PHYS 2025
Test #1
Fall 2009 (Buckley)

This test is broken into two parts – the first is more qualitative and is a combination of multiple choice, fill-in-the-blank, and short answer questions. The second part is the problem-solving area.

For multiple choice answer questions, simply circle the letter corresponding to the best answer. Unless indicated otherwise, multiple choice/short answer questions are worth two points each.

1. Consider two positive charges, \( Q_1 \) and \( Q_2 \), separated by a distance \( r \). If the distance between the two charges is tripled, the force of repulsion will
   a. remain unchanged
   b. increase by a factor of three
   c. decrease by a factor of nine
   d. decrease by a factor of three
   e. increase by a factor of nine

   \[
   F = \frac{k \cdot Q_1 \cdot Q_2}{r^2} \quad \text{(triple)}
   \]

2. Two charges experience a force between them of 180 N. If the charge of one of the charges is increased by a factor of 5, the other increased by a factor of two, and the distance between the charges is doubled, the new force between the charges is:
   a. 450 N
   b. 72 N
   c. 45 N
   d. 1800 N
   e. 900 N

   \[
   F = \frac{k \cdot Q_1 \cdot Q_2}{r^2} \quad \text{\Rightarrow} \quad \frac{5 \cdot Q_1 \cdot 2 \cdot Q_2}{(2r)^2} = \frac{10}{4} F
   \]

3. Which of the following exactly (no more, no less) all of the factors that will affect the electric field a distance \( r \) from a point charge \( Q \)?
   a. the size of the test charge used to evaluate the field and the size of \( Q \)
   b. the charge on \( Q \) and the distance \( r \)
   c. the size of the test charge used to evaluate the field and the distance \( r \)
   d. the charge on \( Q \), the distance \( r \), and the size of the test charge used to evaluate the field
   e. the distance \( r \)
4. How much work is done by the electric field in moving a 3.0 μC charge from 15.0 V to 4.0 V?

\[ W = -\Delta \rho E \]

\[ \Delta \rho E = (3.0 \times 10^{-6} \text{ C})(4.0 \text{ V} - 15.0 \text{ V}) = -3.3 \times 10^{-5} \text{ J} \]

\[ W = +3.3 \times 10^{-5} \text{ J} \]

a. \( 3.3 \times 10^{-5} \text{ J} \)

b. \( -3.3 \times 10^{-5} \text{ J} \)

c. \( 2.7 \times 10^{-7} \text{ J} \)

d. \( -2.7 \times 10^{-7} \text{ J} \)

e. \( 3.7 \times 10^6 \text{ J} \)

5. A dielectric inserted between the plates of a capacitor (check all that apply):

- [ ] allows greater charge to be held on the plates before breakdown
- [x] allows the plates to be closer together
- [ ] decreases the capacitance
- [ ] allows greater current to flow

6. Which of the following represents a possible unit for capacitance?

a. \( \text{J/V} \)

b. \( \text{C/V} \)

c. \( \text{J/C} \)

d. \( \text{C/s} \)

e. \( \text{N/C} \)

7. An electroscope is charged by induction. This means:

a. the electroscope is negatively charged

b. the electroscope is positively charged

c. [x] a charged rod is brought near the electroscope to charge it

d. a charged rod is brought into contact with the electroscope to charge it

8. Dielectric material A has a higher dielectric constant than material B. Which will produce the higher capacitance capacitor when placed between the plates of the same parallel plate capacitor?

- [x] Material A

- [ ] Material B
9. (5 points) The figure shows five enclosed surfaces that surround various charges in a plane, as indicated. Determine the electric flux through each surface, $S_1$, $S_2$, $S_3$, $S_4$, and $S_5$. The surfaces are flat "pillbox" surfaces that extend only slightly above and below the plane in which the charges lie.

\[
\mathbf{\int \mathbf{E} \cdot d\mathbf{A}} = \frac{Q_{net}}{\varepsilon_0}
\]

- $S_1$: $Q + (-3Q) = -2Q$
- $S_2$: $Q - 3Q + 2Q = 0$
- $S_3$: $2Q - 3Q = -Q$
- $S_4$: $0$
- $S_5$: $2Q$

10. (4 points) Objects $O_1$ and $O_2$ in the figure have charges of $+1.0 \mu C$ and $-2.0 \mu C$ respectively, and a third object $O_3$, is electrically neutral.

a. What is the electric flux through the surface $A_1$ that encloses all three objects?

\[
\phi_1 = \frac{Q_{enc}}{\varepsilon_0} = \frac{1.0 \mu C - 2.0 \mu C}{-1.0 \times 10^{-6} C} = -1.0 \times 10^5 \frac{N \cdot m^2}{C}
\]

b. What is the electric flux through the surface $A_2$ that encloses the third object only?

\[
\phi_{enc} = 0 \quad \oint \mathbf{E} \cdot d\mathbf{A} = 0
\]
Quantitative Part. Show your work on these problems. I might suggest setting up your work before getting your calculator out to make sure you have time to get started on all of them. Then go back and carry out the calculations.

