 \sin(kz - \omega t)$$

where B_0 is the amplitude of the magnetic field, k is the wave

number of the wave $\left(k = \frac{2\pi}{\lambda}\right)$, λ is the wavelength, ω is the angular

frequency of the wave $(\omega = 2\pi\nu)$ and t is the time. The frequency of

the wave is

$$f = \frac{\omega}{2\pi}$$

Now the magnetic field energy density of the electromagnetic wave

is given by the relation

$$U_{db} = \frac{1}{2}\frac{B^2}{\mu_0}$$

where μ_0 is the magnetic permeability of free space and its value is

$4\pi \times 10^{-7}$ T m A^{-1}, U_{db} is the magnetic field energy density. Now the energy of the wave over volume V of the region is the product of energy density and the volume V. The energy of the magnetic field is

$$U_B = U_{db} \times V = \frac{1}{2}\frac{B^2}{\mu_0} \times V$$

$$U_B = \frac{1}{2\mu_0}\left(B_0 \sin(kz - \omega t)\right)^2 \times V = \frac{1}{2\mu_0} B_0^2 sin^2(kz - \omega t) \times V$$

$$= \frac{1}{2\mu_0} B_0^2 \left(\frac{1 - cos2(kz - \omega t)}{2} \right) \times V = \frac{1}{4\mu_0} B_0^2 \big(1 - cos2(kz - \omega t)\big) \times V$$

$$U_B = \frac{1}{4\mu_0} B_0^2 \big(1 - cos2(kz - \omega t)\big) \times V$$

The energy of the magnetic field is $\frac{1}{4\mu_0} B_0^2 \big(1 - cos2(kz - \omega t)\big) \times V$.

The angular frequency of the energy of the wave is 2ω, the

Corresponding frequency will be

$$f' = \frac{2\omega}{2\pi}$$

This frequency f' is twice of f, $f' = 2f$.

As for both, electric and magnetic, the energy of wave is double the

frequency of their respective waves, so the overall energy of the

wave has twice the frequency of oscillation of the wave itself.

Exercises

Answer.1

The displacement current I_d is produced by a varying electric

field. It is given by the relation

$$I_d = \epsilon_0 \times \frac{d(\phi_E)}{dt}$$

where ϵ_0 is the electric permittivity of free space(vacuum) and is

equal to $8.85 \times 10^{-12}\ C^2\ N^{-1}\ m^{-2}$ and ϕ_E is the electric flux produced

by the time varying electric field.

To find the dimension of I_d and check whether it is the same as that

of electric current, we need to find the dimension of $\epsilon_0 \frac{d(\phi_E)}{dt}$.

We can simplify $\frac{d(\phi_E)}{dt}$ using Gauss's Law. According to Gauss's law the electric flux ϕ_E through a surface is given as

$$\phi_E = \frac{q_{enclosed}}{\epsilon_0}$$

Using the above relation, the displacement current becomes

$$I_d = \epsilon_0 \times \frac{d(\frac{q_{enclosed}}{\epsilon_0})}{dt} = \epsilon_0 \times \frac{1}{\epsilon_0} \times \frac{dq_{enclosed}}{dt} = \frac{d(q_{enclosed})}{dt}$$

$$I_d = \frac{d(q_{enclosed})}{dt}$$

The dimension of displacement current is the dimension of the

quantity in the R.H.S of the above equation

$$\text{dimension of } I_d = \frac{dimension\ of\ q}{dimension\ of\ time} = \frac{[T\ A\ ]}{[T]} = [A]$$

As [A] is the dimension of electric current so displacement current

has same dimension as that of electric current.

Answer.2

Given: Velocity of charge = v

Area of patch = A

Distance of charge from the patch=x

We have to find the displacement current through the area when it is at a distance x from the charge.

The displacement current arises due to changing electric field which in turn produces a varying electric flux through an area. The displacement current depends on the electric flux as

$$I_d = \epsilon_0 \left|\frac{d(\phi_E)}{dt}\right|$$

where I_d is the displacement current, ϕ_E is the varying electric flux through the area and ϵ_0 is the electric permittivity of free space(vacuum) and is equal to $8.85 \times 10^{-12}\ C^2\ N^{-1}\ m^{-2}$.

