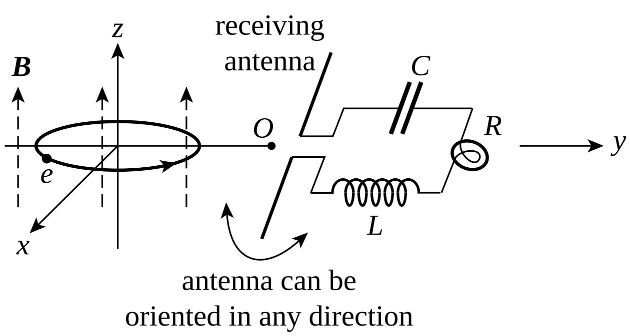
This print-out should have 17 questions, check that it is complete. Multiple-choice questions may continue on the next column or page: find all choices before making your selection. The due time is Central time.

Electron in a magnetic field

34:01, highSchool, multiple choice, > 1 min, fixed.

001

An electron in a uniform magnetic field B in the z direction describes a cyclotron orbit in the xy plane. A physicist along the y axis at point O is trying to detect electromagnetic radiation from the circulating electron using an electric dipole antenna connected in series to an inductor L, variable capacitor C and light bulb of resistance R. As she reorients the antenna and tunes the capacitor the light bulb suddenly lights up.



She then maximizes the bulb's brightness by orienting the antenna

1. along the $\hat{\imath}$ direction. **correct**

2. along the $\hat{\jmath}$ direction.

3. along the $\hat{k}$ direction.

4. at any orientation perpendicular to the $\hat{\jmath}$ direction.

5. at any orientation perpendicular to the $\hat{k}$ direction.

Explanation:

The antenna works best when it is oriented parallel to the electric field vector, or polarization direction, of the propagating EM wave. The electric field of any EM wave propagating in the +y direction can have only x- and z-components (no y-components). Moreover, since the electron circles in the x-y plane, its centripetal acceleration vector has only x- and y-components (no z-components); thus it can only produce EM radiation polarized in the x- and y-directions. Combining the two sets of requirements, EM radiation produced by the circling electron AND propagating in the +y direction must be polarized along the x-direction

002

She then maximumizes the bulb's brightness by tuning the capacitor to

1. $C = \dfrac{e\,B\,R}{m}$.

2. $C = \dfrac{m^2}{e^2\,B^2\,L}$. **correct**

3. $C = \dfrac{R^2\,m}{e\,B\,L}$.

4. $C = \dfrac{e^2\,B^2\,L}{m^2}$.

5. must know electron's velocity.

Explanation:

The electron's cyclotron frequency is omega = eB/m. Thus it generates EM radiation at this frequency. The bulb will be brightest when the LRC receiving circuit is resonant with this frequency: i.e. $\frac{\omega = 1}{\sqrt{(LC)}}$ Equate the two frequencies and solve for C

Hewitt CP9 26 R02

34:01, highSchool, multiple choice, < 1 min, fixed.

003

What does a changing electric field induce?

1. Charges

2. Magnetic field **correct**

3. Light

4. Electrons

5. Nothing

Explanation:

Since a current of charges produces a magnetic field, it follows that a changing electric field produces a magnetic field.

Maxwells Prediction

34:01, highSchool, multiple choice, $<$ 1 min, fixed.

004

Maxwell's equations predict that the speed of light in vacuum is

1. greater for visible light than for radio waves

2. greater for radio waves than for visible light

3. independent of frequency **correct**

4. a function of the distance from the source

5. a function of the size of the source

Explanation:

"Application of Faraday's Law and the Ampere-Maxwell equation to EM radiation results in the prediction that the speed of light is c = $1/Sqrt(\epsilon\ mu)$, independent of frequency

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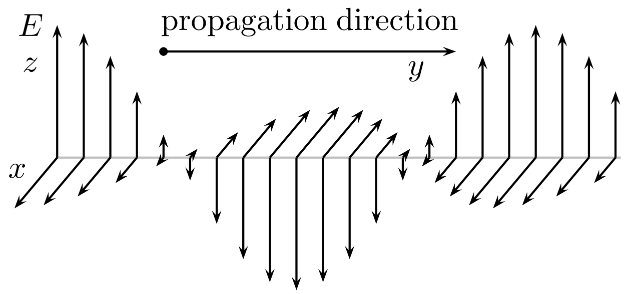
Travelling EMwave

34:01, highSchool, multiple choice, $>$ 1 min, fixed.

