Your name sticker with exam code

1. The exam will last from 3:25pm to 4:25pm. Use a # 2 pencil to make entries on the answer sheet. Enter the following id information now, before the exam starts.

2. In the section labelled NAME, enter your last name, then fill in the empty circle for a blank, then enter your first name, another blank, and finally your middle initial.

3. Under STUDENT # enter your 9-digit Student ID Number. Under COURSE enter 272. Under CODE enter the exam code given above.

4. During the exam, you may use pencils, a calculator, and ONE 8½" × 11" sheet of paper with formulas and notes.

5. There are 16 multiple-choice questions on the exam. For each question, mark only one answer on the answer sheet. There is no subtraction of points for an incorrect answer, so even if you cannot work out the answer to a question, you should make an educated guess. At the end of the exam, hand in only the answer sheet. Retain this question paper for future reference and study.

6. Useful numerical constants are given on the next page. Before starting the exam, make sure that your copy contains the page of constants and all 16 questions. Bring your exam to the proctor if this is not the case.
Acceleration due to gravity $g = 9.8 \text{ m/s}^2$
Elementary charge $e = 1.6 \times 10^{-19} \text{ C}$
Proton charge $= 1.6 \times 10^{-19} \text{ C}$
Electron charge $= -1.6 \times 10^{-19} \text{ C}$
1 electron volt (eV) $= 1.6 \times 10^{-19} \text{ J}$
Proton mass $= 1.673 \times 10^{-27} \text{ kg} = 938.3 \text{ MeV}/c^2$
Electron mass $= 9.11 \times 10^{-31} \text{ kg} = 0.511 \text{ MeV}/c^2$
$1/4\pi\varepsilon_0 = 9 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2$
$\mu_0 = 4\pi \times 10^{-7} \text{ T} \cdot \text{m}/\text{A}$

Powers of ten:

<table>
<thead>
<tr>
<th>femto (f)</th>
<th>pico (p)</th>
<th>nano (n)</th>
<th>micro (µ)</th>
<th>milli (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$10^{-15}$</td>
<td>$10^{-12}$</td>
<td>$10^{-9}$</td>
<td>$10^{-6}$</td>
<td>$10^{-3}$</td>
</tr>
<tr>
<td>centi (c)</td>
<td>kilo (k)</td>
<td>Mega (M)</td>
<td>Giga (G)</td>
<td>Tera (T)</td>
</tr>
<tr>
<td>$10^{-2}$</td>
<td>$10^3$</td>
<td>$10^6$</td>
<td>$10^9$</td>
<td>$10^{12}$</td>
</tr>
</tbody>
</table>

Questions 14, 15
1. A point charge is placed at the center of a spherical Gaussian surface. Which of the following will cause the total electric flux through the surface to change?

- I: Moving the charge off center, but still inside the sphere
- II: Increasing the radius of the sphere
- III: Replacing the sphere by a cube of the SAME volume

a) I will change the flux, but not II or III
b) II will change the flux, but not I or III
c) II and III will change the flux, but not I
d) I and II will change the flux, but not III
e) None of these will change the flux

$$\Phi = \frac{1}{\varepsilon_0} Q_{\text{ENCLOSED}}$$

Enclosed charge stays the same.

2. A charge of $+4Q$ is at the origin. Concentric with it is a conducting spherical shell of inner radius $R_1$ and outer radius $R_2$. The shell is given a NET charge of $-6Q$. The distance $r$ is measured from the origin. The electric field in the region $r > R_2$ is $1/4\pi \varepsilon_0$ times

a) $6Q/r^2$ in magnitude and pointing away from the origin
b) $6Q/r^2$ in magnitude and pointing towards the origin
c) $2Q/r^2$ in magnitude and pointing away from the origin
d) $2Q/r^2$ in magnitude and pointing towards the origin
e) $4Q/r^2$ in magnitude and pointing away from the origin

3. A charge $Q$ is at the origin. Concentric with it is a conducting spherical shell of inner radius $R_1$ and outer radius $R_2$. The shell is given a NET charge of $+6 \mu C$, of which $-2 \mu C$ lies on the OUTER surface of the shell. What is the value of $Q$?

a) $+2 \mu C$
b) $+8 \mu C$
c) $-8 \mu C$
d) $+4 \mu C$
e) $-4 \mu C$

From charge conservation, inner surface has charge $+6 - (-2) = +8 \mu C$.

