[After PS2 turned in]

In problem set 2, you showed

$$U(\vec{r}) = \frac{Kqq_0}{r}$$

is the potential energy of charge q_0 that is a distance $r = |\vec{r}|$ from a fixed point charge q.

Therefore the electrostatic potential caused by q is

$$V(\vec{r}) = \frac{U(\vec{r})}{q_0} = \frac{Kq}{r} \Rightarrow V(\vec{r}) = \frac{Kq_1}{|\vec{r}-\vec{r}_1|}$$

Like the electric field, the electrostatic potential obeys the superposition principle.

That is, the potential caused by several charges is the sum of the potential caused by each

e.g. for 2 point charges q_1 & q_2 at $\vec{r}_1$ & $\vec{r}_2$

$$V(\vec{r}) = \frac{Kq_1}{|\vec{r}-\vec{r}_1|} + \frac{Kq_2}{|\vec{r}-\vec{r}_2|}$$

[HRK 5e: 38-4, 38-5]

Electric + magnetic fields

- static and moving charges create electric ($\vec{E}$) and magnetic ($\vec{B}$) fields as described by Maxwell's equations (1867)

- $\vec{E}$ + $\vec{B}$ fields influence the motion of charges

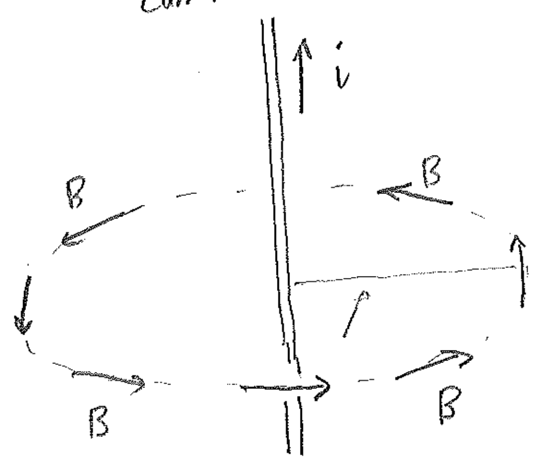
Recall: a static charge q produces a radially directed $\vec{E}$ field

$$|\vec{E}| = \frac{Kq}{r^2} = \frac{q}{4\pi\epsilon_0 r^2}$$

Electric dipole = pair of opposite charges

A moving charge (current) produces a $\vec{B}$ field as well

current-carrying wire



$\vec{B}$ is directed circumferentially

[i.e. around the circumference of a circle surrounding the wire]

Right hand rule:
thumb along i
fingers along B

$$|\vec{B}| = \frac{\mu_0}{2\pi} \frac{i}{\rho}$$

ρ = distance from wire

μ_0 = permeability of vacuum

$$\mu_0 = 4\pi \times 10^{-7} \frac{N}{(amp)^2}$$

[$\mu_0 = 4\pi \times 10^{-7} \frac{N}{(amp)^2} = \frac{Tesla \cdot m}{amp}$ (= exact)

$Tesla = \frac{N \cdot s}{C \cdot m} = \frac{J \cdot s}{C \cdot m^2} = 10 \text{ kG}$]

Maxwell showed that an oscillating charge creates oscillating $\vec{E}$ & $\vec{B}$ fields in the form of a wave travelling at speed $\frac{1}{\sqrt{\mu_0 \epsilon_0}}$

$$\frac{1}{\mu_0} = \frac{10^7}{4\pi} \frac{C^2}{N \cdot s^2}$$

$$\frac{1}{\epsilon_0} = 4\pi K = 4\pi (8.99 \times 10^9) \frac{N \cdot m^2}{C^2}$$

$$\frac{1}{\mu_0 \epsilon_0} = 8.99 \times 10^{16} \frac{m^2}{s^2}$$

$$\frac{1}{\sqrt{\mu_0 \epsilon_0}} = 3 \times 10^8 \frac{m}{s} = c \quad \text{(speed of light)}$$

Consider an electric dipole oscillating with period T ↰ [illustrate this]
(T = time for one complete oscillation)

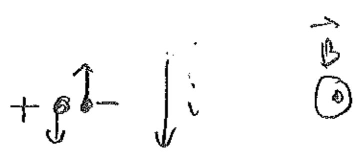
f = frequency of oscillation $= \frac{1}{T}$

units of frequency $= \frac{\text{cycles}}{\text{sec}}$ = Hertz (Hz)

