Final EXAM:

E, M & Radiation

Physics 204

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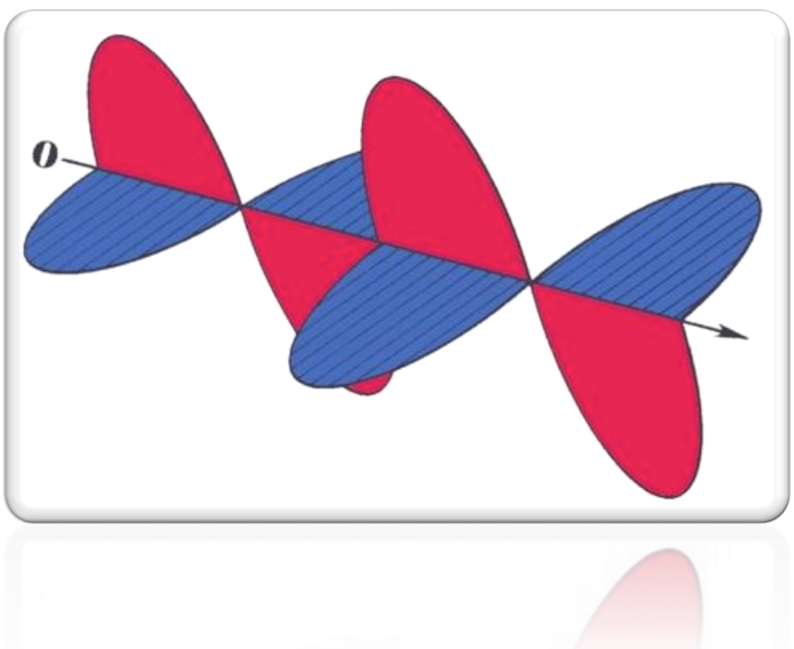
<u>**Email Subject Line: "P204FinalSU14:yourname"**</u>



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Section #: ____________

SCORE: ____________

SOME USEFUL RELATIONS:

1) $\oint \vec{E} \cdot \overrightarrow{da} = \frac{q_{(enc)}}{\varepsilon_0}$.

2) $\oint \vec{B} \cdot \overrightarrow{da} = 0$.

3) $\oint \vec{E} \cdot \overrightarrow{dl} = -\frac{d}{dt}\int \vec{B} \cdot \overrightarrow{da}$.

4) $\oint \vec{B} \cdot \overrightarrow{dl} = \mu_0 I_{(enc)} + \mu_0 \varepsilon_0 \frac{d}{dt}\int \vec{E} \cdot \overrightarrow{da}$.

5) $\vec{E} = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}\hat{r}$.

6) $\vec{F}_E \equiv q\vec{E}$.

7) $\vec{B} = \frac{\mu_0}{4\pi}\frac{q}{r^2}\vec{v} \times \hat{r}$.

8) $\vec{F}_B \equiv q\vec{v} \times \vec{B} = \vec{I}l \times \vec{B}$.

9) $V_a - V_b \equiv \int_a^b \vec{E} \cdot \overrightarrow{dr}$.

10) $C \equiv \frac{Q}{\Delta V}$. (Note: This "C" is capital.)

11) $I \equiv \frac{dq}{dt}$

12) $I = \frac{\Delta V}{R}$.

13) $\mathcal{E} - IR - \frac{Q}{C} = 0$. (Capital "C".)

14) $c \approx 3\ x\ 10^8\ m/s$.

15) $n \equiv \frac{c}{v}$. (Lower-case "c".)

16) $n_1 \sin\theta_1 = n_2 \sin\theta_2$.

17) $\frac{Yd}{L} = \frac{n\lambda}{2}$

18) $sin^2\theta + cos^2\theta = 1$.

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19) $\bar{v} \equiv \frac{\Delta x}{\Delta t}$.

20) $\Delta\, t' = \frac{\Delta t}{\sqrt{1-\frac{v^2}{c^2}}}$. Lower-case “c”. Bold-face conclusion.

21) $\sum \vec{F} = m\vec{a}$.

22) $F = -Kx$.

23) $x = Acos(\omega t)$.

24) $\omega = 2\pi f$.

25) $f = \frac{1}{T}$.

26) $KE = \frac{1}{2}mv^2$

27) $PE_{elastic} = \frac{1}{2}Kx^2$

28) $v = \lambda f$.

29) $v = \sqrt{\frac{T}{\mu}}$.

30) $\frac{\partial^2 y}{\partial t^2} = (v^2)\frac{\partial^2 y}{\partial x^2}$.

31) $L = \frac{n\lambda}{2}$.

32) $\Delta l = \frac{n\lambda}{2}$.

