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

Electric & magnetic fields

Takeaways

- 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

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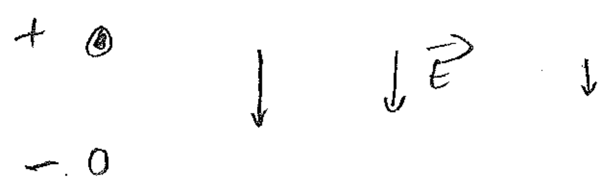
Recall: a static charge q produces a radially directed $\vec{E}$ field

Magnitude of field

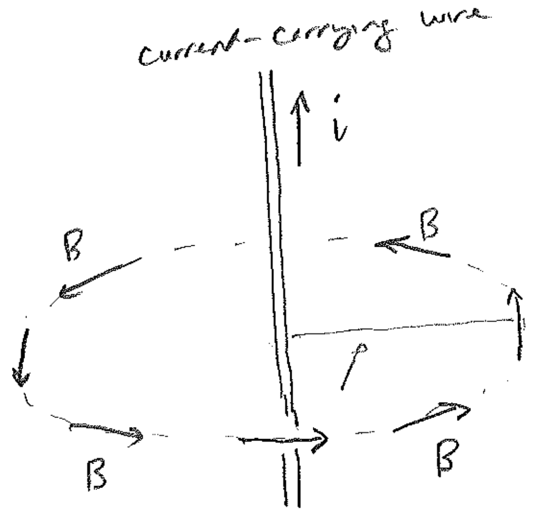
$$|\vec{E}| = \frac{Kq}{r^2} = \frac{q}{4\pi\epsilon_0 r^2}$$

ϵ_0 = permittivity of vacuum

static electric dipole (pair of opposite charges) produces a transverse field



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



$\vec{B}$ is directed circumferentially

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

Right hand rule:
thumb along i
fingers along B

Magnitude of field

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

ρ = distance from wire

μ_0 = permeability of vacuum

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

[$\mu_0 = 4\pi\times10^{-7} \left(\frac{N}{(amp)^2} \quad \frac{Tesla \cdot m}{amp} \right)$ (↑ exact)

Tesla = $\frac{N \cdot s}{C \cdot m} = \frac{J \cdot s}{C \cdot m^2}$ = 10 kG] ← <u>not</u> for class

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

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

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

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

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

He surmised that light therefore <u>is</u> an electromagnetic wave

[without Maxwell's equations]

Qualitative explanation of generation of EM wave

Consider an electric dipole oscillating with period T [show this with heads]

