# Physics 227 – First Midterm Exam
Tuesday, February 20, 2018

CIZEWSKI

Physics 227, Section
RUID:
**Code: 000**

Your name with **exam code**

**Your signature** ______________________________

Turn off and put away ALL electronic devices NOW. NO cell phones, NO smart watches, NO calculators.

1. The exam will last from 5:15 to 6:10 PM.
   Use a # 2 pencil to make entries in the circles at the bottom of the cover sheet.
2. Make sure your name and RU ID are correct on the cover page. **CAREFULLY detach the cover sheet (with your name, ID and the answer circless.**
3. During the exam, you may use pencils, NO calculator. and **ONE** $8\frac{1}{2}'' \times 11''$ sheet of paper with handwritten (both sides) equations and notes.
4. There are 12 multiple-choice questions on the exam. For each question, mark only ONE and 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.

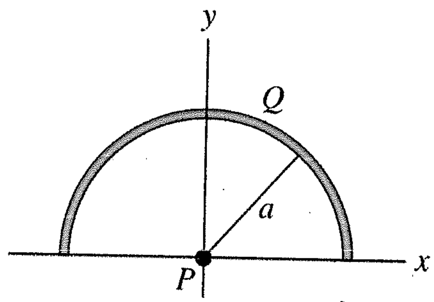
No marks except filled in answer circles below the line, please.

| | A | B | C | D | E |
|---|---|---|---|---|---|
| 1: | A | B | C | D | E |
| 2: | A | B | C | D | E |
| 3: | A | B | C | D | E |
| 4: | A | B | C | D | E |
| 5: | A | B | C | D | E |
| 6: | A | B | C | D | E |
| 7: | A | B | C | D | E |
| 8: | A | B | C | D | E |
| 9: | A | B | C | D | E |
| 10: | A | B | C | D | E |
| 11: | A | B | C | D | E |
| 12: | A | B | C | D | E |

**Possibly useful constants:**

$\epsilon_0 = 1/\mu_0 c^2 = 8.85 \times 10^{-12}$ C$^2$/N·m$^2$
$k = 1/4\pi\epsilon_0 = 8.99 \times 10^9$ N·m$^2$/C$^2$
$c$ = speed of light = $3.00 \times 10^8$ m/s
$-q_{electron} = q_{proton} = 1.602 \times 10^{-19}$ C
$m_{electron}$ = electron mass = $9.11 \times 10^{-31}$ kg
$m_{proton}$ = proton mass = $1.67 \times 10^{-27}$ kg
1 eV = $1.602 \times 10^{-19}$ J
Circumference of a circle $=2\pi r$; area of a circle is $\pi r^2$
Surface area of a sphere = $4\pi r^2$; Volume of a sphere = $\frac{4}{3}\pi r^3$
Surface area of a cylinder = $2\pi r h + 2\pi r^2$; Volume of cylinder = $\pi r^2 h$
$\sin(0°) = \cos(90°) = 0$
$\sin(90°) = \cos(0°) = 1$
$\sin(30°) = \cos(60°) = 1/2$
$\sin(60°) = \cos(30°) = \sqrt{3}/2$
$\sin(45°) = \cos(45°) = \sqrt{2}/2$
$\frac{dx^n}{dx} = nx^{n-1}$
$\int x^n = \frac{1}{n+1}x^{n+1}$ except when $n = -1$. For $n = -1$, $\int dx/x = \ln x$
Some metric prefixes:
f = femto = $10^{-15}$
p = pico = $10^{-12}$
n = nano = $10^{-9}$
$\mu$ = micro = $10^{-6}$
m = milli = $10^{-3}$
k = kilo = $10^3$
M = mega = $10^6$
G = giga = $10^9$

1. Positive charge is uniformly distributed around a semicircle in the Figure. Which statement is correct for the electric field $\vec{E}$ that this charge produces at the center of curvature (point P)?




a) $\vec{E}$ is in the $+x$-direction.
b) $\vec{E}$ is in the $-x$-direction.
c) $\vec{E}$ is in the $+y$-direction.
(d)) $\vec{E}$ is in the $-y$-direction.
e) $\vec{E}$ is out of the plane of the paper.

