Exams on Feb. 7 and Feb 21

DON'T READ SECTIONS 3-2 and the first part of 3-3.   Start chapter 3 at eqn M-2

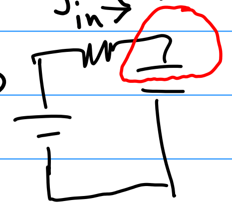
Magnetic force: This lecture covers Shadowitz section 3-3 plus material not in text

Assume magneto-statics: $\vec{\nabla}\cdot\vec{J} = -\frac{\partial\rho}{\partial t} = 0$ $\int \vec{J}_{in}\cdot d\vec{a}$ $\left(\frac{C}{s}\ in\right)$

$\vec{J} = \rho\vec{v}$

$\vec{J}_{in}$

This surface has $\frac{\partial\rho}{\partial t} \neq 0$



Questions:

no moving point charges are allowed in magnetostatics

current in wire is same everywhere even though the wire may change shape

Force law: $\vec{F} = q\vec{E} + q\vec{v}\times\vec{B}$ Lorentz force

What evidence is there that a moving q is the same as a stationary one?

What have we done?

(1) given charge or charge density we can find E and therefore the force

(2) Coulomb's law is expressed as $\vec{\nabla}\cdot\vec{E} = \rho/\epsilon_0$ or $\oint \vec{E}\cdot da = \frac{Q_{encl}}{\epsilon_0}$

What are we going to do?

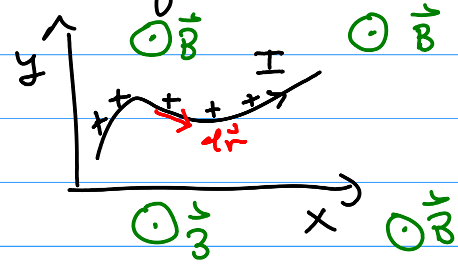
(1) Calculate the force given currents and B

(2) Calculate B given currents

Given B find force on currents using $\vec{F} = q\vec{v}\times\vec{B}$

1.) charge moving along a line $dq = \lambda |d\vec{r}|$ (where $|d\vec{r}| = d\ell$)

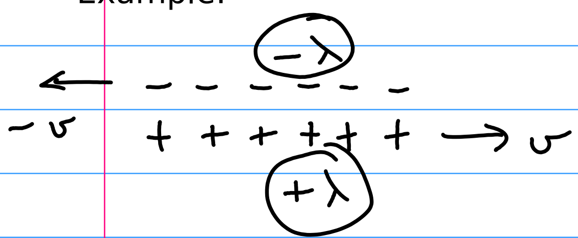
$d\vec{F} = \lambda |d\vec{r}|\, \vec{v}\times\vec{B}$



$\lambda v = I \left(\frac{C}{s}\right)$

$\frac{C}{m}\ \frac{m}{s}$

Example:

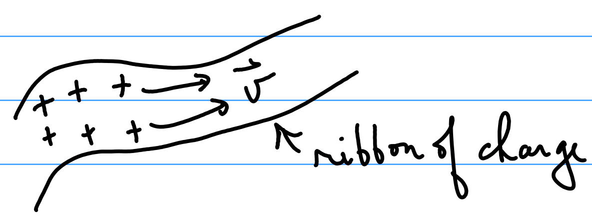


What is $I_{total} = (-\lambda)(-v) + \lambda v$

$= 2\lambda v$

For charge moving in 1-D $\vec{F} = \int I\, d\vec{\ell} \times \vec{B}$ (where $d\vec{\ell} = d\vec{r}$)

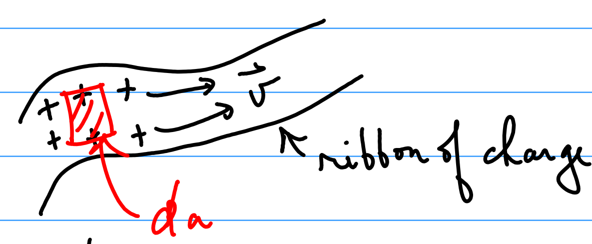
2.) Charge moving along a surface.



$dq = \sigma\, da$

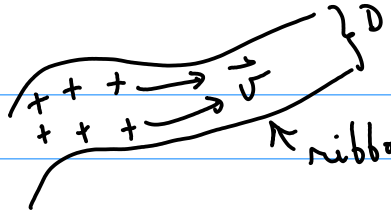
$d\vec{F} = dq\, \vec{v}\times\vec{B}$

$= \sigma\, da\, \vec{v}\times\vec{B}$



$\sigma v = K \left(\frac{C}{m\cdot s}\right)$

$\frac{C}{m^2}\ \frac{m}{s}$

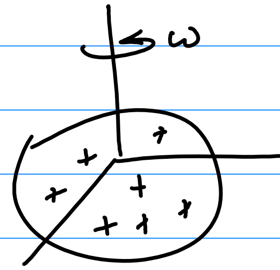


$KD \quad \frac{C}{m \cdot s} m \to I \text{ Amps}\left(\frac{C}{s}\right)$

$\sigma \vec{v} = \vec{K}$

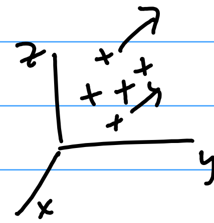
$d\vec{F} = q\vec{v} \times \vec{B} = \vec{K} \times \vec{B}\, da$

