Lecture 39  iq34

Demo: Generation of EM waves from a Tesla coil

Homework: Ch24.h3

1. Sinusoidal running waves:
   - Wavelength, period, speed,
   - Spectrum of EM waves

2. Radiation: Energy density, intensity and time averaged intensity
   - Equal partition between electric and magnetic energies
   - Intensity vector (the Poynting vector)
   - Intensity from a spherical wave (h3:4) vs from a 1D plane wave (h3: 1).

3. Radiation pressure
   - Relation between energy and momentum – Relativistic kinematics
   - Radiative force (magnetic force) on a charge is along the direction of motion and is independent of sign of the charge. (h3:14)
   - Pressure on an absorptive (black) surface vs reflective surface (h3:3, 10-12)

4. Polarization of the radiative waves
   - Parallel metal strips allows the passage of perpendicularly polarized light. Polarizer has the transmission axis perpendicular to the strip.
   - A polarized light through a polarizer. Malus’ law
   - Unpolarized light through two polarizers. LM MI-Ch24 6-7. 001-002

5. Rescattered sunlight in the sky (h3: 7-8)
   - It is polarized.
   - Its intensity (I=cυ=c eps E^2) depends on the inverse fourth power of the wavelength. (why?)

Class announcement:

- The updated course summary of unit 4 has been posted with the date 4/21/13.
  - Since LM covered Malus Law, we have added it in the summary page.
  - We have left out h5 in our updated lesson plan, the corresponding course-material on lens has been removed from the summary.
- Office hour today will be postponed by 15 minutes. It will be from 9:30am to 10:30am.
- Application of the LA position is now available. For those of you who do well in this course are encouraged to apply. LAs are playing an important part in helping students through their interaction with
Demonstration of EM wave:

\[ E(x, t) = E_0 \cos(\omega t - kx) \]  

\[ k = \frac{\omega}{c} \]  

Propagation speed (phase velocity) \( v = \frac{\lambda}{T} = \frac{c}{f} \)  

Example: KLBJ AM Radio wave: find \( f \), \( T = \frac{3 \times 10^8}{390 \times 10^6} \)
Spectrum: Radio AM $\approx 0.5 \times 10^3$ m Ultrawave

Microwave 1 cm beam

Visible light 400-700 nm $\approx 2.5 \times 10^{-6}$ meter

X-ray $\approx 10^{-10}$ meter atomic size

2. Radiation energy density

\[ u_E = \frac{1}{2} E^2, \quad u_B = \frac{1}{2} \mu_0 B^2 \]

EM wave: \( E = c B, \quad c^2 = \frac{1}{\varepsilon_0} \Rightarrow u_E = u_B \quad \text{Equation} \)

Check: \( \frac{1}{2} \varepsilon_0 E^2 = \frac{1}{2} \varepsilon_0 c^2 B^2 = \frac{1}{2} \varepsilon_0 \frac{1}{\varepsilon_0} B^2 = \frac{1}{2} \mu_0 B^2 \)

Intensity:

\[ I = \frac{\Delta U}{A \Delta t} = \frac{\Delta U}{A (dx)} = cu \]

\[ \Delta x = c \Delta t = 2 \varepsilon_0 u_E = c \varepsilon_0 E^2 \]

Time dependence of \( I \) at \( x = x_1 \):

\[ I(x_1, t) = I(0) \]

Time averaged value:

\[ \bar{I} = c \varepsilon_0 E_{\text{max}}^2 \cos(\omega t - kx) \]

\[ \bar{E}^2 = c \varepsilon_0 E_{\text{max}}^2 \Rightarrow E_{\text{max}} = \sqrt{\bar{E}^2} \]

\[ I = \text{Time Averaged Intensity} = c \varepsilon_0 E_{\text{max}}^2 \]

Invariance (Projecting vector):

\[ s^2 = \frac{E^2 B^2}{\mu_0}, \quad \text{Show} \quad \frac{E B \cdot \mu_0}{E_0} = c u^2 = c \varepsilon_0 E^2 \]
Check: $LHS = \frac{EB}{\mu_0} = \frac{E^2}{\mu_0}$. $RHS = \frac{c_0 E_2^2}{\epsilon_0} = \frac{1}{\epsilon_0}$.

Energy-momentum relationship: Relativistic kinematics $\gamma \approx \frac{1}{\sqrt{1-v^2}}$.

For a particle with mass $m$:

Energy: $E = mc^2$\[1\]

Momentum: $p = mv$\[2\]

Energy\[2\] = $\frac{E^2}{c^2} \rightarrow$ EM particle: photon $U = \frac{E^2}{c^2} = \frac{p^2}{c^2}$.

Radiation pressure:

Pressure: \[P = \frac{F}{A} = \frac{dp}{dt}/A\]

Absorptive: \[\frac{dU}{dtA} = \frac{dU}{dA} = 0\]

Reflective: \[2U\]

Geometry-dependent $A$: Reflective example

$F = 2U A$

Geometric considerations: $I = \frac{\Delta U}{\Delta t A} = \frac{Power}{A}$

Light beam shining on a book: \[\frac{1}{2A} \quad \frac{DA}{A}\]

Bulb shining on a book:

$I = \frac{\text{Power}}{DA} \cdot \frac{DA}{2\pi R} \rightarrow \frac{1}{A} \quad I_{\text{back}} = \left(\frac{\text{Power} \cdot DA}{2\pi R^2}\right)$
Polarization

- Definition: \( \text{Dir. of polarization} = \text{Dir. of Oscillation of } E \)

**Metal II stripes**

- \( E_{||} \) moves electron oscillation
- Large induced current
- Energy absorbed by medium

- Negligible induced current
- This component can be transmitted.

The strip setup serves as a polarizer.

- If the incident light is unpolarized (i.e., polarization is uniformly distributed in the amplitude direction), the outgoing light will be polarized in the vertical direction - direction of \( E_{||} \).

- If the incident light is polarized along \( E \) where there is a angle between \( E_{||} \) and \( E \), then \( E_{||} = E \cos \theta \), outgoing intensity \( I_{\text{out}} = I_0 \cos^2 \theta \). This is Malus' Law.