From superposition: all contributions to $\vec{E}$ field from x direction cancel; all contributions in $-y$ direction add up

2. Consider an empty hollow spherical conductor with inner radius $r$ and outer radius $R$. There is a charge $Q$ on the conductor. Which of the following statements is FALSE?

a) There is a surface charge density of $Q/4\pi R^2$ on the outer surface of the sphere. TRUE
(b)) The electric field inside the cavity is $kQ/r^2\,\hat{r}$. FALSE – no $\vec{E}$ inside of conductor
c) The potential inside the cavity is constant. – TRUE
d) The potential inside the conductor is constant. – TRUE
e) The charge density inside the cavity is zero. – TRUE

3. A tiny object carrying a charge of $q_1 = 60\ \mu C$ and a second tiny charged object with charge $q_2$ are initially very far apart. It takes 30 J of work to bring them to a final configuration where $q_1$ is at $(x_1 = 1, y_1 = 1)$ in mm and $q_2$ is at $(x_2 = 1, y_2 = 3)$ in mm (Cartesian coordinate system). What is the magnitude of the charge $q_2$? Assume $k = 1/4\pi\epsilon_0 \approx 10 \times 10^9\ \text{N·m}^2/\text{C}^2$.

(a)) $q_2 = 0.1\ \mu C$
b) $q_2 = 1.0\ \mu C$
c) $q_2 = 0.5\ \mu C$
d) $q_2 = 0.05\ \mu C$
e) $q_2 = 2.0\ \mu C$

$$W_{\infty \to r} = U(\infty) - U(r) = 30\,J$$

$$= 0 - \frac{k q_1 q_2}{\sqrt{(x_2-x_1)^2 + (y_2-y_1)^2}}$$

$$= \frac{(10\times10^9\ \text{N-m}^2/\text{C}^2)(60\times10^{-6}\,C)\,q_2}{\sqrt{(0)^2+(3-1)^2}\ \text{mm}}$$

$$q_2 = \frac{30\,J\,(2)\times10^{-3}}{10\times10^9\ \frac{\text{N-m}^2}{\text{C}^2}\,(60\times10^{-6}\,C)}$$

$$= \frac{60\times10^{-3}}{60\times10^{+4}} = 1\times10^{-7}$$

$$\boxed{q_2 = 0.1\ \mu C}$$

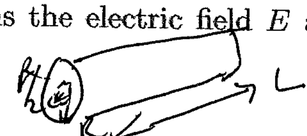
4. When two point charges are separated by a distance $d_1$, the electric force that each one feels from the other has magnitude $F_1$. In order to make this force twice as strong, the distance $d_2$ between the two charges would have to be changed to

a) $d_2 = 2d_1$
b) $d_2 = \sqrt{2}d_1$
c) $d_2 = d_1/\sqrt{2}$
d) $d_2 = d_1/2$
e) $d_2 = d_1/4$

$F_1 \propto \frac{1}{d_1^2} \quad F_2 \propto \frac{1}{d_2^2} = 2F_1$

$\frac{F_2}{F_1} = 2 = \frac{\frac{1}{d_2^2}}{\frac{1}{d_1^2}} = \frac{d_1^2}{d_2^2} \Rightarrow d_2 = \frac{d_1}{\sqrt{2}}$

5. An infinitely long non-conducting (insulating) cylinder of radius $R$ carries a uniform volume charge density of $\rho$. What is the electric field $E$ at a distance $r = R/2$ from the axis of the cylinder?



a) $E = \rho/\epsilon_0$
b) None of the other options is correct because need to know length of the cylinder.
c) $E = \rho R/(4\epsilon_0)$
d) $E = \rho R/(6\epsilon_0)$
e) $E = \rho/(4\pi\epsilon_0 R^2)$

$\oint E \cdot dA = E(A) = Q_{enc}/\varepsilon_0 \Rightarrow E = \frac{Q_{enc}}{A\varepsilon_0}$

$A(\text{cylinder}) = 2\pi r L$

$Q_{enc} = \rho(\pi r^2 L)$

$E = \frac{\rho(\pi r^2 L)}{2\pi r L \varepsilon_0} = \frac{\rho r}{2\varepsilon_0} = \frac{\rho R}{4\varepsilon_0}$

6. Capacitors A and B have capacitances of 2 $\mu$F and 4 $\mu$F, respectively. They are connected in series to a 300 V battery. What will be the charges $Q_A$ and $Q_B$ on capacitors A and B, respectively?

