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Midterm 1 physics 230, chapters 19-34 May 13, 2008

NOTE: TO ENSURE FULL CREDIT EMPHASIZE YOUR ANSWERS AND **INCLUDE DIMENSIONS**. SPECIFY WHICH PRINCIPLES OR LAWS YOU ARE USING. EXPLAIN BRIEFLY WHAT YOU ARE TRYING TO DO. ORGANIZE YOUR WORK LOGICALLY. USE DRAWINGS! Use the correct number of significant figures. **USE scientific notation for numbers larger than 1000 and smaller than 1/1000. Unless otherwise specified, do not use more than 3 significant figures.**

1. [10] A circular polarized electromagnetic wave propagates in the x-direction with a wavelength of 12.0 cm. The amplitude of the electric field is 120V/m. At a time when the magnetic field points in the +z direction, what is the direction of the electric field? Make a drawing with the correct directions for E and B fields. Find the angular frequency and the wavenumber.

2. [10] The capacitor of a RLC circuit is first charged to a maximum charge of 15.0 μC, then the emf is being removed. R=45 Ohms, L=5.00mH, C=8mF. Write down the differential equation for the charge in this circuit. Find the resoncance angular frequency at which the charge oscillates in the circuit. Compare this to the oscillation of the spring with damping. Write down the total energy of the circuit and show that it loses power according to RI^2.

3. [10] Use Ampere's law to calculate the magnetic field inside of a toroid with 850 turns. The inner radius of the rectangular coils is 3.00 cm, the outer radius is 7.00 cm. The current in the coil is 2.50A. The current is 1.58A

4. [10] Calculate the change in entropy of 250g of water, heated slowly from 20 to 80ºC. (Note that dQ=mcdT)

5. [10] Find the density of oxygen gas at a pressure of 1.00atm and a temperature of 50.0ºC.

6. [10] The rotating coil with 800 loops in an ac generator has a radius of 1.50m. It is rotated at 60.0Hz in a uniform field of 0.800T. a) Calculate the flux through the loop as a function of time, and the emf induced in the loop.

7. [10] An RLC (in series) circuit is driven by an ac voltage with V_{max}=120V. R=10.0 Ohms, L=5.00mH, C=100μF, ω=1000/s. Find the maximum current in the circuit and the phase change with respect to the voltage. Find the rms current. Use complex impedances. Calculate the resonance frequency of this circuit. Find the maximum power of the circuit.

   Calculate the voltage across the capacitor.

For vector fields of the form $Ae^{i(\vec{k}\bullet\vec{r}-\omega t)}$ we can simplify the rules of derivation as seen in class:

8. [10] $\frac{\partial}{\partial t} = -i\omega$

$\vec{\nabla} = i\vec{k}$

Show that the direction of propagation is perpendicular to both the electric field vector and the magnetic field vector. (Use $div\vec{E} = 0$ *and* $div\vec{B} = 0$)

Apply all this to Faraday's law and prove that E=cB.

9. [10] Calculate the capacitance of a coaxial cable with inner radius a and outer radius b. Start with Gauss's law to calculate the electric field inside of the capacitor. Then calculate the potential difference between the two cylinders, which you may consider to be infinitely thin. Make a drawing and show the Gaussian surface and the electric field lines.

10. In SI units the magnetic field in an em wave is described as $B_y = 10^{-5}\sin\left(10^3 x - \omega t\right)$ Find the amplitude of the corresponding electric field oscillations, wavelength and frequency.

11. Show that the electric potential V of a static electric charge q obeys the differential equation: $\Delta V = -\frac{\rho}{\varepsilon_0}$ In a region of space where there are no charges, the right side of this equation is 0.