The electric field produced by the charge when it is at a distance x from the surface is given by Coulumb's law and is equal to

$$E = \frac{q}{4\pi\epsilon_0 x^2}$$

This electric field produces an electric flux through the area whose magnitude is given by Gauss's law

$$\phi_E = \oint \vec{E} \cdot \vec{dS}$$

$\phi_E = \oint \vec{E} \cdot \vec{dS} = \oint E\ dS\ cos\theta = \oint E\ dS$. This is because the electric field lines are directed along the normal to the area vector of the surface.

The angle θ between them is 0° so cos 0° =1.

$$\phi_E = \oint E\ dS = E \oint dS = EA = \frac{qA}{4\pi\epsilon_0 x^2}$$

The displacement current will be

$$I_d = \epsilon_0 \left|\frac{d(\phi_E)}{dt}\right| = \epsilon_0 \left|\frac{d(\frac{qA}{4\pi\epsilon_0 x^2})}{dt}\right| = \epsilon_0 \times \frac{qA}{4\pi\epsilon_0} \times \left|\frac{d(x^{-2})}{dt}\right|$$

$$= \frac{qA}{4\pi}\left|(-2) \times (x^{-3}) \times \frac{dx}{dt}\right|$$

$$= \frac{qA}{2\pi x^3} \times \frac{dx}{dt}$$

As x is the distance of the charge from the area at different intervals of time so the rate at which the particle is changing its position is its velocity v

$$I_d = \frac{qAv}{2\pi x^3}$$

Thus the displacement current through the area is $\frac{qAv}{2\pi x^3}$.

Answer.3

Given: Area of capacitor plates=A

Separation between the plates=d

Emf of the battery = ϵ

Internal resistance of the battery = R

Area of plane surface= A/2

Displacement current is the current which is generated by a time varying electric field, not by the flow of charge carriers.

This current is also responsible for the generation of a time varying magnetic field. The displacement current I_d is generated due to the fact that the charge on capacitor plates is changing with time.

The displacement current is given by

$$I_d = \epsilon_0 \left|\frac{d(\phi_E)}{dt}\right|$$

where ϕ_E is the time varying electric flux through the plane surface and ϵ_0 is the electric permittivity of free space(vacuum) and is equal to $8.85 \times 10^{-12}\ C^2\ N^{-1}\ m^{-2}$.

The electric field in the space between the plates can be given by Guass's Law. If the charge on the capacitor plate is Q and the area of the plate is A(given), then by Guass's law,

$$\oint \vec{E} \cdot \vec{dS} = \frac{Q}{\epsilon_0}$$

where E is the electric field and ϵ_0 is the electric permittivity of free space and dS is a small area element on the plate.

Further $\oint \vec{E}.\vec{dS} = \oint EdS\cos\theta = \oint EdS = EA$. (because the area vector and electric field lines are both normal to the surface and in same direction i.e. $\theta=0^{\circ}$ so $\cos\theta=1$)

So $EA = \frac{Q}{\epsilon_0} \rightarrow E = \frac{Q}{A\epsilon_0}$, the electric field between the plates is $\frac{Q}{A\epsilon_0}$.

This electric field produces and electric flux through the plane surface given by

$$\phi_E = \oint \vec{E}.\vec{dS} = \oint EdS\ cos\theta = \oint EdS$$

(because the area vector and electric field lines are both normal to the surface and in same direction i.e. $\theta=0^{\circ}$ so $\cos\theta=1$)

$$\oint EdS = E\oint dS = \frac{EA}{2} = \frac{Q}{A\epsilon_0} \times \frac{A}{2} = \frac{Q}{2\epsilon_0} = \phi_E$$

Now the charge on the capacitor is changing with time as it is charging. If the capacitance of the capacitor is C, then the charge Q at time t will be

$Q = \epsilon C(1 - e^{\frac{-t}{RC}})$ where ϵ is the potential between plates which is equal to the emf of battery and R is the resistance attached in series.