<u>initially</u>

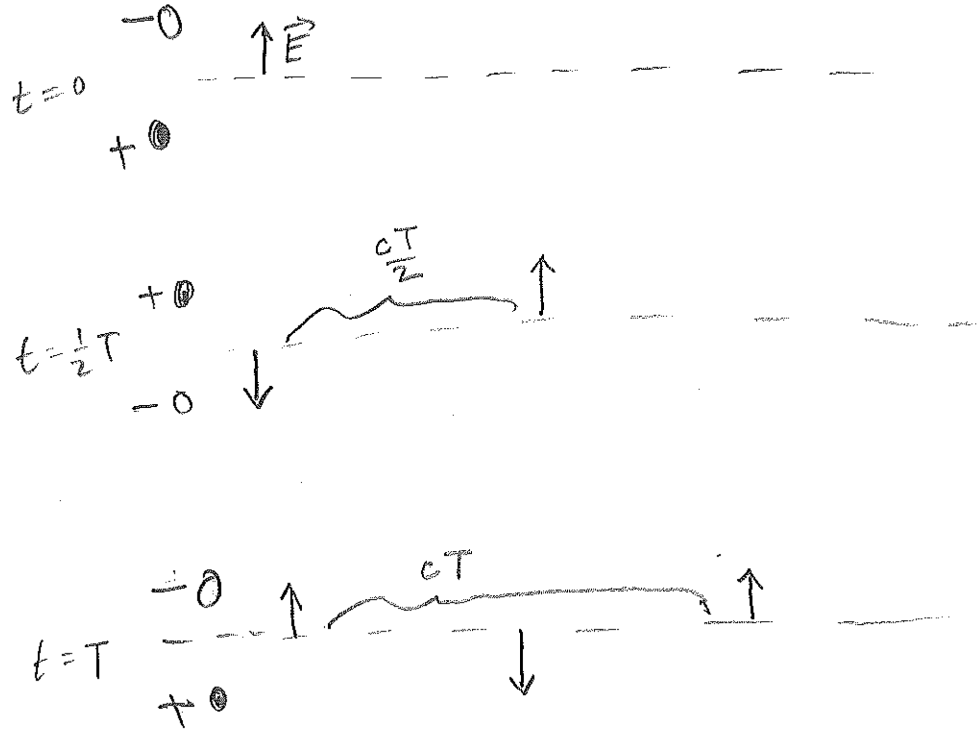
<u>later</u>

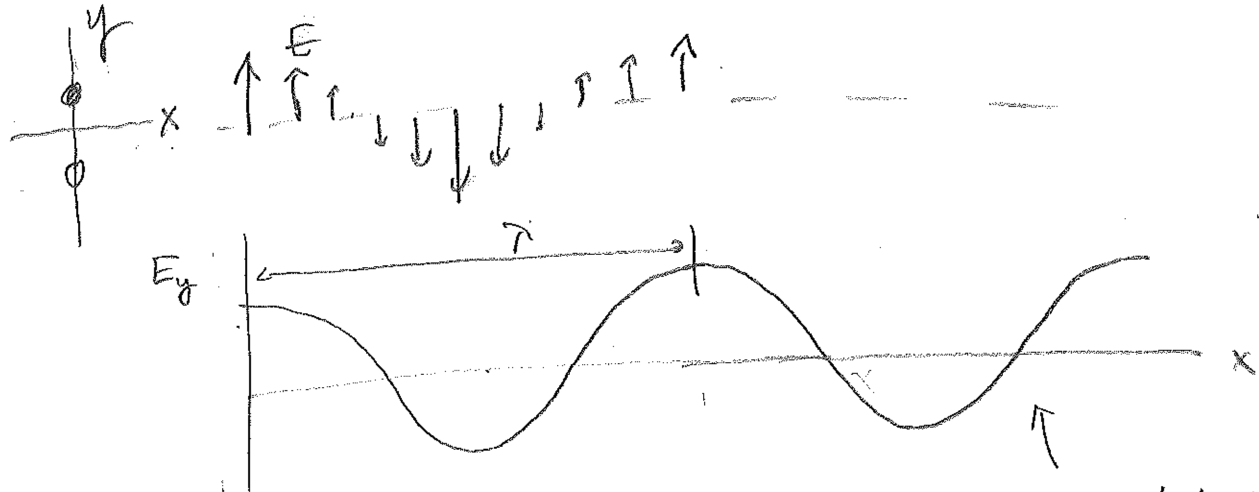
An oscillating dipole creates a current



An oscillating dipole creates $\vec{E}$ + $\vec{B}$ fields
oscillating w/ the same frequency