Hmwk: charged record



For a charge moving in 2-D $\vec{F} = \int \vec{K} \times \vec{B}\, da$

3.) Charge moving through a volume



$d\vec{F} = dq\, \vec{v} \times \vec{B}$

$dq = \rho\, d\text{volume} = d\tau$

$d\vec{F} = \rho\, d\tau\, \vec{v} \times \vec{B}$

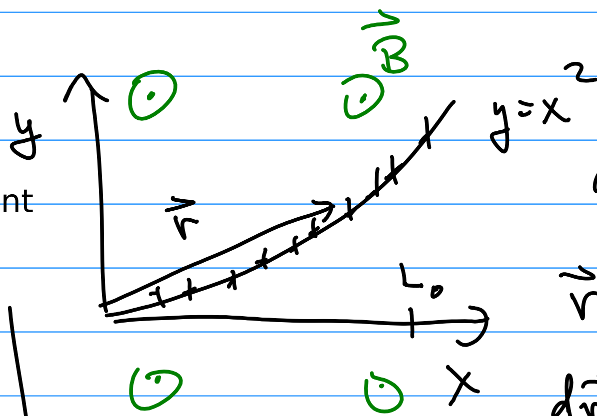
$\vec{J} = \rho \vec{v}$ current density

Remember $\vec{J}$ in $\nabla \cdot \vec{J} = -\frac{\partial \rho}{\partial t}$

$d\vec{F} = \vec{J} \times \vec{B}\, d\tau$

Example:

Find the force on the wire seqment from x=0 to x=L



$d\vec{F} = I\, d\vec{r} \times \vec{B}$

$\vec{r} = x\hat{x} + x^2\hat{y}$

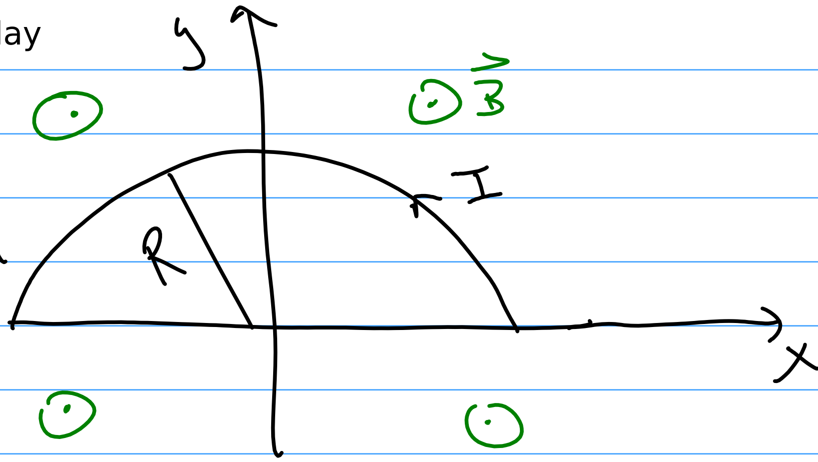
$d\vec{r} = dx\,\hat{x} + 2x\,dx\,\hat{y}$

$$d\vec{F} = I \begin{vmatrix} \hat{x} & \hat{y} & \hat{z} \\ dx & 2x\,dx & 0 \\ B_x & B_y & B_z \end{vmatrix}$$ ← expand and integrate

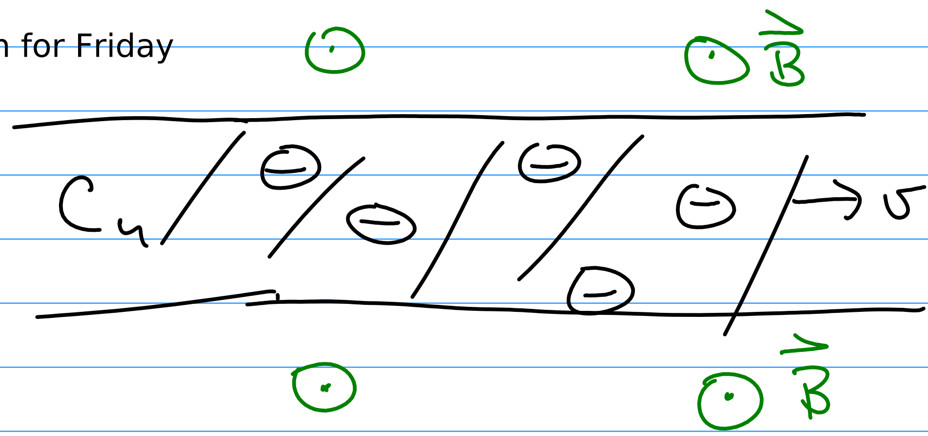
For a charge moving in 3-D $\vec{F} = \int \vec{J} \times \vec{B}\, d\tau$

InkSurvey question for Friday

Find $d\vec{l} = d\vec{r}$ needed to determine $d\vec{F}$



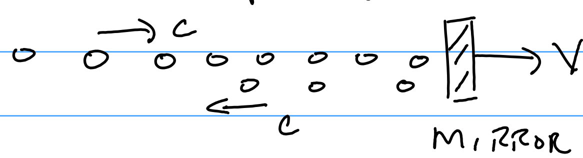
InkSurvey question for Friday



How can there be a force on a wire if the electrons are free to move?