005

A snapshot at time $t = 0$ of the electric field for a plane electromagnetic wave with angular velocity ω traveling in the y direction at velocity c is shown.



If the electric field has amplitude E_0 then the accompanying magnetic field is given at time t by

1. $\vec{B} = -\dfrac{E_0}{c}\cos(k\,y - \omega\,t)\ \hat{k}$.

2. $\vec{B} = +c\,E_0\sin(k\,y - \omega\,t)\ \hat{\imath}$.

3. $\vec{B} = +c\,E_0\sin(k\,y + \omega\,t)\ \hat{k}$.

4. $\vec{B} = -\dfrac{E_0}{c}\cos(k\,y - \omega\,t)\ \hat{\imath}$.

5. $\vec{B} = +\dfrac{E_0}{c}\cos(k\,y - \omega\,t)\ \hat{\imath}$. **correct**

Explanation:

Maxwell's derivation of the properties of EM radiation shows that the B-field must be perpendicular to both the E-field and to the direction of propagation. Thus, the B-vector must be along the x-axis in this example.

Moreover, Maxwell's derivation shows that the oscillations of the B-field are in phase with those of the E-field, so B must have a $\cos(k\,y-\omega\,t)$ dependence like the E-field. Finally, to distinguish between $\vec{B} = +\dfrac{E_0}{c}\cos(k\,y - \omega\,t)$ and $\vec{B} = -\dfrac{E_0}{c}\cos(k\,y - \omega\,t)$.

Note: The Poynting vector $S = E \times B$ must point in the direction of propagation. Thus, for example, at the point $y = 0$, B must point in the $+x$ direction, which, at $t = 0$, corresponds to the answer $B = +\dfrac{E_0}{c}\cos(k\,y-\omega\,t)$.

006

If the angular velocity ω of the wave is decreased, then the ratio of the electric to magnetic field

1. $\dfrac{E_0}{B_0}$ increases.

2. $\dfrac{E_0}{B_0}$ decreases.

3. $\dfrac{E_0}{B_0}$ remains the same. **correct**

Explanation:

$\frac{E_0}{B_0} = c$, independent of angular velocity

007

If the angular velocity ω of the wave is decreased, then the velocity of the wave

1. v increases.

2. v decreases.

3. v remains the same. **correct**

Explanation:

$c \equiv \frac{1}{\sqrt{\epsilon_0\,\mu_0}}$, independent of angular velocity

008

If the angular velocity ω of the wave is decreased, then the wavelength of the wave

1. λ increases. **correct**

2. λ decreases.

3. λ remains the same.

Explanation:

wavelength $\lambda = \frac{c}{\nu} = \frac{2\,\pi\,c}{\omega}$.

Poynting Vector again

34:01, highSchool, multiple choice, < 1 min, fixed.

009

For an electromagnetic wave the direction of the vector $\vec{E}$ x $\vec{B}$ gives the direction of:

1. the electric field

2. the magnetic field

3. wave propagation **correct**

4. the electromagnetic force on a proton

5. the emf induced by the wave

Explanation:

Sinusoidal Displacement Current

34:01, highSchool, multiple choice, < 1 min, fixed.

010

A sinusoidal emf is connected to a parallel plate capacitor. The magnetic field between the plates

1. is 0.

2. is constant.

3. is sinusoidal and its amplitude is independent of the frequency of the source.

4. is sinusoidal and its amplitude is proportional to the frequency of the source. **correct**

5. is sinusoidal and its amplitude is inversely proportional to the frequency of the source.

