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Multiple Choice [5 pts each] Bubble in the most correct answer on your bubble sheet and circle the correct answer here.

1. [5 pts] Find the net charge of a system consisting of 180 electrons and 235 protons.

88%

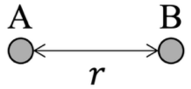
- A. 3.76×10^{-17} C
- B. -2.88×10^{-17} C
- C. 6.13×10^{-18} C
- [✓ D. 8.80×10^{-18} C]
- E. 4.27×10^{-18} C

$Q = 180(-e) + 235(e)$

$= 55e = 55 \times 1.6 \times 10^{-19}$

$= 8.8 \times 10^{-18}$ C

2. [5 pts] When charge B is separated from charge A by a distance r, charge B experiences a force of magnitude F. If the separation between the charges is increased to $2r$, what force does charge B experience?



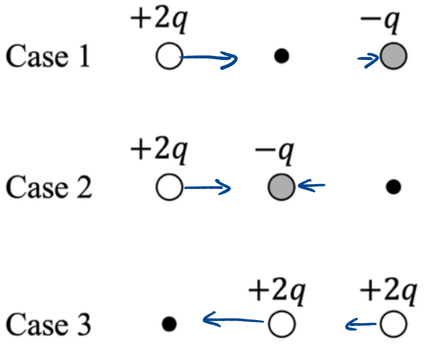
87%

- A. $4F$
- B. $2F$
- C. F
- D. $F/2$
- [✓ E. $F/4$]

$F = \frac{Kq_Aq_B}{r^2}$

$r \to 2r \Rightarrow F \to \frac{Kq_Aq_B}{(2r)^2} = \frac{F}{4}$

3. [5 pts] Consider the three cases at right. The positive charges each have magnitude $2q$ and the negative charges each have magnitude q. Rank the magnitude of the electric field at the black dot in each case from largest to smallest. Treat each case separately (the charges in case 1 do not interact with the charges in case 2 and so on).



57%

- A. 1 > 2 > 3
- B. 2 > 3 > 1
- C. 1 > 2 = 3
- D. 1 = 3 > 2
- [✓ E. 1 > 3 > 2]

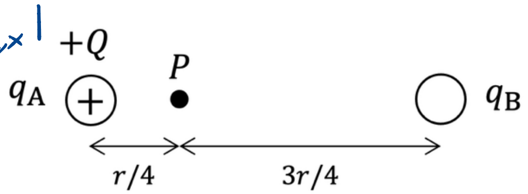
Case 1: $E_{1,x} = K\left[+\frac{|-q|}{r^2} + \frac{|2q|}{r^2}\right] = \frac{3Kq}{r^2}$

Case 2: $E_{2,x} = K\left[-\frac{|-q|}{r^2} + \frac{|2q|}{4r^2}\right] = \frac{Kq}{r^2}\left[-1 + \frac{2}{4}\right] = -\frac{Kq}{2r^2}$

Case 3: $E_{3,x} = K\left[-\frac{|2q|}{r^2} - \frac{|2q|}{4r^2}\right] = -\frac{Kq}{r^2}\left[2 + \frac{2}{4}\right] = -\frac{2.5Kq}{r^2}$

$\Rightarrow |E_{1,x}| > |E_{3,x}| > |E_{2,x}|$

4. [5 pts] Point charges q_A and q_B are separated by a distance r as shown at right. It is known that the electric field is zero at point P. If $q_A = +Q$, what is the charge of q_B?



48%

- A. $q_B = +3Q$
- X B. $q_B = -3Q$
- C. $q_B = +6Q$
- [✓ D. $q_B = +9Q$]
- X E. $q_B = -9Q$

q_B cannot be negative ⇒ B and E are out

$E_{P,x} = \frac{K|q_A|}{(r/4)^2} - \frac{K|q_B|}{(3r/4)^2} = 0$

$\Rightarrow \frac{\cancel{16K}Q}{\cancel{r^2}} = \frac{\cancel{16K}|q_B|}{9\cancel{r^2}} \Rightarrow |q_B| = 9Q$

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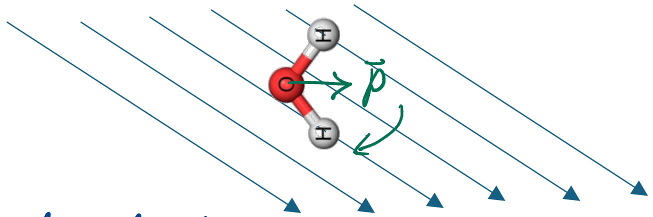
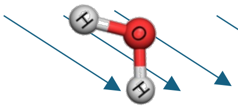
79%

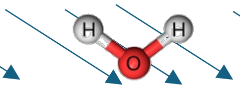
5. [5 pts] A water molecule is polar, since the oxygen side more negative than the hydrogen side. One water molecule is present in a region of a uniform electric field. Initially, the molecule has the orientation shown at right and is at rest. After equilibrium, which one of the following represents the correct orientation of the molecule?