The displacement current I_d is given as

$$I_d = \epsilon_0 \left|\frac{d(\phi_E)}{dt}\right| = \epsilon_0 \left|\frac{d(\frac{Q}{2\epsilon_0})}{dt}\right| = \frac{1}{2}\left|\frac{d(\epsilon C(1 - e^{\frac{-t}{RC}}))}{dt}\right|$$

$$= \frac{1}{2}\left|\frac{d(\epsilon C(1 - e^{\frac{-t}{RC}}))}{dt}\right|$$

$$= \frac{1}{2}\left|\epsilon C \times \left(-\frac{1}{RC}\right) \times \left(-e^{\frac{-t}{RC}}\right)\right|$$

$$= \frac{1}{2} \times \frac{\epsilon}{R} \times \left(e^{\frac{-t}{RC}}\right) = \frac{\epsilon}{2R}\ e^{\frac{-t}{RC}}$$

Thus the displacement current as a function of time is $\frac{\epsilon}{2R}\ e^{\frac{-t}{RC}}$.

Answer.4

Given: The displacement resistance $R_d = \frac{V}{I_d}$

We will first calculate the displacement current.

The displacement current I_d is generated due to the fact that the charge on capacitor plates is changing with time.

The displacement current is given by

$$I_d = \epsilon_0 \left|\frac{d(\phi_E)}{dt}\right|$$

where ϕ_E is the time varying electric flux through the plane surface and ϵ_0 is the electric permittivity of free space(vacuum) and is equal to $8.85 \times 10^{-12}\ C^2\ N^{-1}\ m^{-2}$.

We need to calculate the electric flux through the capacitor plate.

As the charge on the capacitor plate at time t can be taken as Q so by using Gauss's law, we will calculate the electric flux.

According to Gauss's law

$$\phi_E = \frac{charge\ enclosed}{\epsilon_0}$$

so the electric flux would be

$$\phi_E = \frac{Q}{\epsilon_0}.$$

As the capacitor is charging, the charge will be a function of time given as

$$Q = CV = CV_0 e^{\frac{-t}{RC}}$$

where C is the capacitance of the capacitor, V is the potential drop at time t, R is the series resistance and V_0 is the potential at time t=0. Now the flux is $\frac{CV_0 e^{\frac{-t}{RC}}}{\epsilon_0}$.

Now by our definition, the displacement current is given by

$$I_d = \epsilon_0 \left|\frac{d(\phi_E)}{dt}\right|$$

which is

$$I_d = \epsilon_0 \left|\frac{d\left(\frac{CV_0 e^{\frac{-t}{RC}}}{\epsilon_0}\right)}{dt}\right| = \epsilon_0 \times \frac{CV_0}{\epsilon_0}\left|\frac{d\left(e^{\frac{-t}{RC}}\right)}{dt}\right| = CV_0 \left|\left(\frac{-1}{RC}\right) \times \left(e^{-t/_{RC}}\right)\right|$$

$$= \frac{V_0}{R} e^{\frac{-t}{RC}}$$

The displacement current is $\frac{V_0}{R} e^{\frac{-t}{RC}}$.

We know that $R_d = \frac{V_0}{I_d} - R$

$$R_d = \frac{V_0}{\frac{V_0 e^{\frac{-t}{RC}}}{R}} - R = Re^{\frac{t}{RC}} - R = R\left(e^{\frac{t}{RC}} - 1\right) = R\left(e^{\frac{t}{\tau}} - 1\right)$$

therefore $R_d = R\left(e^{\frac{t}{\tau}} - 1\right)$, where τ is the time constant.

Answer.5

Given: The magnetic field density and the magnetic field strength

as related by the relation

$$B = \mu_m H$$

where B is the magnetic field density, μ_m is the relative magnetic

permeability of the material and depends on the nature of the

material or the medium and H is the magnetic field strength which

tells upto what extent a material can be magnetized.

For free space, the relation becomes

$B_0 = \mu_0 H_0$ .... (i)

where B_0 is the field intensity in free space(vacuum), H_0 is the strength in free space and μ_0 is the magnetic permeability of free space. μ_0 is a universal constant and its value is $4\pi \times 10^{-7}$ T m A^{-1}.