a) $Q_A$=600 $\mu$C and $Q_B$=1000 $\mu$C
b) $Q_A$=400 $\mu$C and $Q_B$=400 $\mu$C
c) $Q_A$=2400 $\mu$C and $Q_B$=2400 $\mu$C
d) $Q_A$=1000 $\mu$C and $Q_B$=600 $\mu$C
e) $Q_A$=225 $\mu$C and $Q_B$=225 $\mu$C

$\frac{1}{C_{eq}} = \frac{1}{2\mu F} + \frac{1}{4\mu F} = \frac{2+1}{4\mu F}$

$C_{eq} = \frac{4}{3}\mu F$

$Q = Q_A = Q_B$ when in series

$Q = C_{eq}V = (\frac{4}{3}\mu F)(300 V) = 400\mu C$

7. An initially-stationary electric dipole of dipole moment

$$\vec{p} = (5 \times 10^{-10})\ \hat{\imath}\ \text{C-m}$$

is placed in an electric field

$$\vec{E} = (5 \times 10^6)\ \hat{\imath} + (2 \times 10^6)\ \hat{\jmath}\ \text{N/C}.$$

What is the magnitude of the maximum torque $\tau$ that the electric field exerts on the dipole?

a) $\tau = 1 \times 10^{-3}$ N·m
b) $\tau = 0$ N·m
c) $\tau = 2 \times 10^{-3}$ N·m
d) $\tau = 2.5 \times 10^{-3}$ N·m
e) $\tau = \sqrt{29} \times 10^{-4}$ N·m

$\vec{\tau} = \vec{p} \times \vec{E} = p_x E_y \hat{z}$

$\tau = (5\times10^{-10})(2\times10^{6})$ N-m $= 10\times10^{-4} = 10^{-3}$ N-m.

8. Two identical large parallel sheets carry equal but opposite charges. When they are $d_1 = 2.00$ cm apart, the potential difference between them is $V_1 = 20.0$ V. If they are now moved closer until they are $d_2 = 1.00$ cm apart, what is the new potential difference $V_2$?

a) $V_2 = 5.00$ V
b) $V_2 = 20.0$ V
c) $V_2 = 40.0$ V
d) $V_2 = 80.0$ V
e) $V_2 = 10.0$ V

This is a capacitor $C = \varepsilon_0 A/d$.
$Q_1 = Q_2 \Rightarrow C_1 V_1 = C_2 V_2$.
$\frac{\varepsilon_0 A}{d_1} V_1 = \frac{\varepsilon_0 A}{d_2} V_2 \Rightarrow V_2 = \frac{d_2}{d_1} V_1 = 10\,V$

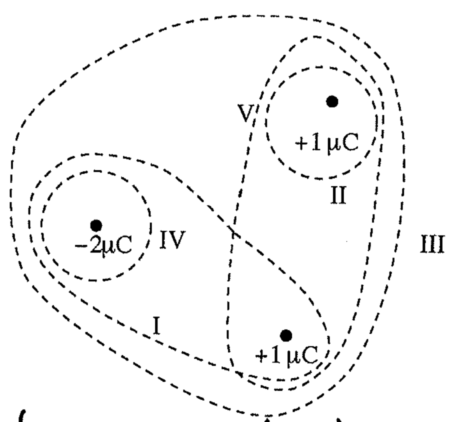
9. A dielectric-filled parallel-plate capacitor has plate area $A$, plate separation $d$ and dielectric constant $K$. The capacitor is connected to a battery that creates a constant voltage $V$. The dielectric plate is now slowly pulled out of the capacitor, which remains connected to the battery. What is the energy $U$ stored in the capacitor at the moment when the capacitor is half-filled with the dielectric?

a) $U = K\epsilon_0 AV^2/d$
b) $U = (K+1)\epsilon_0 AV^2/4d$
c) $U = (K+1)\epsilon_0 AV^2/2d$
d) $U = K\epsilon_0 AV^2/4d$
e) $U = K\epsilon_0 AV^2/d$

$V_1 = V_2 = V$ $\quad A/2$
$U_2 = \frac{1}{2} C_2 V^2$
$U_2 = \frac{1}{2}\left(\frac{\varepsilon_0 A}{2d}\right)(K+1)V^2 \Leftarrow C_2 = \frac{K\varepsilon_0 A}{2d} + \frac{\varepsilon_0 A}{2d} = \frac{\varepsilon_0 A}{2d}(K+1)$