Explanation:

According to maxwell's Equations, in the region between the parallel plates,

$$\oint B\,ds = \epsilon_0\,\mu_0\,\frac{d\,\phi_E}{dt}\,.$$

Since the parallel plates get charged sinusoidally due the emf type, this gives a sinusoidal ϕ_E as well as B, and the amplitude of B is proportional to the frequency as can be seen when we perform the derivative above.

Which Maxwell Equation

34:01, highSchool, multiple choice, < 1 min, fixed.

011

Which of Maxwell's equations can be used, along with a symmetry argument, to calculate the electric field of a point charge?

1. $\oint \vec{B}\cdot d\vec{s} = 0$

2. $\oint \vec{B}\cdot d\vec{A} = \mu_0\,\epsilon_0\,\frac{\partial\,\Phi_E}{\partial t}$

3. $\oint \vec{B}\cdot d\vec{A} = \mu_0\,I$

4. $\oint \vec{E}\cdot d\vec{s} = \frac{Q}{\epsilon_0}$

5. $\oint \vec{B}\cdot d\vec{A} = 0$

6. $\oint \vec{E}\cdot d\vec{A} = \frac{Q}{\epsilon_0}$ **correct**

7. $\oint \vec{B}\cdot d\vec{A} = \frac{Q}{\epsilon_0}$

8. $\oint \vec{B}\cdot d\vec{s} = \mu_0 I + \mu_0 \epsilon_0 \frac{\partial \Phi_E}{\partial t}$

9. $\oint \vec{E}\cdot d\vec{A} = -\frac{\partial \Phi_B}{\partial t}$

10. $\oint \vec{E}\cdot d\vec{s} = -\frac{\partial \Phi_B}{\partial t}$

Explanation:

Maxwell equation, $\oint \vec{E}\cdot d\vec{A} = \frac{Q}{\epsilon_0}$, comes from Gauss's Law and can be used to calculate the electric field of a point charge.

$$\oint \vec{E}\cdot d\vec{A} = \frac{Q}{\epsilon_0}$$
$$E \oint d\vec{A} = \frac{Q}{\epsilon_0}$$
$$E\,(4\,\pi\,r^2) = \frac{Q}{\epsilon_0}$$
$$E = \frac{1}{4\,\pi\,\epsilon_0}\frac{Q}{r^2},$$

where $\oint d\vec{A} = 4\,\pi\,r^2$ is the surface area of a sphere of radius r. The equation is also know as Coulomb's Law.

012

Which of Maxwell's equations can be used, along with a symmetry argument, to calculate magnetic field produced by a uniform time-varying electric field?

1. $\oint \vec{B}\cdot d\vec{s} = 0$

2. $\oint \vec{B}\cdot d\vec{A} = \mu_0 \epsilon_0 \frac{\partial \Phi_E}{\partial t}$

3. $\oint \vec{B}\cdot d\vec{A} = \mu_0 I$

4. $\oint \vec{E}\cdot d\vec{s} = \frac{Q}{\epsilon_0}$

5. $\oint \vec{B}\cdot d\vec{A} = 0$

6. $\oint \vec{E}\cdot d\vec{A} = \frac{Q}{\epsilon_0}$

7. $\oint \vec{B}\cdot d\vec{A} = \frac{Q}{\epsilon_0}$

8. $\oint \vec{B}\cdot d\vec{s} = \mu_0 I + \mu_0 \epsilon_0 \frac{\partial \Phi_E}{\partial t}$ **correct**

9. $\oint \vec{E}\cdot d\vec{A} = -\frac{\partial \Phi_B}{\partial t}$

10. $\oint \vec{E}\cdot d\vec{s} = -\frac{\partial \Phi_B}{\partial t}$

Explanation:

To calculate the magnetic field produced by a uniform time-varying electric field, we can simply use $\oint \vec{B}\cdot d\vec{s} = \mu_0 \epsilon_0 \frac{\partial \Phi_E}{\partial t}$.

013

Which of Maxwell's equations can be used, along with a symmetry argument, to calculate that magnetic field lines form closed loops?

