FLIP TANEDO
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EUCALYPTO RM 240
SEC: TUE 7-8pm Hew 103
OH: SUN 8-9pm Var 3rd FLOOR

ANNOUNCEMENT
- NEXT TUE (4/11) SECTION TIME SHIFTED TO ______, VARIAN 3RD FLOOR CONF. ROOM
- OFFICE HOURS :
  OR BY APPT.

AGENDA - ask for Q's first!
WELCOME - NAMES (YR, SUMMER PLANS, DORM)
INTRO TO ME : WHY I'M A BAD TA / WHY I'M A GOOD TA
- UG → BUT I WAS EXACTLY IN YOUR SHOES (SAME PROF, EVEN!)
- DON'T KNOW AS MUCH → BUT I'M EXCITED ABOUT LEARNING IT
- YOUNGER → COOLER! (ADVICE re. GRAD SCHOOL PATH)

ABOUT P121 W/ PROF. SHEN (TAKE SUGGESTIONS ON DIS SEC FORMAT)
REVIEW OF WHAT YOU SHOULD KNOW ← & ORGANIZATIONAL
- HW POLICY & HONOR
- SECTION : WHICH ONE
- SUGGESTIONS → ALL PRACTICE? NEW MAT? HARD STUFF? RANDOM?

CH. 8 : CONSERVATION LAWS
EXTRA: FAILURE OF CLASSICAL MECH & WHY IT MATTERS TODAY

OH VS. SECTION; STUDY GRPS

P121 W/ PROF. SHEN - UNSOLICITED ADVICE
HERE ARE MY SUGGESTIONS/THOUGHTS ON P121 AS A FORMER STUDENT

- P121 BECOMES SIGNIFICANTLY MORE TECHNICAL THAN P120
  - → EQUATIONS GET LONGER & UGLIER
  - → CALCULATIONS & PROOFS REQUIRE MORE TIME TO DIGEST
  - → THIS IS NOT MATERIAL YOU SAW IN THE 60-SERIES
  - ⇒ MAKE SURE YOU ARE COMFORTABLE WITH THE MATHEMATICAL TOOLS OF P120 (VECTOR CALCULUS, FOURIER SERIES, PDEs, etc)
  - ⇒ DO NOT GET LOST IN TEDIOUS MATH / MANIPULATION OF EQUATIONS
  - ⇒ UNDERSTAND THE UNDERLYING PHYSICS

- LECTURES FOLLOW THE BOOK'S OUTLINE W/ PROF SHEN'S OWN COMMENTARY
  - ⇒ ADAPT YOUR LEARNING STYLE TO ACCOMODATE THIS
    eg. JOT DOWN NOTES IN YOUR BOOK (VS. IN A SEPARATE NOTEBOOK)
  - ⇒ READ CHAPTERS AHEAD OF TIME, SO YOU CAN USE LECTURE AS A PLACE TO ASK QUESTIONS ABOUT DIFFICULT DERIVATIONS & CONCEPTS. (ALSO, THIS ALLOWS YOU TO BETTER PICK UP ON THE INSIGHT PROF SHEN OFFERS)

- MATERIAL IN THIS CLASS FORMS THE CORE OF THE MOST DIFFICULT PHYSICS GRE PROBLEMS
  - ⇒ LEARN THE PHYSICS INSTEAD OF MEMORIZING EQUATIONS

- 1 HR 15 MIN CLASSES ARE LONG
  - ⇒ IF THE WHOLE CLASS IS ZONING OUT AFTER AN HOUR, ASK FOR A 5 MIN BREAK AFTER 40 MINS.
  - ⇒ BRING A SNACK