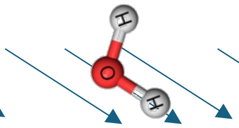
The molecule will rotate so that its dipole moment aligns with the field



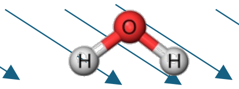
A



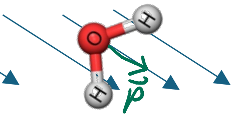
B



C



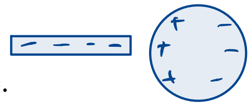
D



[✓ E]

40%

6. [5 pts] A plastic rod is charged uniformly with negative charge. The tip of the rod is brought close (without touching) to a neutral solid metallic sphere and held in place. Which one of the following is true? Assume that electrostatic equilibrium has been reached and that no charges jumped across between the two objects.



A. The negative charges on the rod accumulate at the tip close to the sphere. No, it's an insulator

B. The electric field inside the sphere has its maximum value close to the rod. $E_{in} = 0$

[✓ C. A force of attraction forms between the rod and sphere.] +ve charge closer to rod than -ve

D. The sphere does not react to the presence of the rod, as it is neutral. Gets polarized

E. Electrons in the sphere move as far away from the rod as they can and protons accumulate close to it. Since the sphere is metal protons are not likely to move.

60%

$\Delta K = 0$

7. [5 pts] A charge of -5.3×10^{-9} C is moved at constant speed by an external agent from a point where the electric potential is -6.0 V to a point where the potential is $+8.0$ V. How much work did the external agent do to move the charge?

A. $+7.4 \times 10^{-8}$ J

[✓ B. -7.4×10^{-8} J]

C. -1.1×10^{-8} J

D. $+1.1 \times 10^{-8}$ J

E. 0 J

$$W_{ext} = \Delta E = \Delta K + \Delta U_{elec}$$

$$= \Delta U_{elec} = q\,\Delta V$$

$$= (-5.3 \times 10^{-9}\,C)(8.0V - (-6.0V))$$

$$= -7.4 \times 10^{-8}\,J$$

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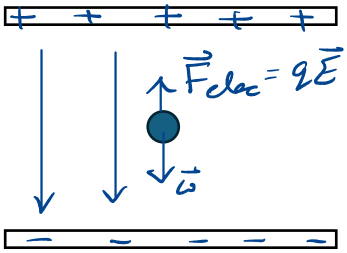
Use the following scenario to answer the next two questions:

A small oil drop of mass 3.2×10^{-15}kg is suspended between two horizontal charged plates separated by a distance of 5.0×10^{-2} m, as shown at right. The uniform electric field between the plates is measured to be 1.2×10^4 N/C and is pointing downward.



8. [5 pts] Calculate the approximate amount charge the oil drop has in terms of electrons. *Hint*: Do not neglect gravity, recall $g = 9.8\ \text{m/s}^2$.
   - A. About 2 electrons were added to the drop.
   - B. About 2 electrons were removed from the drop.
   - C. About 20 electrons were removed from the drop.
   - [✓ D. About 20 electrons were added to the drop.]
   - E. The correct answer is not listed above.

36%

$\vec{F}_{net} = 0 = +qE - w$

$\Rightarrow qE = w = mg$

$\Rightarrow q = \frac{mg}{E} = \frac{(3.2\times10^{-15}kg)(9.8 m/s^2)}{1.2\times10^4 N/C}$

$= 2.6\times10^{-18}$

$\Rightarrow \#e = \frac{2.6\times10^{-18}C}{1.6\times10^{-19}C} = 16 \approx 20$

Since $\vec{F}_{elec}$ is towards +ve plate ⇒ electrons were added to the drop.

