Lecture 39 iq34

Demo: Generation of EM waves from a Tesla coil

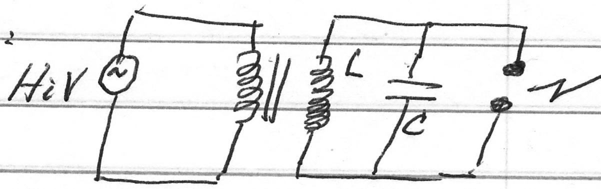
Homework: Ch24.h3

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 momemtum – 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. Malius' 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=cu=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

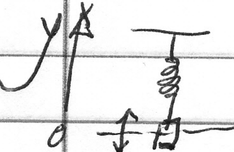
Demo: Generation of EM wave:




Transformer

Charge oscillations leads to radiation

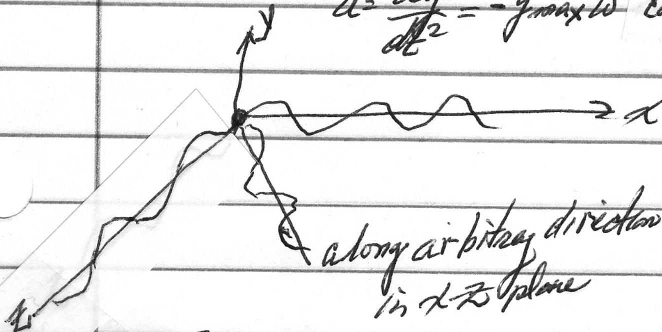
1. Sinusoidal running waves




initial phase

$y = y_{max}\sin(\omega t + \delta)$ $\xrightarrow{\text{this example}}$ $y_{max}\cos\omega t$.

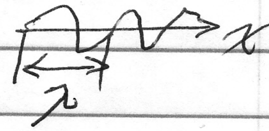
$a = \frac{d^2y}{dt^2} = -y_{max}\omega^2\cos\omega t = -\omega^2 y$




To be specific look at the situation in x direction

Running wave function: $E(x,t) = E_{max}\cos(\omega t - kx)$ See Lec 25...

Fix $t=t_1$ RHS $= E_{max}\cos(\omega t_1 - kx)$ p 1043




$k\lambda = 2\pi$, $k = \frac{2\pi}{\lambda}$

Fix $x = x_1$ : $\cos(\omega t - kx_1)$


$\omega T = 2\pi$, $\omega = \frac{2\pi}{T}$

Fix $\phi = \phi_1$ $(\omega t - kx) = \phi_1$, $x = \frac{-\phi_1 + \omega t}{k}$, $\frac{dx}{dt} = \frac{\omega}{k} = \frac{\lambda}{T}$

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

Example: KLBJ AM radio wave find $\lambda$. $\lambda = \frac{3\times10^8}{590\times10^3} \doteq 50$ m

Spectrum: Radio AM $\sim 0.5\times 10^{3}\,m$ UT stadium

microwaves $1\,cm$ bean

Visible light $400\text{–}700\,nm$ $\sim 0.5\times 10^{-6}\,m$ fraction of a micron

X-ray $\sim 10^{-10}\,m$ atomic size

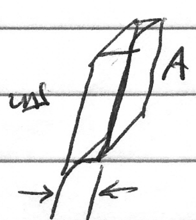
2. Radiation energy density

$$u_E = \frac{1}{2}\epsilon_0 E^2, \quad u_B = \frac{1}{2\mu_0}B^2$$

EM wave: $E = cB$, $c^2 = \frac{1}{\mu_0\epsilon_0}$ $\Rightarrow$ $u_E \overset{?}{=} u_B$ Equipartition

Check: $\frac{1}{2}\epsilon_0 E^2 = \frac{1}{2}\epsilon_0 c^2 B^2 = \frac{1}{2}\epsilon_0 \frac{1}{\epsilon_0\mu_0} B = \frac{1}{2\mu_0}B^2$

Intensity:

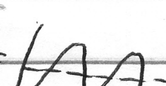



$\Delta x = c\Delta t$

$$I = \frac{\Delta U}{A\Delta t} = \frac{\Delta U}{A\left(\frac{\Delta x}{c}\right)} = cu$$

$$= 2cu_E = c\epsilon_0 E^2$$

Time dependence of $I$ at $x = x_1$: $I(x_1, t) =$



Time averaged value: $I = c\epsilon_0 E_{max}^2 \cos^2(\omega t - kx_1)$

$\therefore \overline{E^2} = \frac{c\epsilon_0 E_{max}^2}{2}$, $E_{rms} = \sqrt{\overline{E^2}}$.

$I$ = Time Ave intensity $= c\epsilon_0 E_{rms}^2$.

Intensity vector (Poynting vector):

$\vec{S} = \frac{\vec{E}\times\vec{B}}{\mu_0}$. Show $\frac{EB}{\mu_0} = cu \overset{?}{=} c\epsilon_0 E^2$

Check: $LHS = \frac{EB}{\mu_0} = \frac{E^2}{c\mu_0}$, $RHS = c\epsilon_0 E^2$, $\frac{1}{c\mu_0} \stackrel{?}{=} c\epsilon_0$ ✓

Energy-momentum relationship: Relativistic kinematic $\gamma \equiv \frac{1}{\sqrt{1-\beta^2}}$, $\beta = v/c$.

For a particle with mass $m$

$$\begin{cases} \text{Energy} = mc^2\gamma \\ \text{Mom} = mv\gamma \end{cases}$$

$\frac{\text{Energy}}{\text{mom}} = \frac{c^2}{v} \Rightarrow$ EM particle: photon $\frac{U}{p} = \frac{c^2}{c} = c$

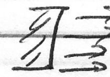
Radiation pressure:

$$\text{Pressure} = \frac{F}{A} = \frac{dp}{dt}/A \begin{cases} \text{absorptive: } \frac{d\,U/c}{dt\,A} = \frac{\Delta U}{\Delta t\, c A} = u \\ \text{Reflective: } 2u \end{cases}$$

Geometry dependent A: Reflective example

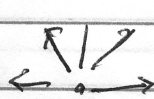
$F = 2uA$

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

Lightbeam shining on a book:  $|\Delta A$

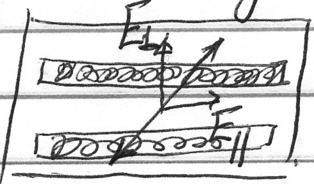
$I = \frac{\text{Power}}{\Delta A}$

Bulb shining on a book:

$I = \frac{\text{Power}}{\Delta A} \cdot \frac{\Delta A}{2\pi R^2}$  $|\Delta A$ $I_{book} = \left(\frac{\text{Power}\ \Delta A}{2\pi R^2}\right)$

Polarization

- Dfn: Dir of polarization = Dir of oscillation of E
- Metal ∥ strips




$E_\parallel$ drives electron oscillation
Large induced current
Energy absorbed by medium

$E_\perp$ 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 azimuthal direction) the outgoing light will be polarized in the vertical direction — direction of $E_\perp$)
- If the incident light is polarized along $\vec{E}$ where there is $\theta$ angle between $E_\perp$ and $E$, then $E_\perp = E\cos\theta$, outgoing intensity $I_{out} = I_{in}\cos^2\theta$. This is Malus Law.