OTHER BOOKS ON E&M THAT MAY BE USEFUL

- MICHAEL PESKINS P120-121-124 LECTURE NOTES (ONLINE)
- JACKSON, CLASSICAL ELECTRODYNAMICS
  - ⇒ FETTER PHYS 220/221 COURSE READER (like cliff's notes for Jackson) } slightly different approach (more formal PDE background)
- LANDAU & LIFSHITZ, THE CLASSICAL THEORY OF FIELDS (for those who have had GR)
- YOUR FAVORITE ADVANCED PROBLEM BOOK (eg. UM, PRINCETON, etc)
- FEYNMAN LECTURES, VOL II

REVIEW OF E&M UP TO NOW

SEE GRIFFITH'S "INTERMISSION" COMMENT P. 343

$$\nabla \cdot \vec{E} = \frac{1}{\epsilon_0}\rho \qquad \leftarrow \text{GAUSS' LAW}$$

$$\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t} \qquad \leftarrow \text{FARADAY'S LAW}$$

$$\nabla \cdot \vec{B} = 0 \qquad \leftarrow \text{NO MAGNETIC SOURCES/SINKS (MONOPOLES)}$$

$$\nabla \times \vec{B} = \mu_0 \vec{J} + \mu_0 \epsilon_0 \frac{\partial \vec{E}}{\partial t} \qquad \leftarrow \text{AMPERE'S LAW + DISPLACEMENT}$$

"DISPLACEMENT CURRENT" (ANALOG OF FARADAY'S LAW)

$$\vec{F} = q(\vec{E} + \vec{v} \times \vec{B}) \qquad \text{FORCE LAW}$$

$$\nabla \cdot \vec{J} = -\frac{\partial \rho}{\partial t} \qquad \text{CONTINUITY (CONSERVATION OF CHARGE)}$$

(derived from $\nabla \times \vec{B}$ & $\nabla \cdot \vec{E}$ eqns)

WE ALSO KNOW THAT THINGS BECOME MORE COMPLICATED IN MATTER (INTRODUCE NEW FIELDS $\vec{D}$, $\vec{H}$; MUST SPECIFY BOUNDARY CONDITIONS.)

BUT, IN PRINCIPLE, THIS IS THE HEART OF THE PHYSICS THAT YOU'VE LEARNED.

YOU HAVE ALSO LEARNED IMPORTANT MATHEMATICAL TOOLS:
- VECTOR CALCULUS
- PDE'S: LAPLACE/POISSON EQ., SEPARATION OF VARS (↓ Fourier Series), MULTIPOLE EXPANSION
- ALSO "TRICKS": METHOD OF IMAGES (preview of GREEN'S FUNCTIONS)
  GAUSS LAW & AMPERE'S LAW (i.e. SYMMETRY)
  → YIELD PHYSICAL INSIGHT

★ YOU SHOULD BE COMFORTABLE W/ ALL OF THIS; IF NOT → O.H./REVIEW OLD HW

★ TOGETHER W/ NEWTONIAN MECHANICS, THIS FORMS BASIS OF CLASSICAL MECH
"ALL THAT REMAINS TO BE DONE IS TO CALCULATE EXTRA DECIMALS ..."

Chapter 8 - Conservation Laws

MANY OF THE DERIVATIONS IN THIS SECTION (well, ONE IN PARTICULAR) ARE MATHEMATICALLY TEDIOUS!

YOU SHOULD:

(1) UNDERSTAND THE LITTLE MATHEMATICAL TRICKS USED IN GRIFFITHS
(2) **NOT** SPEND TOO MUCH TIME ON IT!!

(3) REALLY UNDERSTAND THE PHYSICS (INTUITION) INVOLVED

SINCE THIS IS THE 1st SECTION & I'M NOT SURE WHERE PEOPLE ARE & WHAT YOU WANT ME TO DO, I'LL BRIEFLY REVIEW THE KEY IDEAS OF CH. 8

POYNTING VECTOR: $\vec{S} \equiv \frac{1}{\mu_0}(\vec{E}\times\vec{B})$

= ENERGY per TIME per AREA CARRIED BY EM FIELDS

→ DO YOU UNDERSTAND WHY IT IS A VECTOR?
→ WHAT DOES S_x MEAN? $\vec{S}\cdot d\vec{a}$?