9. [5 pts] Calculate the electric potential difference ΔV between the negative plate and the midway point between the two plates, i.e. $\Delta V = V_{\text{midway}} - V_{\text{negative plate}}$.
   - A. 600 V
   - [✓ B. 300 V]
   - C. 240 V
   - D. 150 V
   - E. 0 V

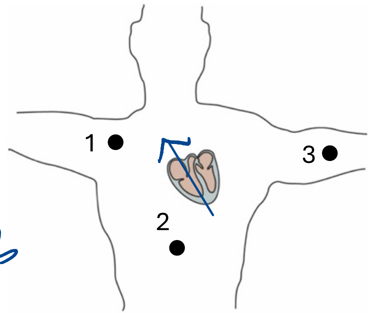
66%

$\frac{\Delta V_c}{d} = E \Rightarrow \Delta V_{mid} = \frac{\Delta V_c}{2} = \frac{Ed}{2}$

$= \frac{(1.2\times10^4 N/C)(5.0\times10^{-2}m)}{2}$

$= 300 V$

10. [5 pts] An ECG machine has three electrodes connected to a patient's body at the points designated 1, 2 and 3 in the figure. At one instant, the readings of the electric potential at those electrodes shows that $V_1 > V_3 > V_2$. Choose the correct orientation of the heart's dipole moment vector at that instant.
    - A. ↓
    - B. ↗
    - C. ↙
    - [✓ D. ↖]
    - E. ↘



62%

Dipole moment vector points in the direction of increase of V ⇒ points towards (1)

Lowest point is (2) ⇒ tail of dipole would be there

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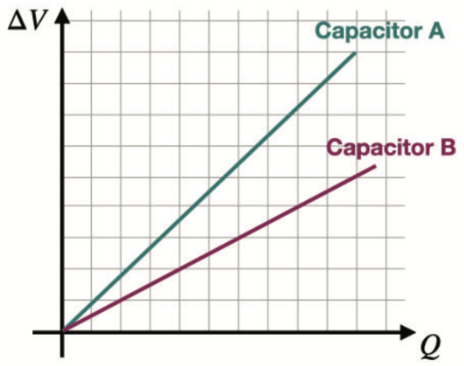
11. [5 pts] You are exploring the behavior of two different capacitors, Capacitor A and Capacitor B. You apply a varying amount of charge to each capacitor and measure the potential difference across them. Using your data, you develop two models shown in the graph. Which of the following would explain your data?



For the answer choices,

d_A represents the plate separation of capacitor A,
d_B represents the plate separation of capacitor B,
A_A represents the plate area of capacitor A, and
A_B represents the plate area of capacitor B.

46%

[✓ A. $d_A > d_B$ and $A_A = A_B$]
B. $d_A < d_B$ and $A_A = A_B$
C. $d_A = d_B$ and $A_A = A_B$
D. $d_A = d_B$ and $A_A > A_B$
E. None of these are possible.

slope is $\frac{\Delta V}{Q} = \frac{1}{C}$

$\Rightarrow C_B > C_A$

$\Rightarrow \frac{\cancel{\epsilon_0} A_B}{d_B} > \frac{\cancel{\epsilon_0} A_A}{d_A}$

If $d_A = d_B = A_B > A_A$

If $A_A = A_B \Rightarrow \frac{1}{d_B} > \frac{1}{d_A} \Rightarrow d_B < d_A$

12. [5 pts] Two resistors of the same length L are made from wire of resistivity ρ. Resistor 1 has twice the cross-sectional area of resistor 2. What is the relationship between the resistances R_1 and R_2?

63%

A. $R_1 = R_2$
B. $R_1 = 2R_2$
[✓ C. $R_1 = \frac{1}{2}R_2$]
D. $R_1 = 4R_2$
E. $R_1 = \frac{1}{4}R_2$

$$\left.\begin{aligned} L_1 &= L_2 = L \\ \rho_1 &= \rho_2 = \rho \\ A_1 &= 2A_2 \end{aligned}\right\} \Rightarrow \quad R_1 = \frac{\rho L}{A_1} = \frac{\rho L}{2A_2} = \frac{R_2}{2}$$

Lecture free response (20 points total)

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Lecture free response (20 points total)

Lecture Free Response [20 pts total]: Show work and/or explain reasoning where indicated.

The electric field inside a vacuum-filled parallel-plate capacitor is measured to be $400\ \mathrm{N/C}$. Each plate has an area of $1.6 \times 10^{-3}\mathrm{m}^2$.