34) $\epsilon_0 \approx 8.85\ x\ 10^{-12}\ \frac{C^2}{Nm^2}$.

35) $\mu_0 \approx 1.26 \times 10^{-7}\ \frac{N}{A^2}$.

36) $m_e \approx 9.11\ x\ 10^{-31}$ kg.

37) $q_e \approx 1.60\ x\ 10^{-19}\ C$.

SCORE: ________________

DIRECTIONS

The following pages contain **100** points worth of physics.

Solve anything and everything you can.

Make the ORIGINAL &
AUTHENTIC UNDERSTANDING

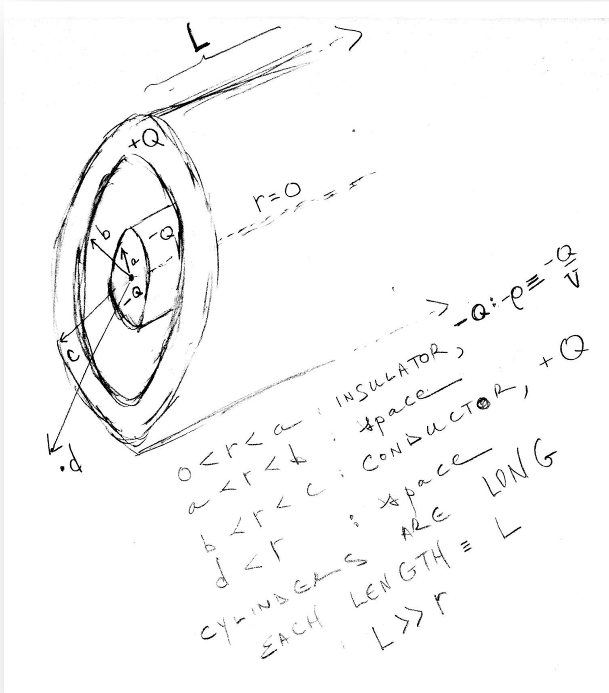
OF YOUR WORK

AS EXPLICIT AND CONVINCING AS POSSIBLE.

May the field be with you.

SCORE: ______________

I. Electrostatics (from a continuous charge distribution) (45 pts).



The above depicts the face-on view (cross-section) of a set of concentric ***CYLINDERS***, EACH of LENGTH ***L.***

The innermost cylinder, radius ***a***, is made of ***insulating*** material.
This ***insulator*** contains a net ***negative*** charge of ***-Q.***
The net ***negative*** charge, ***-Q***, is uniformly distributed throughout the ***cylinder***; $-\boldsymbol{\rho} \equiv \frac{-Q}{V}$.

Outside the ***insulating cylinder***, there is some empty space (vacuum):
Here, there is simply no material to contain charges of any kind.
The space extends from radius ***a*** to a larger radius, ***b***.

Both the ***insulating cylinder*** and the space are surrounded by a ***cylindrical shell***—inner radius, ***b***, outer radius ***c***.

This ***cylindrical shell*** is made of ***conducting material***.
The conducting ***shell*** contains a net ***positive*** charge of +***Q.***

Point ***d*** refers to an arbitrary location of interest fully outside the entire arrangement configuration of cylinder within shell.

This entire configuration has been sitting on a lab table for a long time; it is electrically stable.

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a) Quickly sketch a simplified version of the diagram above. Then draw +'s and –'s to ***indicate where*** all ***charges are*** located (2 pts).

b) Use your simplified sketch above. ***Draw*** properly representative ***field lines*** anywhere they apply. Draw enough lines to provide a clear sense of ***direction and*** comparative ***magnitude*** (3 pts).

c) Determine the magnitude of the ***electric field*** as a function of position (measured out from the insulator's central axis) for each of the following regions:

i. b < r < c: $\boldsymbol{E}(\boldsymbol{r}) = ?$ (5 pts.)

ii. a < r < b: $\boldsymbol{E}(\boldsymbol{r}) = ?$ (5 pts.)

SCORE: ______________

iii. 0 < r < a: $\boldsymbol{E(r)} = ?$ (3 pts.)

iv. d < r: $\boldsymbol{E(r)} = ?$ (2 pts.)

d) Determine the ***electric potential difference*** as a function of position across each of the following regions. If it helps you, you may assume that $V \to 0 \; as \; r \to \infty$.

i. V(a) – V(0) = ? (5 pts.)

ii. V(0) – (b) = ? (5 pts.)

SCORE: _______________

iii. V(b) – (c) = ? (3 pts.)

iv. V(0) – V(d) = ? (2 pts.)

v. V(d) – V(0) = ? (3 pts.)

vi. V(0) – $V(\infty)$ = ? (2 pts.)

e) Find ***C***, the ***capacitance*** of this physical arrangement:
Specifically, find ***C*** between ***r*** = ***0*** and ***r*** = ***d*** (3 pts).