POYNTING THM = CONSERVATION OF ENERGY

$$\frac{d}{dt}\int_V (u_{mech} + u_{em})\, d\tau = -\oint_S \vec{S}\cdot d\vec{a}$$

$$\frac{dW}{dt} = \frac{d}{dt}\int_V u_{mech}\, d\tau \qquad u_{em} = \frac{1}{2}\left(\epsilon_0 E^2 + \frac{1}{\mu_0}B^2\right)$$

or: $$\boxed{\frac{\partial}{\partial t}(u_{mech} + u_{em}) = -\nabla\cdot\vec{S}}$$

Physics: FIELDS THEMSELVES CARRY ENERGY
next step: " " " MOMENTUM

ONE STEP MORE COMPLICATED

(LOOKS LIKE HORNS → SCARY NOTATION)

MAXWELL STRESS TENSOR T_{ij} or $\overleftrightarrow{T}$

= momentum in i^{th} dir carried by fields in j^{th} dir (per unit time)

P_i

OR FORCE PER AREA IN i^{th} dir carried in j^{th} dir

"MOMENTUM FLUX DENSITY"

WARNING: THE MATH INVOLVED IN WRITING THE COMPONENTS OF T_{ij} IS NASTY! DON'T GET BOGGED DOWN IN IT.

JUST AS POYNTING VECTOR WAS USED TO DESCRIBE THE FLUX OF ENERGY ($\rightarrow$ CONS OF E),

T_{ij} USED TO DESCRIBE FLUX OF MOMENTUM ($\rightarrow$ CONS OF $\vec{p}$)

PUNCHLINE: $\frac{\partial}{\partial t}(\vec{\wp}_{MECH} + \vec{\wp}_{EM}) = \nabla \cdot \overleftrightarrow{T}$

$\vec{\wp}_{MECH}$: DENSITY OF (MECH) MOMENTUM

$\vec{\wp}_{EM}$: $\mu_0 \epsilon_0 \vec{S}$

next step: ANGULAR MOMENTUM: $\vec{l}_{em} = \vec{r} \times \vec{\wp}_{em}$

SEE EXAMPLE 8.4.

EXAMPLE 8.2

YOU SHOULD BE TRYING THESE ON YOUR OWN!

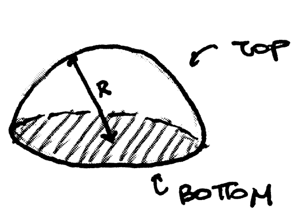
Q: DETERMINE NET FORCE ON NORTHERN HEMISPHERE OF CHARGED BALL OF RADIUS R, CHARGE Q.

$$\vec{F} = \oint_S \overleftrightarrow{T} \cdot d\vec{a} - \epsilon_0 \mu_0 \frac{d}{dt} \int_V \vec{S}\, d\tau \qquad (8.22)$$

What is $\vec{S}$? $= 0$ (statics. great.)

SO NOW WE CARE ABOUT $\overleftrightarrow{T}$ ON S.

$\vec{B} = 0$, NEED TO DETERMINE $\vec{E}$.



$$E_{top} = \frac{1}{4\pi\epsilon_0} \frac{Q}{R^2} \hat{r}$$

$$\hat{r} = \sin\theta \cos\phi\, \hat{x} + \sin\theta \sin\phi\, \hat{y} + \cos\theta\, \hat{z}$$

$\Rightarrow$ PLUG IN E_x, E_y, E_z INTO FORMULAE FOR T_{ij}

$$T_{xx} = \frac{1}{2}\epsilon_0 (E_x^2 - E_y^2 - E_z^2) + (\text{B terms})$$
$$T_{xy} = \epsilon_0 (E_x E_y) + (\text{B terms})$$

