Physics 202, Lecture 7

Today’s Topics

- Middle Term 1 Review

About Exam 1

- When and where
  - Monday Sept. 27th 5:30-7:00 pm
  - 2301, 2241 Chamberlin (room allocation to be announced)

- Format
  - Close book
  - One 8x11 formula sheet allowed, must be self prepared, no photo copying/download-printing of solutions, lecture slides, etc.
  - 20-25 multiple choice questions
  - Bring a calculator (but no computer). Only basic calculation functionality can be used.
  - Bring a B2 pencil for Scantron.

- Special requests:
  - Must have been approved by now.
  - All specially arranged tests (e.g. those at alternative time) are held in our 202 labs. (for approved requests only)

Chapters Covered

- Chapter 23: Electric Fields
- Chapter 24: Gauss’s Law
- Chapter 25: Electric Potential

I will not post past/sample exams as none that I can find are representative. Often those can be misleading.

Exercises in this review may give you hints on level and style of the test problems.

Disclaimer

- This review is a supplement to your own preparation.
- Hints and exercises presented in this review are not meant to be complete.
Exam Topics (1)
- Key concepts
  - “key”: those in “Concepts and Principles” box at the end of each chapter
- Basic Quantities:
  - Electric Charge
  - Electric Charge
  - Electric Force
  - Electric Field, Field Lines
  - Electric Flux
  - Electric Potential
  - Electric Potential Energy

Exam Topics (2)
- Electric charge
  - Two types
  - Total charge is conserved.
- Electric force
  - Can be attractive/reputitive
  - Coulomb’s Law
- Electric field
  - Electric field is a form of matter, it carries energy.
  - Electric field is independent of test charge.
  - Electric field is a vector quantity.
  - Three ways to calculate electric field
    - direct vector sum, Gauss’s Law, derivative of V
  - \( F = qE \) (note: \( E \) does not include the one created by test charge \( q \))

Exam Topics (3)
- Electric potential energy.
  - Electric force is a conservative force
  - Electric potential energy depends on both the source and test charge.
  - Like all potential energies, the electric potential energy is relative to a certain reference state. (Usually, an “infinity” state is taken as \( U = 0 \).)
  - Energy conservation, work-kinetic energy theorem, etc. are applicable to electric potential energy too.
- Electric potential
  - Electric potential depends only on the source.
  - Electric Potential and Electric Field are closely related. \( E \leftrightarrow V \)
  - Electric potential \( V \) and electric potential energy \( U \) are different quantities.
  - Higher \( V \) does not necessarily mean higher \( U \).
  - Electric potential and Electric potential energy are related: \( U = qV \)

Exam Topics (4)
- Conductors and Electrostatic Equilibrium
  - Regardless of shape:
    - The electric field is zero inside the conductor.
    - All net charges reside on the surface of conductor.
    - \( E \) field on the surface of conductor is always normal to the surface, and has a magnitude of \( \frac{d\sigma}{dS} \)
    - The electric field is also zero inside an empty cavity within the conductor.
    - Potential is the same throughout the whole conductor (Equipotential)
Reminder: Three Ways to Calculate Electrostatic Field

- Superposition with Coulomb’s Law (first principle):
  \[ \vec{E} = k \sum_i \frac{q_i}{r_i^2} \hat{r}_i = k \int \frac{dq}{r} \hat{r} \]

- Apply Gauss’s Law:
  (Practical only for cases with high symmetry)
  \[ \Phi = \oint \vec{E} \cdot d\vec{A} = \sum_i \frac{q_i}{\varepsilon_0} \]

- From a known potential:
  \[ E = \frac{\partial V}{\partial x}, \quad E_y = \frac{\partial V}{\partial y}, \quad E_z = \frac{\partial V}{\partial z} \]

Exercise 1: Three Charges

A particle \( q_1 = 40 \mu C \) is located on the x axis at the point \( x = -20 \text{ cm} \), and a second particle \( q_2 = 50 \mu C \) is placed on the x axis at \( x = 30 \text{ cm} \). What is the magnitude of the total electrostatic force on a third particle \( q_3 = -4.0 \mu C \) placed at the origin \( (x = 0) \)? \( k_e = 9 \times 10^9 \text{ Nm}^2/\text{C}^2 \)

- a. 16 N
- b. 56 N
- c. 35 N
- d. 72 N

Solution:

\[ F_13 = k_e \frac{q_1 \cdot q_3}{r_{13}^2} = 36 \text{ N to the left} \]
\[ F_23 = k_e \frac{q_2 \cdot q_3}{r_{23}^2} = 20 \text{ N to the left} \]
\[ F = F_13 + F_23 = 36 + 20 = 56 \text{ N} \]

Questions that involve basic calculations like this one will make up of 70% of the exam.