(We say ***d***, rather than **c**, just to make absolutely certain that we account for every possible bit of material, charge and space included in this arrangement.)

Your answer will be expressed in terms of given and fundamental constants.

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Now assume the following:

a = 5 cm.
b = 10 cm.
c = 8 cm.
L = 300 cm.

The center of the ***insulating cylinder*** is connected by wire to a ***150 ohm resistor***.
The other end of this resistor is connected to the negative terminal of a ***battery***.
The positive terminal of the battery is connected to the ***conducting shell***.

f) Draw a circuit diagram for this new situation. You may use the standard symbol for capacitor even though this capacitor happens not to be composed of plates (2 pts).

g) From the moment the wires are all connected, current flows. As it flows, its rate of flow continuously slows down.

From the moment the wires are all connected, how much time will pass until this current decays to 1 ***pi***th (approx.. $\frac{1}{3.14...}$) of its initial value (5 pts)?

THIS ANSWER WILL BE NUMERICAL – and should be expressed with appropriate units.

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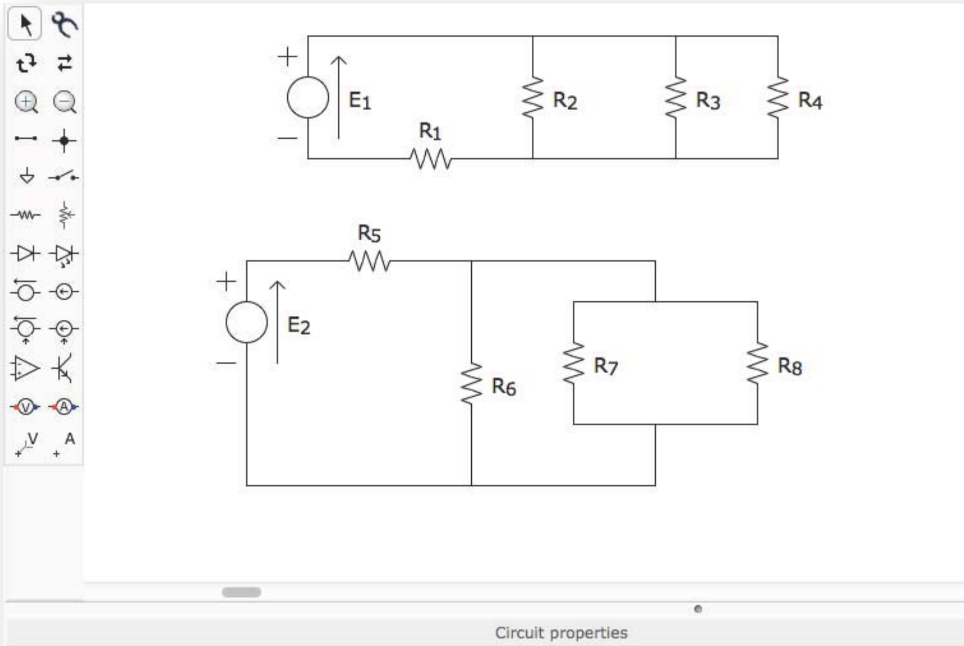
II. A CIRCUIT (20 pts).

A. Examine the following two circuits (Values given under “Circuit Properties”.)



E1	E2	15 Volts
R1	R5	300 Ohms
R2	R6	60 Ohms
R3	R7	50 Ohms
R4	R8	175 Ohms

Is the ***potential difference*** across through R4

Greater than that through R8,
Less than that through R8
OR
The same in both? In a complete English sentence or two, explain! (4 pts.)

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B. For JUST THE FIRST of the two circuits, determine:

i. The ***current*** flowing through each and every RESISTOR (8 pts: 2 pts each).

I (R1):

I (R2):

I (R3):

I (R4):

SCORE: _______________

ii. The ***potential difference*** across each and every RESISTOR (8 pts: 2 pts each).

ΔV (R1):

ΔV (R2):

ΔV (R3):

ΔV (R4):

SCORE: ______________

III. **B-Fields** (20 pts).

A. Use AMPERE's LAW in order to determine the ***magnetic field*** as a function of ***position***
near a LONG, STRAIGHT CURRENT-CARRYING WIRE, $\boldsymbol{I}$ (10 pts).

DRAW AN APPROPRIATE and fully labeled DIAGRAM!

That is, determine $\vec{\boldsymbol{B}}(\boldsymbol{r})$.