WE ONLY WANT FORCE IN $\hat{z}$ DIRECTION

$$(\overleftrightarrow{T} \cdot d\vec{a})_z = T_{zx}\, da_x + T_{zy}\, da_y + T_{zz}\, da_z = \frac{\epsilon_0}{2}\left(\frac{Q}{4\pi\epsilon_0 R}\right)^2 \sin\theta \cos\theta\, d\theta\, d\phi$$

What about the BOTTOM? INSIDE SPHERE

$$\rightarrow \vec{E} = \frac{1}{4\pi\epsilon_0}\frac{Q}{R^3}\hat{r} \qquad \text{(REMEMBER?)}$$

$$= \frac{1}{4\pi\epsilon_0}\frac{Q}{R^3}(\cos\phi\,\hat{x} + \sin\phi\,\hat{y})$$

$T_{zx} = T_{zy} = 0$ SINCE $E_z = 0$

$$T_{zz} = -\frac{\epsilon_0}{2}\left(\frac{Q}{4\pi\epsilon_0 R^3}\right)^2 r^2$$

$$(\overleftrightarrow{T}\cdot d\vec{a})_z = +\frac{\epsilon_0}{2}\left(\frac{Q}{4\pi\epsilon_0 R^3}\right)^2 r^2\,(r\,dr\,d\phi)$$

↑ ORIENTATION OF $d\vec{a}$

NOW INTEGRATING TO GET $\vec{F}$

$$\vec{F} = \oint_S \overleftrightarrow{T}\cdot d\vec{a} - \epsilon_0\mu_0\frac{d}{dt}\int_V \vec{S}\,d\tau \rightarrow 0$$

$$= \oint_{TOP}(\overleftrightarrow{T}\cdot d\vec{a})_{TOP} + \oint_{BOT}(\overleftrightarrow{T}\cdot d\vec{a})_{BOT}$$

$$= \frac{\epsilon_0}{2}\left(\frac{Q}{4\pi\epsilon_0 R}\right)^2 2\pi\int_0^{\pi/2}\sin\theta\cos\theta\,d\theta + \frac{\epsilon_0}{2}\left(\frac{Q}{4\pi\epsilon_0 R^3}\right)^2 2\pi\int_0^R r^3\,dr$$

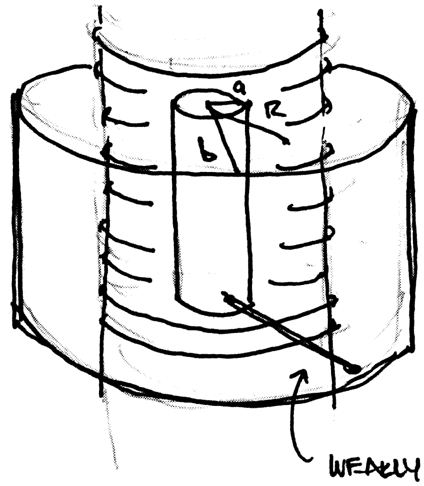
$$= \frac{1}{4\pi\epsilon_0}\frac{Q^2}{8R^2} + \frac{1}{4\pi\epsilon_0}\frac{1}{16R^2}$$

$$= \frac{1}{4\pi\epsilon_0}\frac{3Q^2}{16R^2}$$

one note: could have picked any other surface that doesn't enclose extra charge!

(SEE P. 354)

HINT ON # 8.7



WEAKLY CONDUCTING (→ NO DISPLACEMENT $\vec{E}$)

WHAT IS THE $\vec{B}$?
WHAT IS THE FORCE ON THE WIRE? ($d\vec{F}(d\vec{\ell})$)
WHAT IS THE TORQUE? ($\int \vec{r} \times d\vec{F}$)

WHAT IS THE ANGULAR MOMENTUM? ($\vec{L} = \int \vec{N}\, dt$)

COMPARE W (8.35)
↳ WHAT DOES YOUR INTUITION SAY?