10. The curves in the figure represent closed Gaussian surfaces that surround different parts of the charge configuration. The flux across each surface $i$ is denoted $\Phi_i$. Rank the flux values across these surfaces.

a) $\Phi_I > \Phi_{II} > \Phi_{III} > \Phi_{IV} > \Phi_V$
b) $\Phi_V > \Phi_{II} = \Phi_I > \Phi_{III} > \Phi_{IV}$
c) $\Phi_I = \Phi_{II} > \Phi_{III} = \Phi_{IV} > \Phi_V$
d) $\Phi_V = \Phi_{IV} > \Phi_{II} = \Phi_I > \Phi_{III}$
e) $\Phi_V > \Phi_{II} > \Phi_{III} > \Phi_I > \Phi_{IV}$



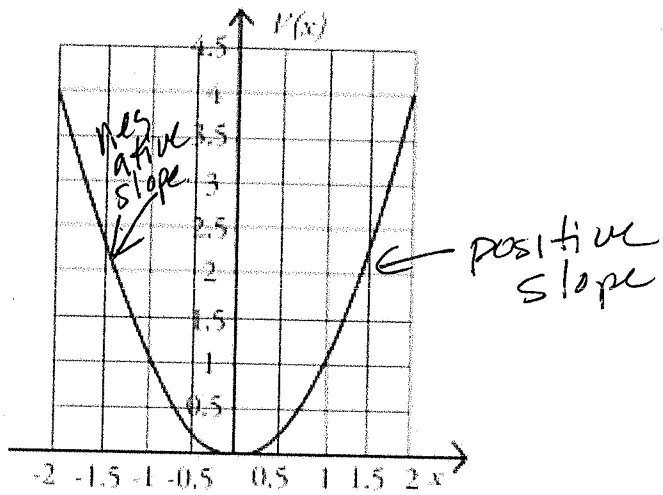

$\Phi = \frac{Q_{enclosed}}{\varepsilon_0}$

$\Phi_1 = \frac{+1+(-2)}{\varepsilon_0} = \frac{-1\mu C}{\varepsilon_0}$
$\Phi_2 = \frac{+1\mu C}{\varepsilon_0}$
$\Phi_3 = (+1 - 2 + 1)\mu C = 0$
$\Phi_4 = \frac{-2\mu C}{\varepsilon_0}$ $\quad \Phi_5 = \frac{(+1+1)\mu C}{\varepsilon_0} = \frac{2\mu C}{\varepsilon_0}$

$\Phi_5 \sim +2 > \Phi_2 \sim +1 > \Phi_3 = 0 > \Phi_1 \sim -1 > \Phi_4 \sim -2$

11. The graph in the figure shows the variation of the electric potential $V(x)$ as a function of the position $x$. Which of the following correctly describes the orientation of the $x$ component of the electric field $E_x$ along the $x$ axis?

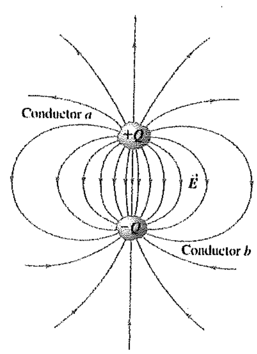
a) $E_x$ is negative from $x = -2$ to $x = +2$.
b) $E_x$ is positive from $x = -2$ to $x = +2$.
c) $E_x$ is negative from $x = -2$ to $x = 0$ and $E_x$ is positive from $x = 0$ to $x = +2$.
d) $E_x$ is positive from $x = -2$ to $x = 0$ and $E_x$ is negative from $x = 0$ to $x = +2$.
e) $E_x$ is zero for all values of $x$.




$E_x = \frac{\partial V_x}{\partial x} \Rightarrow E_x \sim -\text{slope}$

12. In the figure, the two conductors $a$ and $b$ are insulated from each other, forming a capacitor. You increase the charge on $a$ to $+3Q$ and increase the charge on $b$ to $-3Q$, while keeping the conductors in the same positions. As a result of this change, which of the following statements describes the capacitance $C$ of the two conductors?

a) The capacitance C is 9 times as great.
b) The capacitance C is 6 times as great.
c) The capacitance C remains the same.
d) The capacitance C is 1/3 as great.
e) The capacitance C is 1/9 as great.




Capacitance only depends on geometry not the charge.