(T = time for one complete oscillation, or cycle

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

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

Initially

+ •

$\downarrow \vec{E}$

− •

later

− •

$\uparrow \vec{E}$

+ •

An oscillating dipole also represents an oscillating current

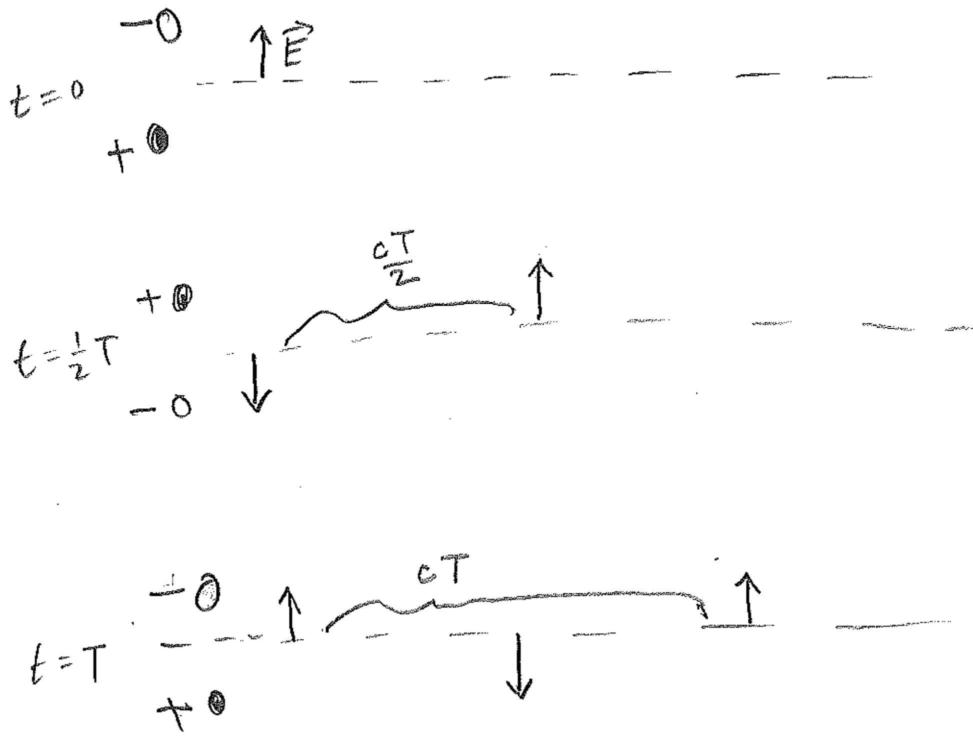
+ q↑ ↓i $\vec{B}$ ⊙

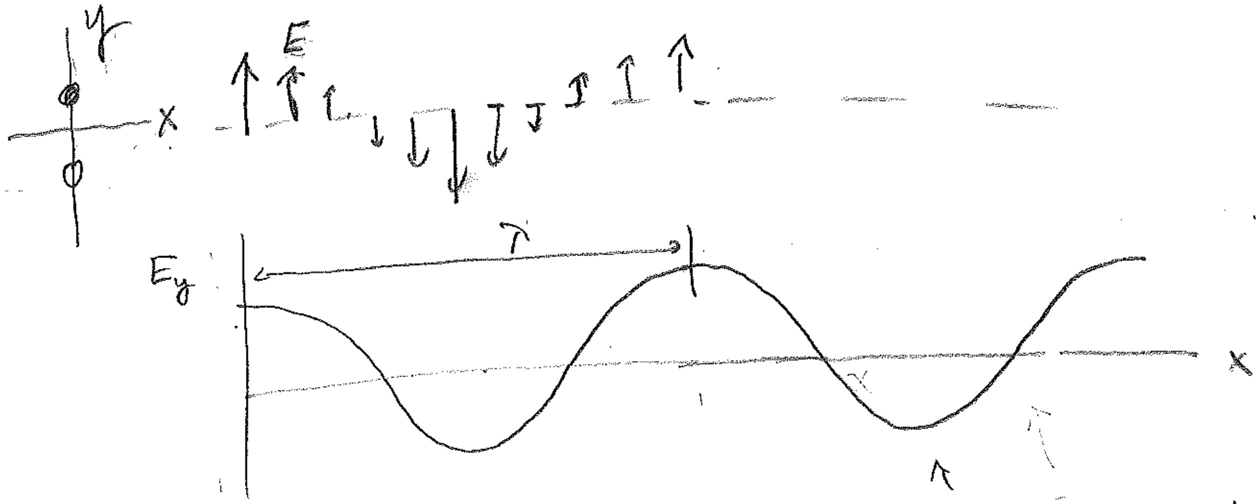
[explain ⊙ and ⊗]

+ q↓ ↑i ⊗ $\vec{B}$

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

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



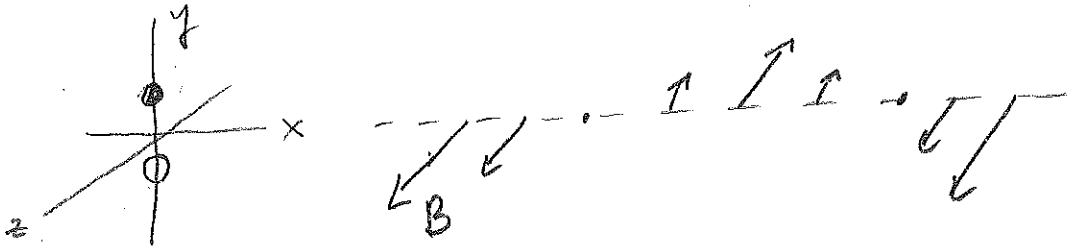


wavelength $\lambda = cT$
(crest to crest)