We can define a relation between the electric field and magnetic field of an electromagnetic wave travelling in vacuum. It is

$C = \frac{E_0}{B_0}$ .... (ii)

where E_0 is the electric field density and C is the speed of light in vacuum.

From (i) and (ii)

$$B_0 = \mu_0 H_0 = \frac{E_0}{C}$$

$$\mu_0 H_0 = \frac{E_0}{C}$$

$\frac{E_0}{H_0} = \mu_0 C$ .... (iii)

To find the dimension of $\frac{E_0}{H_0}$, we will find the dimension of the quantity in the R.H.S.

The dimension of C is $[L\ T^{-1}]$ because it is the speed.

To find the dimension of μ_0, we need to consider the Biot Savart's law which gives the magnetic field due to a current carrying conductor. According to Biot Savart law

$\underset{B}{\rightarrow} = \frac{\mu_0}{4\pi} \times i \times \frac{(\underset{L}{\rightarrow} \times \underset{R}{\rightarrow})}{R^3}$ .... (iv)

where i is the current in the conductor, L is the length of conductor and R is the distance between conductor and point where field is to be found.

The scalar form of the above equation will be simply

$B = \frac{\mu_0}{4\pi} \times \frac{iL}{R^2}$ .... (v)

From (v)

$$\mu_0 = \frac{4\pi R^2 B}{iL}$$

the dimensions of μ_0 will be the dimensions of R.H.S

dimension of B= [M T^{-2} A �$^{-1}$]

dimension of R^2=[L^2]

dimension of L=[L]

dimension of i=[A]

dimension of R.H.S $= \frac{[M\,T^{-2}A^{-1}][L^2]}{[L][A]} = [M\ L^1T^{-2}A^{-2}]$

Therefore dimension of μ_0 is $[M\ L\,T^{-2}A^{-2}]$.

Now the dimension of R.H.S of eq(iii) will be dimension of C × dimension of μ_0

dimension of $\frac{E_0}{H_0} = \ [M\ L\,T^{-2}A^{-2}][L\,T^{-1}] = [M\ L^2\ T^{-3}A^{-2}]$.

As the dimensions of electric resistance given by Ohm's Law(V=iR) is

$$\frac{dimension\ of\ Potential\ difference(V)}{dimension\ of\ current(i)} = \frac{[M\ L^2\ T^{-3}\ A^{-1}]}{[A]} = [M\ L^2T^{-3}A^{-2}]$$

Therefore $\frac{E_0}{H_0}$ has the same dimensions as that of electrical resistance.

Also the value of $\frac{E_0}{H_0}$ is a constant because the R.H.S of eq(iii) is the

product of 2 universal constants.

Answer.6

Given: Maximum electric field E_0 = 810 V m^{-1}.

The sunlight travels through vacuum in outer space to reach the earth. The magnetic field and electric field are related to each other and their relation is

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

where E_0 is the amplitude of the electric field, C is the speed of light in vacuum and B_0 is the amplitude of maximum magnetic field.

Thus the maximum magnetic field is

$$B_0 = \frac{E_0}{c} = \frac{810\ Vm^{-1}}{3 \times 10^8 ms^{-1}} = 2.7\ \times 10^{-6}\ T\ =\ 2.7\ \mu T.$$

The maximum magnetic field is 2.7 μT.

Answer.7

Given: The equation of magnetic field of a plane electromagnetic

wave

$B = (200\ \mu T) \sin [(4.0 \times 10^{15}\ s^{-1})\ (t - x/c)]$

where the amplitude of magnetic field is $B_0 = 200\ \mu T$.

The amplitude of the electric field is related with amplitude of

magnetic field as

$$E_0 = C \times B_0$$

where C is the speed of light in free space and E_0 is the amplitude

of electric field.