B. Use the DIRECTIONS demanded by the ***Biot-Savart*** and ***Lorentz Force Laws*** to explain a historical and common every-day finding:
WHY do two cylindrical bar magnets placed near each other in a certain orientation attract, yet repel once one magnet is rotated 180 degrees (10 pts)?

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IV. Electromagnetic Radiation (15 pts).

FIND & CORRECT ***AT LEAST FOUR IMPORTANT MISTAKES***
IN THE FOLLOWING ARGUMENT. (There are more than 4.)

THE MORE SPECIFICALLY YOU CAN EXPLAIN THE MEANING and/or
SIGNIFICANCE OF THE MISTAKES, the more points you will gain!

*** The Argument →

According to Faraday's Law for Electromagnetic Induction:

$$\oint \vec{E} \cdot \overrightarrow{dl} = -\frac{d}{dt}\int \vec{B} \cdot \overrightarrow{da}.$$

One reasonable way to express the meaning of Faraday's Law is this:

An ***electric field***
will be induced through the ***closed path***
bounding some ***open area***
whenever the ***magnetic flux***
through that area
changes as a ***function of time.***

With the inclusion of Maxwell's Displacement Current, the corrected and most general possible version of Ampere's Law becomes:

$$\oint \vec{B} \cdot \overrightarrow{dl} = \mu_0 I_{(enc)} + \mu_0 \varepsilon_0 \frac{d}{dt}\int \vec{E} \cdot \overrightarrow{da}.$$

One reasonable way to express the meaning of Maxwell's Corrected (version of) Ampere's Law is this:

a ***magnetic field***
will be induced through the ***closed area***
bounding some ***open volume***
whenever the ***electric flux***
through that area
changes as a ***function of time***.

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We can then look at what must be true in the free space—far away from any pieces of charge or current. There, the four Maxwell's Equations become:

$$1)\ \oint \vec{E} \cdot \overrightarrow{da} = 0.$$

$$2)\ \oint \vec{B} \cdot \overrightarrow{da} = 0.$$

$$3)\ \oint \vec{E} \cdot \overrightarrow{dl} = \frac{d}{dt} \int \vec{B} \cdot \overrightarrow{da}.$$

$$4)\ \oint \vec{B} \cdot \overrightarrow{dl} = \mu_0 \varepsilon_0 \frac{d}{dt} \int \vec{E} \cdot \overrightarrow{da}.$$

Rearranging ("decoupling") the equations so that we can look at electric fields on their own and magnetic fields on their own,
and assuming that ***A*** stands for some sort of space variable
(like x, but more general, so that it can include 2 or 3-dimensional space coordinates),

We find:

$$\frac{\partial^2}{\partial A^2} \vec{E} = \mu_0 \varepsilon_0 \frac{\partial^2}{\partial t^2} \vec{B}$$

and

$$\frac{\partial^2}{\partial A^2} \vec{B} = \mu_0 \varepsilon_0 \frac{\partial^2}{\partial t^2} \vec{E}.$$

That is, we find:

Any Current that oscillates harmonically
(like $I = I_0 \cos(\omega t)$)
will create a Electric Field that oscillates harmonically
(like $E = -E_0 \sin\omega t)$).
Any Electric Field that oscillates harmonically
will induce an Magnetic Field that oscillates harmonically
(like $B = -B\cos{(\omega t)}$)
which will induce a Electric Field that oscillates harmonically…

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And the oscillating Electric and Magnetic Fields
will continue to
induce each other,
each field making
a 90 degree
right-hand turn from the other

so that these patterns of oscillations
necessarily travel through space
out and away from any source charge or source current.

As stated above, these traveling field oscillations perpetually obey

$$\frac{\partial^2}{\partial A^2}\vec{E} = \mu_0\varepsilon_0\frac{\partial^2}{\partial t^2}\vec{E}$$

and

$$\frac{\partial^2}{\partial A^2}\vec{B} = \mu_0\varepsilon_0\frac{\partial^2}{\partial t^2}\vec{B};$$

The fields are therefore solutions to equations of the same form as:

$$\frac{\partial^2}{\partial t^2}y = v^2\frac{\partial^2}{\partial y^2}x$$

The mutually inducing perpendicular fields therefore
travel through space as three-dimensional WAVES for which

$$v = \frac{1}{\sqrt{\mu_0\varepsilon_0}} = \boldsymbol{c}$$

Since the medium for these waves are fields,
And since all fields extend infinitely through all space,
these waves travel at a speed
which is constant
relative to
all of space.

Thus, the head-***light*** from an express train travels at ***c***
relative to observers on that speeding train, yet also
travels at (that same) ***c***
relative to observers on the platform.

(And this, therefore, is either the beginning of the end or the end of the beginning.)

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