Fundamental Charge $e = 1.602 \times 10^{-19}$ C
Earth's gravitational field $g = 9.81$ N/kg
Coulomb constant $K = 8.988 \times 10^9$ N·m²/C²
Speed of Light $c = 2.998 \times 10^8$ m/s

Mass of an Electron $m_e = 9.109 \times 10^{-31}$ kg
Mass of a Proton $m_p = 1.673 \times 10^{-27}$ kg
Vacuum Permittivity $\varepsilon_0 = 8.854 \times 10^{-12}$ C²/N·m²
Vacuum Permeability $\mu_0 = 4\pi \times 10^{-7}$ T·m/A

Unless otherwise directed, friction, drag, and gravity should be neglected, and all batteries and wires are ideal.
All derivatives and integrals in free-response problems must be evaluated.

Please remove this sheet from your Quiz or Exam
Recitation Sections

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<th>Clough 127</th>
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**Monday**

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<td>J06 Bapat, Chaitanya</td>
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<td>6:00 pm</td>
<td>G07 &amp; J07 Bernardes, Sarah</td>
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**Tuesday**

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<tr>
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<td>J08 Daum, Marcus</td>
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<td>3:00 pm</td>
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**Wednesday**

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<td>4:30 pm</td>
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**Thursday**

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<tr>
<td>3:00 pm</td>
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I. (16 points) An electron (mass $m_e$, charge $-e$) is at rest on the surface of a fixed uniform insulating sphere with positive charge $Q$ and radius $R$. The electron is then given a speed $v_0$ away from the sphere. What maximum distance from the center of the sphere will the electron reach? Express your answer in terms of the parameters defined in the problem, and physical or mathematical constants.
II. (16 points) A radially symmetric insulating sphere of charge has a radius $R$ and a non-uniform volume charge density $\rho$ that depends on distance $r$ from the center according to

$$\rho = \rho_0 \left( \frac{r}{R} \right)^2$$

where $\rho_0$ is a positive constant. What is the magnitude of the electric field at a distance $2R/3$ from the center? Express your answer in terms of the parameters defined in the problem, and physical or mathematical constants.

1. (6 points) The sphere in the problem above is shown at the right. What is the direction of the electric field at the point indicated with an asterisk, a distance $2R/3$ from the center?
   (a) Away from the center.
   (b) Toward the center.
   (c) Up the page.
   (d) Out of the page.
   (e) Down the page.
III. (16 points) A positively charged insulating cylinder with radius \( R/2 \) has the uniform volume charge density \( \rho_0 \). The cylinder is placed at the center of a negatively charged insulating hollow cylinder with inner radius \( R \), outer radius \( 3R \), and volume charge density \(-\rho_0/4\). Calculate the magnitude of electric field at a distance \( 2R \) from the center of the cylinders. Express your answer in terms of the parameters defined in the problem, and physical or mathematical constants.

2. (6 points) In the problem above, the charge per unit length of the hollow insulating cylinder is \( \lambda_{HC} = -8\lambda_{IC} \), where \( \lambda_{IC} \) is the charge per unit length on the inner insulating cylinder. Consider two cylindrical Gaussian surfaces with the same length. Gaussian surface \( A \) has radius \( R/2 < r_A < R \), and Gaussian surface \( B \) has radius \( r_B = 4R \). What is the relationship between the electric fluxes \( \Phi_A \) and \( \Phi_B \) measured through the surfaces \( A \) and \( B \), respectively?
   (a) \( \Phi_B = +9\Phi_A \)
   (b) \( \Phi_B = -7\Phi_A \)
   (c) \( \Phi_B = +7\Phi_A \)
   (d) \( \Phi_B = \Phi_A \)
   (e) \( \Phi_B = -8\Phi_A \)
3. (8 points) An infinite insulating slab has thickness 2\(t\). It extends to \(\pm \infty\) in the \(x\) and \(y\) directions, and is centered on the \(z\) axis, extending to \(\pm t\). It has a non-uniform volume charge density \(\rho\) that depends on position \(z\) according to

\[ \rho = \rho_0 \left( \frac{z}{t} \right)^2 \]

where \(\rho_0\) is a constant. If it can be determined, what is the magnitude of the electric field at the origin?

(a) The magnitude cannot be determined because the sign of \(\rho_0\) is not specified.
(b) The magnitude cannot be determined because the slab is infinite.
(c) \(K\rho_0/t^2\)
(d) \(K\rho_0/z^2\)
(e) Zero.

4. (8 points) Three particles with charges \(+2Q\), \(-2Q\), and \(-Q\) are located at the vertices of an equilateral triangle with sides of length \(s\). What is the electric potential energy of this system, with respect to zero at infinity?

(a) \(-KQ/s\)
(b) \(5KQ^2/s\)
(c) \(KQ^2/s^2\)
(d) \(-4KQ^2/s\)
(e) \(4KQ^2/s\)
5. (8 points) A negatively charged sphere is moved from some initial point to the final point in the direction of a uniform electric field. Considering a system consisting of the sphere and the source of the uniform field, during this displacement:

(a) the potential energy of the system decreases.
(b) the potential energy of the system increases if the speed of the sphere increases and the potential energy of the system decreases if the speed decreases.
(c) the potential energy of the system does not change.
(d) the potential energy of the system decreases if the speed of the sphere increases and the potential energy of the system increases if the speed decreases.
(e) the potential energy of the system increases.

6. (8 points) A conductor with a hollow cavity has a total charge $Q_{\text{tot}}$ placed upon it. A small point charge $q$ is then placed within the cavity, through a negligibly small hole in the conductor. What will be the resulting residual charge $Q_{\text{out}}$ on the outer surface of the conductor, after equilibrium is reached?

(a) $Q_{\text{out}} = Q_{\text{tot}} - q$
(b) $Q_{\text{out}} = -Q_{\text{tot}} - q$
(c) $Q_{\text{out}} = -Q_{\text{tot}} + q$
(d) $Q_{\text{out}} = Q_{\text{tot}}$
(e) $Q_{\text{out}} = Q_{\text{tot}} + q$
7. (8 points) Two parallel conducting plates are separated by 7.5 cm and one of them is taken to be at zero volts. What is the potential difference between the plates if the electric potential 5.0 cm from the zero volt plate (and 2.5 cm away from the other plate) is +300 Volts?

(a) +150 Volts
(b) +900 Volts
(c) -150 Volts
(d) +450 Volts
(e) +600 Volts