Example: conservation of photons in a laser beam reflecting from a moving mirror

Photons reflecting as a stream of particles 1-D



$\vec{J}_{in} = \rho_{in}\vec{v}_{in} \rightarrow \lambda_{in} c$

$J_{reflected} = \rho_{ref}\vec{v}_{ref} \rightarrow \lambda_{ref} c$

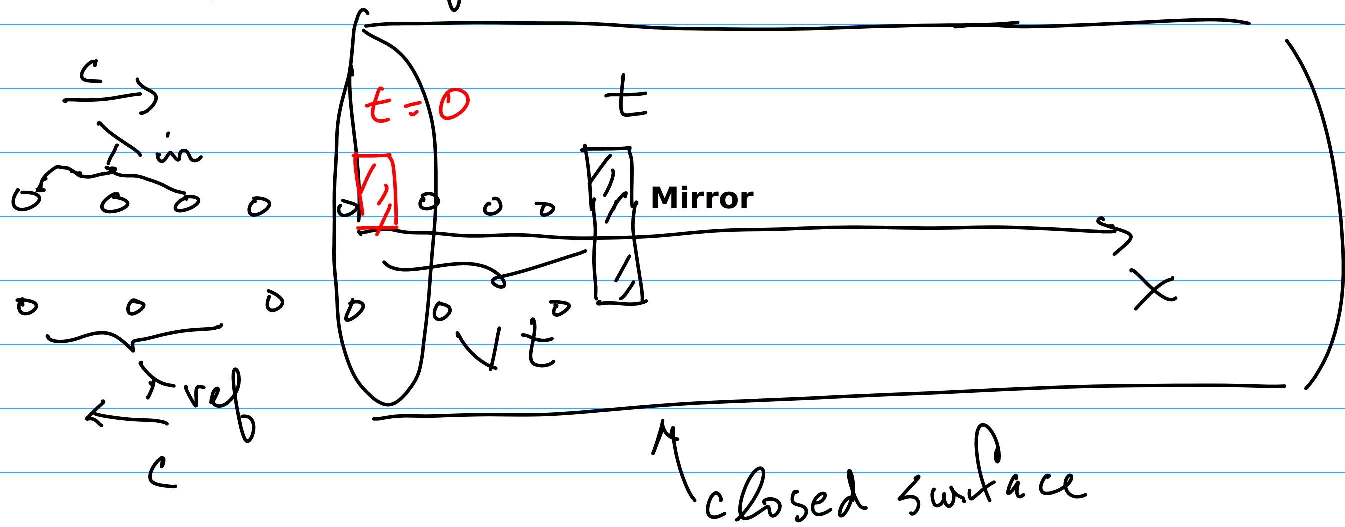
Model

$\vec{J}_{in} = \lambda_{in} c \hat{x}$

$\vec{J}_{ref} = -\lambda_{ref} c \hat{x}$

Reality

$10^{14} \frac{\text{photons}}{\text{sec}} \pm \sqrt{10^{14}}$



Conservation eqn?

$J_{in} - J_{ref} = \frac{\partial N_{inside}}{\partial t}$ ← time rate of change of # inside

J_{in} ↑ flux of particles into surface

J_{ref} ↑ flux of particles out surface

$$\lambda_{in} c - \lambda_{ref} c = \frac{d}{dt}(\lambda_{in} + \lambda_{ref}) vt = (\lambda_{in} + \lambda_{ref}) v$$

$$\lambda_{ref} = \frac{c-v}{c+v}\lambda_{in} = \frac{c(1-v/c)}{c(1+v/c)}\lambda_{in} \simeq \lambda_{in}\left(1 - \frac{2v}{c}\right)$$

$$J_{ref} = J_{in}\left(1 - \frac{2v}{c}\right)$$

Series approx in $\delta = \frac{v}{c}$

Use Series in Mathematica

Photodetector (photodiode or photomultiplier) measures photon flux

Questions:

Incongruous:

How can this be correct since light is a wave?

Congruous:

How do I apply the continuity equation if the reflection is not normal to the surface of the mirror?

Modifying:

How do I calculate conservation of photon number if the mirror accelerates?

How does the calculation change if particles with non-zero rest mass are used?

Generalizing/Analogy:

How does this model match the classical electromagnetic wave model?

Causal/Creative:

How do I change from conservation of number to conservation of energy?

How do I change from conservation of number to conservation of momentum?

Informational:

How many photons per second are emitted by a He-Ne laser?