Formulas:

$$k_B = 1.38\cdot 10^{-23}; R = 8.314 J/mole\cdot{}^\circ K = 0.08206 Latm/mole\cdot{}^\circ K; \hbar = \frac{h}{2\pi} = 1.05\cdot 10^{-34} Js;$$

$$\sigma = 5.67\cdot 10^{-8}(Stefan); \dot{Q} = eA\sigma T^4; \Delta U = nC_V\Delta T; C_P - C_V = R; \frac{1}{2}m\overline{\mathrm{v}^2} = \frac{3}{2}k_BT; \dot{Q} = \frac{A\Delta T}{\sum \frac{L_i}{k_i}}$$

$$TV^{\gamma-1} = \text{const}; \text{PV}=Nk_BT = nRT; PV^\gamma = \text{const}; \Delta U = Q + W; \Delta S = \int_i^f \frac{dQ_r}{T}; \lambda = 1/\sqrt{2}\pi d^2 n_V$$

$$ndE = n_0 e^{-\frac{E}{k_BT}}dE; W = -\int_{V_i}^{V_f} PdV; 1cal = 4.186J; L_{water} = 80cal/g$$

$$k_e = \frac{1}{4\pi\varepsilon_0} = 8.89\cdot 10^9;\quad \varepsilon_0 = 8.85\cdot 10^{-12}\,S.I.\ \text{;parallel plate capacitor: } E = \frac{\sigma}{\varepsilon_0}; C = \kappa\frac{\varepsilon_0 A}{d}$$

$$E = \frac{Q}{4\pi\varepsilon_0}\frac{1}{r^2}; \vec{E} = -\overrightarrow{grad}\cdot V; \Delta V_{ab} = -\int_a^b \vec{E}\cdot d\vec{s}; C = \frac{Q}{\Delta V}; \vec{F} = q\vec{E}; U = \frac{1}{2}\frac{Q^2}{C} = \frac{1}{2}C(\Delta V)^2;$$

$$dW = qdV; U_{dipole} = -\vec{p}\bullet\vec{E}; \vec{\tau} = \vec{p}\times\vec{E}; q = C\varepsilon\left(1 - e^{\frac{-t}{RC}}\right); m_p = 1.67E-27kg = 938MeV/c^2$$

$$coaxial: C = L/2k_e \ln\frac{b}{a}; I = \dot{Q} = \iint_{surface}\vec{j}d\vec{A}; \vec{j} = nq\vec{\mathrm{v}}_{\mathrm{d}}; \vec{j} = \sigma\vec{E}; \rho_\Omega = \frac{1}{\sigma}; \frac{\Delta\rho}{\rho} = \alpha\Delta T$$

$$copper: \rho_\Omega = 1.7\cdot 10^{-8}\Omega m \text{ at } 20^\circ C; \alpha = 3.9\cdot 10^{-5}/C^\circ; \Delta V = RI; P = I\Delta V = RI^2; \Delta V = \varepsilon - rI$$

(1.1) $div\vec{E} = \frac{\rho}{\varepsilon_0}$;(1.2) $\vec{F}_B = q\vec{\mathrm{v}}\times\vec{B}$

(1.3) $d\vec{F}_B = I\left(d\vec{s}\times\vec{B}\right)$

(1.4) $\vec{\mu} = I\vec{A} =$ magnetic dipole moment

(1.5) $U_B = -\vec{\mu}\cdot\vec{B}$; $\vec{\tau}_B = \vec{\mu}\times\vec{B}$

(1.6) $curl\vec{B} = \mu_0\vec{j}$

(1.7) $d\vec{B} = \frac{\mu_0 I}{4\pi}\frac{d\vec{s}\times\vec{r}}{r^3} = \frac{\mu_0 I}{4\pi}\frac{d\vec{s}\times\vec{u}_r}{r^2}$; Biot-Savart **;** $\frac{\mu_0}{4\pi} = 10^{-7}; \mu_0 = 1.2566\cdot 10^{-6}$

(1.8) $curl\vec{B} = \mu_0\left(\vec{j} + \underbrace{\varepsilon_0\frac{\partial\vec{E}}{\partial t}}_{\vec{j}_d}\right)$ displacement current

(1.9) Faraday's law $\vec{\nabla}\times\vec{E} = -\frac{\partial\vec{B}}{\partial t}$ $\varepsilon = -N\frac{d\Phi_B}{dt}$