The $\vec{E}$ field forms a wave travelling at c = speed of light



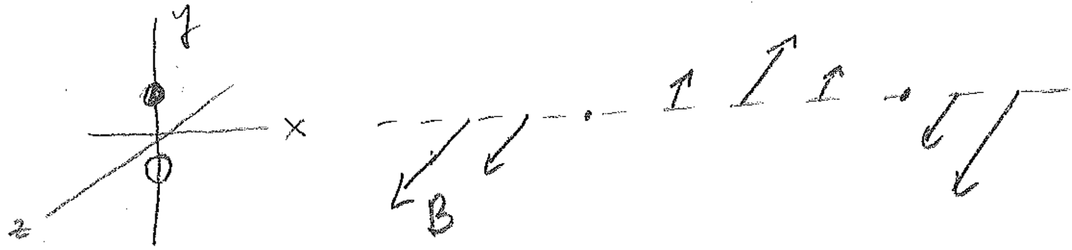


wavelength $\lambda = cT$
(crest to crest)

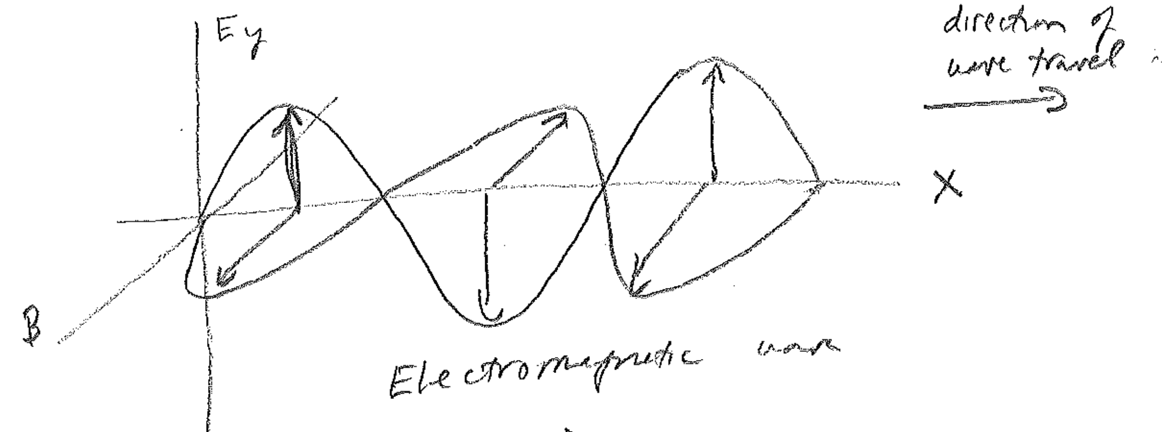
Snapshot of one moment in time
(freeze frame)

wave travels to the right
away from the oscillating dipole

Similarly, $\vec{B}$ fields form a travelling wave



right-handed coordinate system



Electromagnetic wave

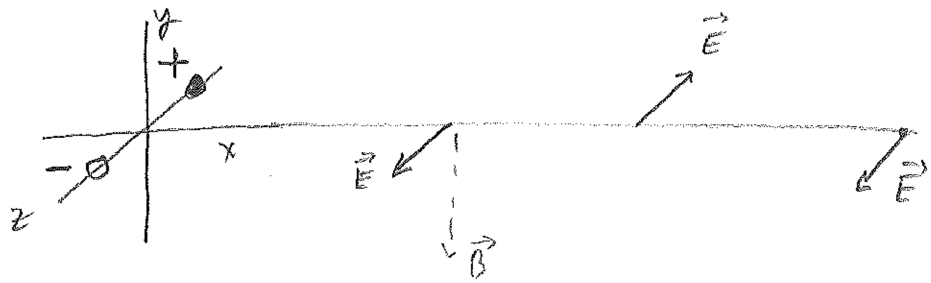
- $\vec{B}$ is perpendicular to $\vec{E}$ [SHOW MODEL]
- $\vec{E}$ + $\vec{B}$ fields are both perpendicular (transverse) to the direction of wave travel, which is indicated by the <u>wavevector</u> $\vec{k}$

The wavevector $\vec{k}$ is parallel to $\vec{E} \times \vec{B}$

[review cross product: right hand rule]

[verify in diagram above]

Consider dipole oscillating along the z-axis



[Now ask about direction of $\vec{B}$ field]

[Ask about a dipole oscillating up + down (along y axis)
what direction will $\vec{E}$ be at your location?
what direction will $\vec{B}$ be at your location?]

[Now dipole oscillating left + right (along x axis)]

[What about dipole oscillation toward + away from you?]

[Discuss randomly oscillating dipole ⇒ E in both transverse directions]