13. [5 pts] What is the absolute value of charge on either plate of the capacitor?
Solution:

85%

$$E = \frac{Q}{\epsilon_0 A} \Rightarrow Q = \epsilon_0 EA = (8.85 \times 10^{-12}\ \mathrm{F/m})(400\ \mathrm{N/C})(1.6 \times 10^{-3}\mathrm{m}^2)$$
$$= \boxed{5.6 \times 10^{-12}\mathrm{C}}$$

Rubric:
2 pts State relationship $E = Q/(\epsilon_0 A)$
2 pts Rearrange the equation to solve for Q
1 pt $Q = 5.6 \times 10^{-12}\mathrm{C}$
0 Incorrect/blank

14. [5 pts] The capacitor is connected to a 1.5 V battery. How far part are the plates?
Solution:

$$E = \frac{\Delta V_\mathrm{C}}{d} \Rightarrow d = \frac{\Delta V_\mathrm{C}}{E} = \frac{1.5\ \mathrm{V}}{400\ \mathrm{N/C}} = \boxed{3.7 \times 10^{-3}\mathrm{m}}$$

77%

Rubric:
2 pts State relationship $E = \Delta V_\mathrm{C}/d$
2 pts Rearrange the equation to solve for d
1 pt $d = 3.7 \times 10^{-3}\mathrm{m}$
0 incorrect/blank
Alternative Rubric:
2 pts Finds $C = Q/\Delta V$
2 pts Finds d from $C = \epsilon_0 Q/d$
1 pt $d = 3.7 \times 10^{-3}\mathrm{m}$ (or consistent with previous Q)

15. [5 pts] A charged point particle is released midway between the plates. The particle accelerates towards the lower plate, in the direction of higher potential. What is the sign of the particle's charge and what are the signs of the charge on capacitor's plates? Explain your reasoning briefly.

Sign of particle's charge:

72%

Negative. Since the particle moves from rest, its kinetic energy has increased, which means the potential energy decreased ($\Delta U_\mathrm{elec} < 0$). But $\Delta U_\mathrm{elec} = q\Delta V$ and we are told that $\Delta V > 0$ (potential increased), therefore, q must be negative.

Sign of charge on upper plate:

Negative. Since the potential closer to the lower plate was higher, the upper one must have a lower potential, hence it's negative.

Sign of charge on lower plate:

Positive. For the same reasoning in the previous part.

Rubric:

1 pt $Q_{particle} < 0$
1 pt $Q_{upper} < 0$
1 pt $Q_{lower} > 0$
1 pt Explanation for particle charge sign
1 pt Explanation for plate charge signs
0 incorrect/blank

16. [5 pts] We now disconnect the battery from the charged capacitor (ensuring the plates are kept insulated), **then** insert a piece of plastic of dielectric constant $\kappa = 2$ between the plates. Calculate the new value of the potential difference ΔV_C and the new value of charge.

Solution:

57%

When we insert the dielectric with $\kappa = 2$, the capacitance will double; $C = \kappa C_0 = 2C_0$. Since the plates are insulated, the charge will stay the same as before the insertion;

$$\boxed{Q = Q_0}$$

The potential would then be obtained from:

$$\Delta V_C = Q/C \Rightarrow Q_0/(2C_0) = \boxed{\Delta V_C/2}$$

This should make sense, since the charge hasn't changed, but the induced field inside the dielectric has weakened the original field by the plates, and hence the potential has decreased.

Rubric:

2 pts State that Q is unchanged

1 pt Recognize that capacitance increased

1 pt Use the relationship $\Delta V_C = Q/C$

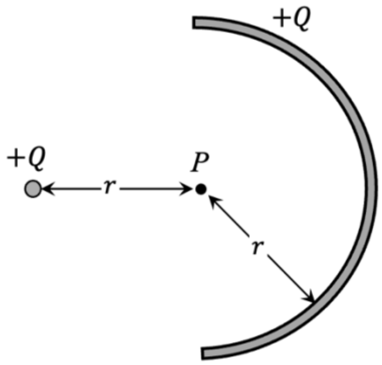
Value of ΔV_C

1 pt State that ΔV_C has halved (or is equal to 0.75 volts using info from Q14)

0.5 pt State that ΔV_C decreased but did not state by what factor (or the factor is incorrect).

0 incorrect/blank

Tutorial Free Response [20 pts total]: Problems 17-20. Show work and/or explain reasoning where indicated.

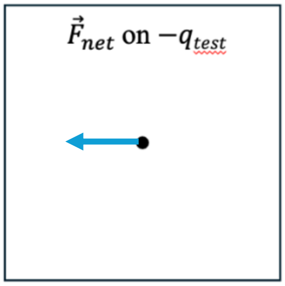


The next two questions are related to the following scenario.

A thin semicircular rod has total charge $+Q$ uniformly distributed along it, and a point charge $+Q$ is placed as shown.

58%

17. [5 pts] Suppose a negative test charge, $-q_{test}$, is placed at point *P*. In the space provided below, sketch a vector to represent the net electric force on $-q_{test}$. **Explain your reasoning**.