(1.10) $\varepsilon = -\frac{d}{dt}\left(\vec{B}\cdot\vec{A}\right) = -\frac{d}{dt}\left(BA\cos\theta\right) = -\frac{d}{dt}\left(BA\cos\omega t\right) = BA\omega\sin\omega t$

(1.11) $\varepsilon_L = -N\frac{d\Phi_B}{dt} = -L\frac{dI}{dt}$

(1.12) $L = \frac{N\Phi_B}{I}$

(1.13) $U_B = \frac{1}{2}LI^2$ electromagnetic energy in an inductor

Energy (instantaneous) density in a capacitor and coil:

(1.14) $u_E = \frac{1}{2}\varepsilon_0 E^2; u_B = \frac{B^2}{2\mu_0}$

ac currents

$\hat{I}(t) = \frac{\hat{V}(t)}{\hat{z}_{eq}}; I_{rms} = \frac{I_{\max}}{\sqrt{2}}; V_{rms} = \frac{V_{\max}}{\sqrt{2}}$

(1.15) $\hat{Z}_L = i\omega L \Rightarrow \hat{I}(t) = \frac{\hat{V}(t)}{i\omega L}; I_{\max} = \frac{V_{\max}}{\omega L}$

$\hat{Z}_C = \frac{1}{i\omega C} \Rightarrow \hat{I}(t) = i\omega C\hat{V}(t); I_{\max} = \omega C V_{\max}$

(1.16) $P = \hat{V}_{rms}\hat{I}_{rms}\cos\Phi$

(1.17) In electromagnetic fields: $E = cB; u_E(t) = \frac{1}{2}\varepsilon_0 E^2; u_B(t) = \frac{1}{2\mu_0}B^2$

Instantaneous energy density in an em wave with equal contributions from the electric field and the magnetic field:

(1.18) $u(t)_{total} = \frac{B^2}{\mu_0} = \varepsilon_0 E^2$

$\bar{u}_{avg} = \frac{1}{2}\frac{B_{\max}^2}{\mu_0} = \frac{\varepsilon_0}{2}E_{\max}^2$

Poynting vector, averaged over a period

(1.19) $\bar{S}_{avg} = \frac{1}{2}\frac{E_{\max}^2}{\mu_0 c} = \frac{1}{2}\frac{cB_{\max}^2}{\mu_0}; \mu_0\varepsilon_0 c^2 = 1$ $;\varepsilon_0\mu_0 = \frac{1}{c^2}$

(1.20) $\frac{S}{c} = u = \frac{U}{V} = \frac{Fdx}{Adx} = pressure\ P$ in an em-wave

(1.21) *momentum* of e.m. wave $p = \frac{2U}{c}$ Perfect reflector

(1.22) *momentum* of e.m. wave $p = \frac{U}{c}$ Perfect absorber

(1.23) $\vec{A}\times(\vec{B}\times\vec{C})=\vec{B}\left(\vec{A}\bullet\vec{C}\right)-\vec{C}\left(\vec{A}\bullet\vec{B}\right)$ for any three vectors $\vec{A},\vec{B},\vec{C}$

(1.24)
$$\vec{E}(x,y,z,t)=\vec{E}=\vec{E}_0 e^{i\left(\vec{k}\bullet\vec{r}-\omega t\right)}$$
$$\vec{B}(x,y,z,t)=\vec{B}=\vec{B}_0 e^{i\left(\vec{k}\bullet\vec{r}-\omega t\right)}$$

$$\frac{\partial}{\partial t}(-i\omega t)=-i\omega$$
$$\vec{\nabla}\Rightarrow i\vec{k}$$

(1.25)
$$\vec{\nabla}\times\vec{B}=curl\vec{B}=i\vec{k}\times\vec{B};\vec{\nabla}\vec{B}=div\vec{B}=i\vec{k}\cdot\vec{B}$$
$$\vec{\nabla}U=\overrightarrow{grad}U=i\vec{k}U$$
$$\vec{\nabla}\bullet\vec{\nabla}=\Delta=Laplace=\left(i\vec{k}\right)^2=-k^2$$