1. $\oint \vec{B}\cdot d\vec{s} = 0$

2. $\oint \vec{B}\cdot d\vec{A} = \mu_0 \epsilon_0 \frac{\partial \Phi_E}{\partial t}$

3. $\oint \vec{B}\cdot d\vec{A} = \mu_0 I$

4. $\oint \vec{E}\cdot d\vec{s} = \frac{Q}{\epsilon_0}$

5. $\oint \vec{B}\cdot d\vec{A} = 0$ **correct**

6. $\oint \vec{E}\cdot d\vec{A} = \frac{Q}{\epsilon_0}$

7. $\oint \vec{B}\cdot d\vec{A} = \frac{Q}{\epsilon_0}$

8. $\oint \vec{B}\cdot d\vec{s} = \mu_0 I + \mu_0 \epsilon_0 \frac{\partial \Phi_E}{\partial t}$

9. $\oint \vec{E}\cdot d\vec{A} = -\frac{\partial \Phi_B}{\partial t}$

10. $\oint \vec{E}\cdot d\vec{s} = -\frac{\partial \Phi_B}{\partial t}$

Explanation:

Unlike the electric field produced by point charge(s), the magnetic field lines form closed loops and always give a zero on the right hand side of Maxwell equation $\oint \vec{B}\cdot d\vec{A} = 0$.

014

Which of Maxwell's equations can be used, along with a symmetry argument, to calculate the magnetic field of a long straight current-carrying wire?

1. $\oint \vec{B} \cdot d\vec{s} = 0$

2. $\oint \vec{B} \cdot d\vec{A} = \mu_0 \epsilon_0 \frac{\partial \Phi_E}{\partial t}$

3. $\oint \vec{B} \cdot d\vec{A} = \mu_0 I$

4. $\oint \vec{E} \cdot d\vec{s} = \frac{Q}{\epsilon_0}$

5. $\oint \vec{B} \cdot d\vec{A} = 0$

6. $\oint \vec{E} \cdot d\vec{A} = \frac{Q}{\epsilon_0}$

7. $\oint \vec{B} \cdot d\vec{A} = \frac{Q}{\epsilon_0}$

8. $\oint \vec{B} \cdot d\vec{s} = \mu_0 I + \mu_0 \epsilon_0 \frac{\partial \Phi_E}{\partial t}$ **correct**

9. $\oint \vec{E} \cdot d\vec{A} = -\frac{\partial \Phi_B}{\partial t}$

10. $\oint \vec{E} \cdot d\vec{s} = -\frac{\partial \Phi_B}{\partial t}$

Explanation:

Here we just use Ampere's Law, namely $\oint \vec{B} \cdot d\vec{s} = \mu_0 I$.

015

Which of Maxwell's equations can be used, along with a symmetry argument, to calculate electric field produced by a uniform time-varying magnetic field?

1. $\oint \vec{B} \cdot d\vec{s} = 0$

2. $\oint \vec{B} \cdot d\vec{A} = \mu_0 \epsilon_0 \frac{\partial \Phi_E}{\partial t}$

3. $\oint \vec{B} \cdot d\vec{A} = \mu_0 I$

4. $\oint \vec{E} \cdot d\vec{s} = \frac{Q}{\epsilon_0}$

5. $\oint \vec{B} \cdot d\vec{A} = 0$

6. $\oint \vec{E} \cdot d\vec{A} = \frac{Q}{\epsilon_0}$

7. $\oint \vec{B} \cdot d\vec{A} = \frac{Q}{\epsilon_0}$

8. $\oint \vec{B} \cdot d\vec{s} = \mu_0 I + \mu_0 \epsilon_0 \frac{\partial \Phi_E}{\partial t}$

9. $\oint \vec{E} \cdot d\vec{A} = -\frac{\partial \Phi_B}{\partial t}$

10. $\oint \vec{E} \cdot d\vec{s} = -\frac{\partial \Phi_B}{\partial t}$ **correct**

Explanation:

Faraday's Law, $\oint \vec{E} \cdot d\vec{s} = -\frac{\partial \Phi_B}{\partial t}$, can be used here to calculate the electric field produced by a uniform time-varying magnetic field.