Thus the electric field intensity is given as

$$E_0 = C \times B_0$$

$$= (3 \times\ 10^8\ ms^{-1}) \times\ (200\ \mu T)$$

$$E_0\ =\ 6\ \times\ 10^4\ NC^{-1}.$$

The energy density associated with an electric field is given as

$$U_d\ =\ ½\epsilon_0 E_0^2$$

where U_d is the energy density, ϵ_0 is the electric permittivity of free space(vacuum) and is equal to $8.85 \times 10^{-12}\ C^2\ N^{-1}\ m^{-2}$ and E_0 is the amplitude of electric field.

Thus the electric field energy density is given by

$U_d = ½\epsilon_0 E_0^2$

$= ½ \times (8.85 \times 10^{-12}\ C^2\ N^{-1}\ m^{-2}) \times (6 \times 10^4\ NC^{-1})^2$

$= 159.3 \times 10^{-4}\ J\ m^{-3}$

$U_d = 1.593 \times 10^{-2}\ J\ m^{-3}$

The maximum electric field is $6 \times 10^4\ NC^{-1}$ and the corresponding

electric field energy density is $1.593 \times 10^{-2}\ J\ m^{-3}$.

Answer.8

Given: The intensity of laser beam $=2.5 \times 10^{14} W\ m^{-2}$.

We have to find the amplitudes of electric and magnetic field. The

amplitude of the electric field is related to the intensity of the wave

by the relation

$I = ½\ \epsilon_0\ E_0^2 C$

where

ϵ_0 is the electric permittivity of free space(vacuum) and is equal to $8.85 \times 10^{-12}\ C^2\ N^{-1}\ m^{-2}$, C is the speed of light in vacuum and is equal to $3 \times 10^8\ m\ s^{-1}$ and E_0 is the amplitude of electric field.

$I = ½\ \epsilon_0\ E_0^2 C$

$$E_0^2 = \frac{2I}{C\epsilon_0}$$

$$E_0 = \sqrt{\frac{2I}{C\epsilon_0}} = \sqrt{\frac{2 \times 2.5 \times 10^{14}}{3 \times 10^8 \times 8.85 \times 10^{-12}}}$$

$E_0 = 4.339 \times 10^8 N/C$.

The amplitudes of electric and magnetic fields are related as

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

where B_0 is the amplitude of magnetic field in free space.

Thus the value of magnetic field will be

$$B_0 = \frac{E_0}{C} = \frac{4.339 \times 10^8 \ N/C}{3 \times 10^8 \ \frac{m}{s}} = 1.43 \ T.$$

The electric field amplitude is $4.339 \times 10^8 N/C$ and the magnetic field amplitude is $1.43 \ T$.

Answer.9

Given: The intensity of sunlight reaching the earth = 1380 W m^{-2}.

We have to find the amplitudes of electric and magnetic field if the

light is a plane electromagnetic wave. The amplitude of the electric

field is related to the intensity of the wave by the relation

$$I = ½ \, \epsilon_0 \, E_0^2 C$$

where

ϵ_0 is the electric permittivity of free space(vacuum) and is equal to 8.85 × 10^{-12} C^2 N^{-1} m^{-2}

C is the speed of light in vacuum and is equal to 3 × 10^8 m s^{-1}

and E^0 is the amplitude of electric field.

$$I = ½ \, \epsilon_0 \, E_0^2 C$$

$$E_0^2 = \frac{2\,I}{C\epsilon_0}$$

$$E_0 = \sqrt{\frac{2I}{C\epsilon_0}} = \sqrt{\frac{2 \times 1380}{3 \times 10^8 \times 8.85 \times 10^{-12}}}$$

$$E_0 = 1.02 \times 10^3 \ N/C$$

The amplitudes of electric and magnetic fields in free space are related as

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

where B_0 is the amplitude of magnetic field in free space.

Thus the value of magnetic field will be

$$B_0 = \frac{E_0}{C} = \frac{1.02 \times 10^3 \, N/C}{3 \times 10^8 \, \frac{m}{s}} = 3.4 \times 10^{-6} T = 3.4 \, \mu T.$$

The electric field amplitude is $1.02 \times 10^3 \frac{N}{C}$ and the magnetic field amplitude is $3.4 \, \mu T$.