Since $E=0$ inside conductor, a Gaussian sphere must enclose zero net charge. Here, enclosed charge is $(R + 8\mu C)$. So $R + 8\mu C = 0 \Rightarrow R = -8\mu C$. 
4. Consider a conductor in electrostatic equilibrium. Which of the following four statements is FALSE? If all four are true, select answer choice e. 
   a) The electric field is zero inside the volume of the conductor. 
   b) Any NET charge can only reside on a surface of the conductor. 
   c) The electric field at a surface must be perpendicular to the surface. 
   d) The electric potential inside the volume of the conductor must be constant. 
   e) The above four statements are all true. 

5. A charge of $-9 \, nC$ is on the y-axis at $y = +12 \, cm$, and a charge of $-7 \, nC$ is on the x-axis at $x = -14 \, cm$. What is the electric potential at the origin, assuming it is taken to be zero at infinity?

   a) $+225 \, V$
   b) $-1125 \, V$
   c) $-225 \, V$
   d) $+811 \, V$
   e) None of the other answers

   $$ V = \frac{(9 \times 10^9 \times -9 \times 10^{-9})}{0.12} + \frac{(9 \times 10^9 \times -7 \times 10^{-9})}{0.14}$$
   $$ \Rightarrow V = -675 - 450 = -1125 \, V $$

6. A hollow, insulating, thin sphere of radius $a$ has a charge $Q$ distributed uniformly over its surface. There is no charge in the cavity inside the sphere. The radial distance $r$ is measured from the sphere’s center. What is the electric potential for $r < a$, if we make the usual choice that it is zero at infinity?

   a) $Q/4\pi\varepsilon_0 a$
   b) $Q/4\pi\varepsilon_0 r$
   c) $Q/4\pi\varepsilon_0 a + Q/4\pi\varepsilon_0 r$
   d) $Q/4\pi\varepsilon_0 a - Q/4\pi\varepsilon_0 r$
   e) Zero

   $$ V = -\int_a^r E_x \, dr - \int_a^r E_\theta \, dr $$

   $$ \Rightarrow V = \frac{1}{4\pi\varepsilon_0} \left[ \frac{Q}{a^2} \right] - 0 = \frac{1}{4\pi\varepsilon_0} \frac{Q}{a} $$

7. A conducting sphere of radius $R_1$ has a charge $Q$ on its surface. Another conducting sphere has radius $R_2$ and is initially uncharged. Then a thin conducting wire is attached to connect the spheres. When equilibrium is reached, what will be the charge on the sphere of radius $R_1$?

   a) $QR_1/R_2$
   b) $QR_2/R_1$
   c) $QR_1/(R_1 + R_2)$
   d) $QR_2/(R_1 + R_2)$
   e) None of the other answers

   Charge conservation: $Q = Q_1 + Q_2$  \hspace{1cm} (2)
8. A particle of mass 2 kg and charge 5 C moves at a speed of 60 m/s. It is subsequently accelerated through a potential difference of 900 V. After this acceleration, what will be the particle’s speed?

a) About 4500 m/s \( u_i = \frac{1}{2} (2 \times 60)^2 = 3600 \text{ J} \)

b) About 4560 m/s

c) About 67 m/s \( u_f = 3600 + (5 \times 900) = 8100 \text{ J} \)

d) About 90 m/s

e) About 127 m/s \( \frac{1}{2} (2) v^2 = 8100 \Rightarrow v = 90 \text{ m/s} \)

9. In one experiment, a capacitor of capacitance \( C \) is given a charge \( Q \) by a battery. In another experiment, the same capacitor is given a charge \( 2Q \) by a different battery. What is the capacitor’s capacitance in the second experiment?

a) \( 4C \) Capacitance depends only on geometry!

b) \( C \)

c) \( 2C \)

d) \( C/4 \)

e) \( C/2 \)

10. Two capacitors are connected in series to an 80 V battery. One capacitor has a capacitance of 4 \( \mu \text{F} \) and acquires a charge of 192 \( \mu \text{C} \). What is the capacitance of the other capacitor?