016

Can Maxwell's equations be used, along with static measurements for μ_0 and ϵ_0, to determine the speed of light?

1. Yes, the speed of light can be determined using only static measurements for μ_0 and ϵ_0. **correct**

2. No, the speed of light can only be determined by directly measuring its speed.

3. No, the speed of light depends on its frequency times Plank's constant, which are not contained in Maxwell's equations.

Explanation:

Maxwell's equations predict the existence of electromagnetic waves which travel with a speed

$$
\begin{aligned}
c &= \frac{1}{\sqrt{\mu_0 \epsilon_0}} \\
&= \frac{1 \text{ m/s}}{\sqrt{(4\pi \times 10^{-7})(8.854187817 \times 10^{-12})}} \\
&\approx 3.00 \times 10^8 \text{ m/s} .
\end{aligned}
$$

The two wave equations are

$$\frac{\partial^2 E}{\partial x^2} = \mu_0 \epsilon_0 \frac{\partial^2 E}{\partial t^2}$$

$$\frac{\partial^2 B}{\partial x^2} = \mu_0\,\epsilon_0\,\frac{\partial^2 B}{\partial t^2}\,,$$

where $\mu_0\,\epsilon_0 = \dfrac{1}{v^2}$ the velocity of the wave.

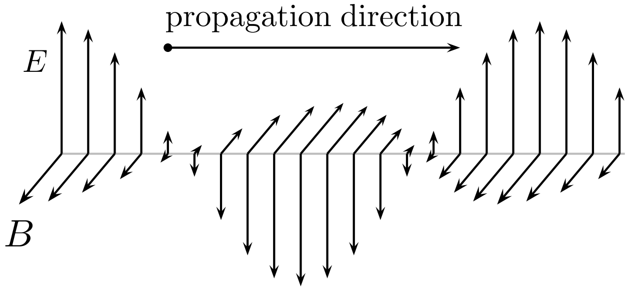
Electromagnetic Wave 06

34:02, highSchool, numeric, > 1 min, wording-variable.

017

$$\begin{aligned} \textit{Given}: \quad \epsilon_0 &= 8.85419\times10^{-12}\ \mathrm{C^2/N/m^2}\,,\\ \mu_0 &= 1.25664\times10^{-6}\ \mathrm{N/A^2}\,, \quad \text{and}\\ c &= 2.99792\times10^{8}\ \mathrm{m/s}\,. \end{aligned}$$

Consider a monochromatic electromagnetic plane wave propagating left to right (as shown below). At a particular point in space, the magnitude of the electric field has an instantaneous value of 10 V/m.



What is the instantaneous magnitude of the Poynting vector at the same point and time?
Correct answer: 0.265442 W/m^2.

Explanation:

Basic Concepts:

$$\frac{E}{B} = c$$

$$\widehat{E}\times\widehat{B} = \widehat{S}\,.$$

The Poynting vector, $\vec{S}$, is given by

$$\vec{S} = \frac{1}{\mu_0}\,\vec{E}\times\vec{B}\,.$$

Solution: For a plane, electromagnetic wave, $\vec{E}$ and $\vec{B}$ are always perpendicular to each other and to the direction of propagation of the wave. In this case, the Poynting vector is in the direction of propagation and has magnitude

$$\begin{aligned} S &= \frac{E\,B}{\mu_0}\\ &= \frac{(10\ \mathrm{V/m})\,(3.33564\times10^{-8}\ \mathrm{T})}{(1.25664\times10^{-6}\ \mathrm{N/A^2})}\\ &= \boxed{0.265442\ \mathrm{W/m^2}}\,, \quad \text{where} \end{aligned}$$

$$\begin{aligned} B &= \frac{(10\ \mathrm{V/m})}{(2.99792\times10^{8}\ \mathrm{m/s})}\\ &= 3.33564\times10^{-8}\ \mathrm{T}\,. \end{aligned}$$