Point totals are indicated in parentheses to the left of each problem number.

11. (5 points) A 5.0 \( \mu \text{C} \) charge is 45.0 cm to the left of a -8.0 \( \mu \text{C} \) charge. Find the force on both charges, being sure to include the magnitude and direction of each force.

\[
\text{FORCE ON 5.0 \( \mu \text{C} \) CHARGE: } F = k \frac{Q_1 Q_2}{r^2} = 9.0 \times 10^9 \frac{N \cdot m^2}{C^2} \left( \frac{5.0 \times 10^{-6} \text{C} \times 8.0 \times 10^{-6} \text{C}}{4.5 \text{m}} \right)^2 = 1.8 \text{ N TO THE RIGHT}
\]

\[
\text{FORCE ON -8.0 \( \mu \text{C} \) CHARGE: SAME MAGNITUDE TO THE LEFT.}
\]

12. (10 points)

a. A parallel plate capacitor is built with two conducting plates of dimensions 5 cm \( \times \) 10 cm and a gap between the plates of 2.0 mm. What would the capacitance of this capacitor be if the gap contains a vacuum? (For vacuum, \( k = 1 \))

\[
C = \frac{k \epsilon_0}{d} = \frac{1}{(8.85 \times 10^{-12} \text{ C}^2 \text{N}^{-1} \text{m}^{-1}) \times \frac{0.05 \text{ m} \times 0.10 \text{ m}}{0.002 \text{ m}}} = 2.2 \times 10^{-11} \text{ F}
\]

b. A capacitor of the same dimensions as in part a is now filled with paraffin with a dielectric constant of 2.2. Find the new capacitance of the capacitor.

\[
C = k \times \text{answer from part a} = 2.2 \times (2.2 \times 10^{-11} \text{ F}) = 4.8 \times 10^{-11} \text{ F}
\]

c. If a 10-V potential difference is applied to the capacitors in parts a and b, how much more charge can the capacitor in part b hold than the capacitor in part a?

\[
Q = CV
\]

For part a: \( Q = 2.2 \times 10^{-11} \text{ F} \times 10 \text{ V} = 2.2 \times 10^{-10} \text{ C} \)

For part b: \( Q = 4.8 \times 10^{-11} \text{ F} \times 10 \text{ V} = 4.8 \times 10^{-10} \text{ C} \)

\[
Q_b - Q_a = 4.8 \times 10^{-10} \text{ C} - 2.2 \times 10^{-10} \text{ C} = 2.6 \times 10^{-10} \text{ C}
\]
13. (10 points) Consider the following assembly of three charges. Find the electric field at point A being sure to give both the magnitude and direction.

**Field due to charge I:**

\[ E = k \frac{q}{r^2} = 9 \times 10^9 \frac{N m^2}{C^2} \frac{5 \times 10^{-6} C}{(0.20 m)^2} = 1.5 \times 10^7 \frac{N}{C} \text{ to the right.} \]

**Field due to charge II:**

\[ E = k \frac{q}{r^2} = 9 \times 10^9 \frac{N m^2}{C^2} \frac{20 \times 10^{-6} C}{(0.10 m)^2} = 1.8 \times 10^7 \frac{N}{C} \text{ to the left.} \]

Notice these two cancel out so the entire field is due to charge III.

**Field due to charge III:**

\[ E = k \frac{q}{r^2} = 9 \times 10^9 \frac{N m^2}{C^2} \frac{50 \times 10^{-6} C}{(0.15 m)^2} = 2.0 \times 10^7 \frac{N}{C} \text{ up.} \]
\[
\begin{array}{|c|}
\hline
\text{Equation} \\
\hline
F = k \frac{Q_1 Q_2}{r^2} = \frac{1}{4\pi \varepsilon_0} \frac{Q_1 Q_2}{r^2} \\
E = k \frac{Q}{r^2} = \frac{1}{4\pi \varepsilon_0} \frac{Q}{r^2} \\
V = k \frac{Q}{r} = \frac{1}{4\pi \varepsilon_0} \frac{Q}{r} \\
E = \frac{V_{bd}}{d} \\
C = \frac{Q}{V} \\
C = \varepsilon_0 \frac{A}{d} \\
C = \varepsilon_0 \frac{A}{d} \\
PE = \frac{1}{2} QV = \frac{1}{2} CV^2 = \frac{1}{2} \frac{Q^2}{C} \\
dE = \frac{1}{4\pi \varepsilon_0} \frac{dQ}{r^2} \text{ coupled with} \\
\vec{E} = \int \vec{dE} \\
\oint \vec{E} \cdot d\vec{A} = \frac{Q_{\text{net}}}{\varepsilon_0} \\
V = \frac{1}{4\pi \varepsilon_0} \int \frac{dq}{r} \\
\hline
\end{array}
\]

\( k = 9.0 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2 \)

\( \varepsilon_0 = 8.85 \times 10^{-12} \text{ C}^2/\text{N} \cdot \text{m}^2 \)

\( k = 1/4\pi \varepsilon_0 \)