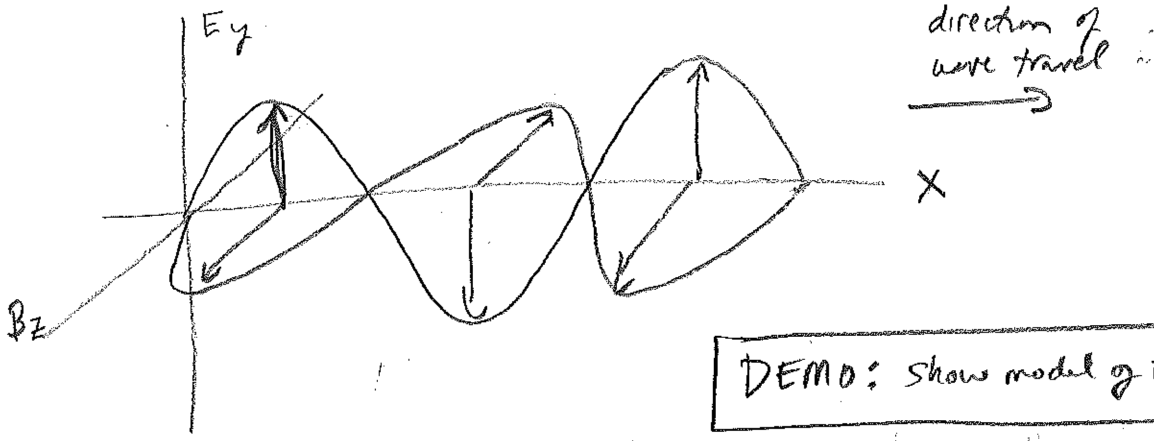
Snapshot of one instant in time
[freeze frame]

wave travels away from oscillating dipole

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



right-handed coordinate system



DEMO: Show model of EM wave

Takeaways for an electromagnetic wave:

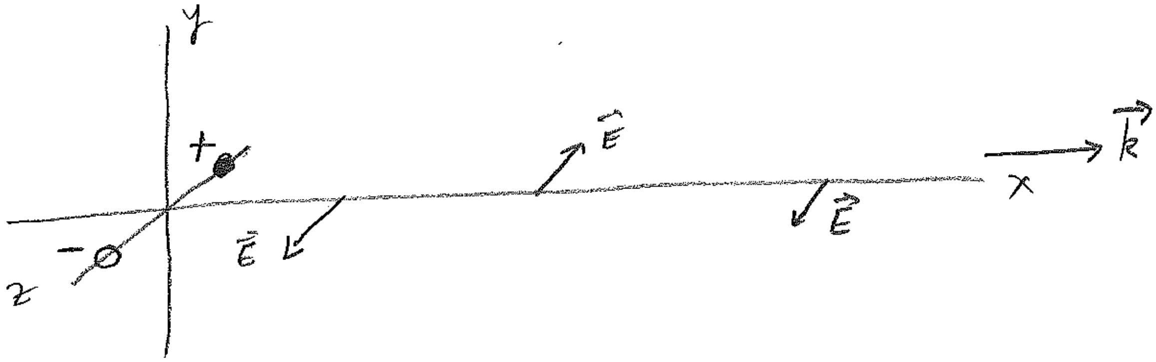
- $\vec{B}$ is perpendicular to $\vec{E}$
- $\vec{E}$ + $\vec{B}$ fields are both perpendicular (transverse) to the direction of wave travel, which is indicated by the <u>wave vector</u> $\vec{k}$

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

[review cross product: right hand rule]

[verify in diagram above]

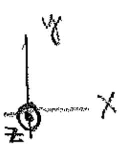
Consider dipole oscillating along the z-axis



[Discuss with class:]

- What is direction of $\vec{B}$ field?

Consider a dipole oscillating along y-axis (up + down)



- Along which axis will $\vec{E}$ point at your location (on z-axis)?
- Along which axis will $\vec{B}$ point at your location?

Consider dipole oscillating along x-axis (left + right).

- $\vec{E}$?
- $\vec{B}$?

Consider dipole oscillating along z-axis (toward + away from you)

- $\vec{E}$ + $\vec{B}$

[discuss carefully]

[$\vec{E}$ field of emitted wave can never be ⊥ to direction of oscillation, ∴ no EM wave]