I won’t do more exercises at this level in this review. Please practice more yourself on those fundamental formulas.

Exercise 2: Seven Point Charges

Six point charges are fixed at corners of a hexagon as shown. A seventh point charge \( q_7 = 2Q \) is placed at the center.

1. What is the force on \( q_7 \)?
2. What is the minimum energy required to bring \( q_7 \) from infinity to its current position at the center?

Solutions: (See board)

- First thoughts:
  - Point charges: Coulomb’s Law
  - Be aware of symmetry
  - Energy: \( \Delta U = q\Delta V \)

- In the test, questions will be converted to multiple choice type
- It belongs to the harder 30% portion of the exam

Exercise 3: Three shells of charge

As shown below three thin sphere shells have radius \( R, 2R, 4R \), and charges \( Q, -Q, 2Q \), respectively.

- Use Gauss’s law, find the electric field distribution

Solution:

- The setting is highly symmetrical
- Gauss’ surface will be concentric sphere

\[ \int \vec{E} \cdot d\vec{A} = 4\pi r^2 \vec{E} = \frac{1}{\varepsilon_0} q_{\text{enclosed}} \]

- \( 0 < r < R: \ q_{\text{enclosed}} = 0 \Rightarrow \vec{E} = 0 \)
- \( R < r < 2R: \ q_{\text{enclosed}} = Q \Rightarrow \vec{E} = \frac{Q}{4\pi \varepsilon_0 r^2} \)
- \( 2R < r < 4R: \ q_{\text{enclosed}} = Q - Q = 0 \Rightarrow \vec{E} = 0 \)
- \( 4R < r: \ q_{\text{enclosed}} = 2Q \Rightarrow \vec{E} = \frac{2Q}{4\pi \varepsilon_0 r^2} \)

Wait! Did I miss something? Don’t forget directions!
Quick Exercise: Charge Distribution On Conductors

The total charge on this conductor shell is $+5q$. A point charge of $+q$ is placed at the center ($r=0$). How is the charge distributed?

(shell radius: $r_{inner}=R$, $r_{outer}=2R$)

- $Q_{inner\_surface} = -q$, $Q_{outer\_surface} = 5q$, $Q_{body} = 0$
- $Q_{inner\_surface} = q$, $Q_{outer\_surface} = 4q$, $Q_{body} = 0$
- $Q_{inner\_surface} = 0$, $Q_{outer\_surface} = 5q$, $Q_{body} = 0$

Challenge to you
Are you able to calculate $E$ and $V$ at $r=0.5R, 1.5R, 2.5R$?
(discuss with your TAs if in puzzle)

Exercise 4: Potential and Field

The electric potential of a field is described by $V = 3x^2y + y^2 + yz$.

- Find the force on a test charge $q=1C$ at $(x,y,z)=(1,1,1)$

Solution:
First Thoughts:
- $E_x = \frac{dV}{dx} = -6x$ @ $(1,1,1)$
- $E_y = \frac{dV}{dy} = -(3x^2 + 2y + z) = -6$ @ $(1,1,1)$
- $E_z = \frac{dV}{dz} = -y = -1$ @ $(1,1,1)$

$(F_x, F_y, F_z) = qE = (-6, -6, -1)$ N

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Reminder: A Picture to Remember

- Field lines always point towards lower electric potential
- Field lines and equal-potential lines are always at a normal angle.
- In an electric field:
  - A $+q$ is always subject a force in the same direction of field line.
    (i.e. towards lower V)
  - A $-q$ is always subject a force in the opposite direction of field line.
    (i.e. towards higher V)

Exercise 5: Potential, Field, and Energy

The equal potential lines surrounding two conductors, $+10V$ and $+15V$, are shown below.

- Draw on the figure the direction of electric field at point C
- If a charge of $Q=+0.5C$ is to be moved from point B to C, how much work is required?

$W_{B\rightarrow C} = U_B - U_C = Q(V_C - V_B) = 0.5 \times (12 - 9) = 1.5J$

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Exercise 6: Electric Potential Energy

- A charged non-conducting ring of radius R has charge $-Q$ distributed on the left side and $2Q$ distributed on the right side.
  - How much energy is required to bring a point charge $q=0.5Q$ from infinity to the center of the ring

Solution: See board

First Thought:
Energy required = external work required to bringing in $q$.

Follow up: How to calculate work?
- integral $dw=Fds$ (won't work, too complicated)
- use energy conservation & the idea of electric potential

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