\( \text{Across 4 \( \mu \text{F} \), voltage} = \frac{192}{4} = 48 \text{ V.} \)

Across other capacitor is \( 80 - 48 = 32 \text{ V.} \)

\( \Rightarrow \text{ Capacitance} = \frac{R}{V} = \frac{192 \mu \text{C}}{32 \text{ V}} = 6 \mu \text{F.} \)

11. Two capacitors are connected in parallel to a battery. One capacitor has a capacitance of 2 \( \mu \text{F} \) and acquires a stored energy of 36 \( \mu \text{J} \). What is the capacitance of the other capacitor, if it acquires a charge of 30 \( \mu \text{C} \)?

a) None of the other answers

b) 2 \( \mu \text{F} \)

c) 5 \( \mu \text{F} \)

d) 12.5 \( \mu \text{F} \)

\( \text{e) 1.67} \) \( \mu \text{F} \)

\( U = \frac{1}{2} CV^2 \Rightarrow V = \sqrt{\frac{(2 \times 36 \times 10^{-6})}{2 \times 10^{-6}}} = 6 \text{ V.} \)

"Parallel", so same \( V \) across other capacitor.

\( \Rightarrow \text{ Capacitance} = \frac{R}{V} = \frac{30 \mu \text{C}}{6 \text{ V}} = 5 \mu \text{F.} \)
12. Two straight wires $A$ and $B$ of circular cross-section are made of the same metal and have equal lengths, but the radius of wire $A$ is twice that of wire $B$. How do their resistances compare?

a) $R_A = R_B/2$

b) $R_A = R_B/4$

c) $R_A = 2R_B$

d) $R_A = 4R_B$

e) $R_A = \sqrt{2}R_B$

\[ R = \rho \frac{L}{A} = \rho \frac{L}{\pi r^2} \]

\[ \frac{R_A}{R_B} = \left( \frac{r_B}{r_A} \right)^2 = \left( \frac{1}{2} \right)^2 = \frac{1}{4} \]

13. Resistors $R_1$ and $R_2$ are connected in series to a 16 V battery. The two resistors have an equivalent resistance of 8 Ω. If the voltage drop across resistor $R_2$ is 15 V, in which of the following ranges does the value of $R_1$ lie, in units of ohms?

a) $R_1 < 1$

b) $1 \leq R_1 < 4$

c) $4 \leq R_1 < 8$

d) $8 \leq R_1 < 12$

e) $R_1 \geq 12$

\[ I = \frac{16}{8} = 2 \text{ A} \]

\[ \Rightarrow \frac{R_2}{R_1} = \frac{15}{2} = 7.5 \text{ Ω} \]

14. See the figure for this question. What is the current in the resistor $R_1$?

a) 0.4 A from left to right

b) 0.1 A from left to right

c) 0.1 A from right to left

d) 0.9 A from left to right

e) 0.9 A from right to left

**Junction rule**: 0.4 + $I_1 = 0.5$

\[ \Rightarrow I_1 = 0.1 \text{ A into bottom junction} \]

15. In the preceding problem, what is the value of $R_2$ in ohms?

a) 14 Ω

b) 8 Ω

c) 4 Ω

d) 10 Ω

e) None of the other answers

\[ 5 - 0.5R_2 - (0.4 \times 5) = 0 \]

\[ \Rightarrow R_2 = 6 \text{ Ω} \]

16. Two light bulbs, one of resistance 20 Ω and the other of resistance 60 Ω, can be connected either in series or in parallel to an emf of 110 V. Which bulb is brighter in each connection?

a) Series: 20 Ω is brighter; Parallel: 20 Ω is brighter

b) Series: 60 Ω is brighter; Parallel: 20 Ω is brighter

c) Series: 20 Ω is brighter; Parallel: 60 Ω is brighter

d) Series: 60 Ω is brighter; Parallel: 60 Ω is brighter

e) The bulbs have the same brightness in each connection

**Series**: $I$ is constant, so use $P = I^2R$.

**Parallel**: $V$ is constant, so use $P = \frac{V^2}{R}$. 