We can treat the $+Q$ point charge and the rod as being made up many smaller charges Δq that add up to total charge $+Q$. In the case of the $+Q$ point charge, all those Δq charges are at the same location, all exerting attractive forces to the left on $-q_{test}$. In the case of the rod, each Δq charge is the same distance from $-q_{test}$ as the point charge was and exerts an attractive force. However, due to the symmetry about the horizontal, the vertical components of the forces from the Δq charges on opposite portions of the rod will cancel, leaving only horizontal components remaining. Thus, the rightward force from the rod is smaller than the leftward force from the $+Q$ point charge, so the net force is to the left.

Rubric:

1 pt Treat the objects as being made of many smaller charges

2 pts Made a complete argument using superposition

1 pt Incomplete superposition argument

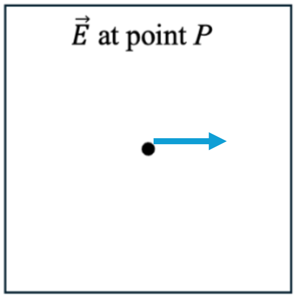
1 pt Recognize that the force from the rod is less than the force from the $+Q$ charge.

1 pt Correct answer (to the left)

0 incorrect/blabk

18. [5 pts] In the space provided below, sketch a vector to represent the net electric field at point P. **Explain your reasoning**.

48%



The electric field is related to the electric force a point charge experiences through $\vec{F} = q\vec{E}$. Since the charge $-q_{test}$ is negative in this case, the direction of the electric field is opposite the direction of the electric force.

Rubric:

Explanation:

3 pts using $\vec{F} = q\vec{E}$

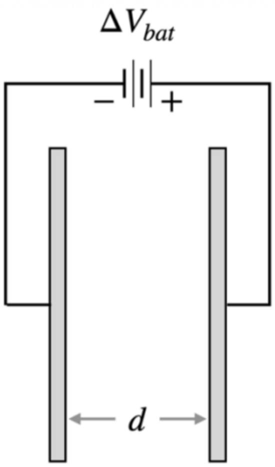
1.5 pts Partially correct explanation

2 Correct answer (to the right), or answer consistent with question 17 answer.

0 incorrect/blank

The next two questions are related to the following scenario.

A capacitor with adjustable plates is connected to a battery. In its initial configuration, the plates are a distance d apart and the battery has a potential difference of ΔV_{bat} as shown. As a result, the charge on one plate is $+Q_o$, the charge on the other plate is $-Q_o$, and the electric field between the plates is E_o.



The circuit is then adjusted. In its final configuration, the plates are a distance $2d$ apart and the potential difference of the battery is increased to $6\Delta V_{bat}$.

19. [5 pts] After the circuit is adjusted, what is the charge on the positive plate? Express your answer in terms of Q_o. **Explain your reasoning**.

72%

Since d was doubled and $C = \epsilon_o A/d$, we can say that the capacitance has been halved. Since capacitance was halved and the potential difference across the capacitor was increased by a factor of 6, we can use the relationship $Q = C\Delta V$ to determine that the charge on the capacitor at the end is

$$Q_f = \left(\frac{C_o}{2}\right)(6\Delta V_{bat}) = 3C_o\Delta V_{bat} = 3Q_o.$$

Rubric:
1 pt State the relationship $C = \epsilon_o A/d$

1 pt Recognize that C is halved
1 pt State the relationship $Q = C\Delta V$
2 pts Correct answer ($Q_f = 3Q_o$)
Answer:
2 pts Correct answer ($Q_f = 3Q_o$)
1 pt State that Q increased but did not state by what factor (or the factor is incorrect)
0 incorrect/blank

20. [5 pts] After the circuit is adjusted, what is the electric field strength between the plates? Express your answer in terms of E_o. **Explain your reasoning**.

72%

The field strength is related to the charge and the plate area through $E = \frac{Q}{A\epsilon_o}$. Since the charge on the plates increased from Q_o to $3Q_o$ and the plate area was unchanged, the field strength must now be three times as large, or $3E_o$.

Rubric:

2 pts State the relationship $E = \frac{Q}{A\epsilon_o}$.

1 pt Mention how Q has changed (determined in Q19)

2 pts Correct answer ($3E_0$) or an answer consistent with student's answer to Q19

0 incorrect/blank

Alternate rubric:

2 pts State the relationship $E = \frac{\Delta V_C}{d}$

1 pt Discuss how relevant quantities have changed

2 pts Correct answer ($3E_o$)

0 blank/incorrect