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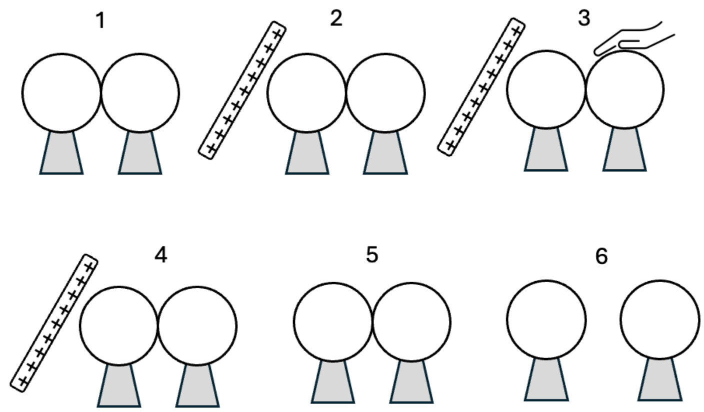
I. Lecture multiple choice (45 points – 9 questions)

1) (5 pts) A pair of uncharged identical metal spheres on insulating stands are taken through the following series of steps:
   1) The spheres are initially in contact.
   2) A **positively** charged rod is brought near to, but doesn't touch, the left sphere.
   3) While the rod is in place, a person touches the right sphere.
   4) The person removes their hand.
   5) The rod is removed.
   6) The spheres are carefully separated (only their stands are touched).



After the spheres are separated (step 6), what is the excess charge on each sphere?

A. The right sphere has zero excess charge, and the left sphere has an excess of negative charge.
B. The right sphere has an excess of positive charge, and the left sphere has an excess of negative charge.
C. The right sphere has an excess of negative charge, and the left sphere has an excess of positive charge.
D. Both spheres have an excess of positive charge.
E. Both spheres have an excess of negative charge.

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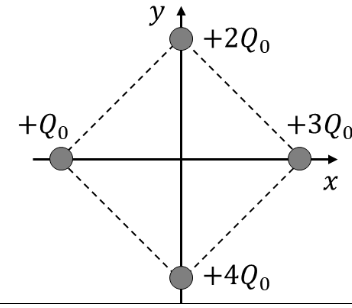
2) (5 pts) Two charged point particles, A and B, are arranged on the x-axis at $x_A = 0$ and $x_B = 2d$. If a third charged particle C is placed at $x_C = 3d$, it will remain at rest. What is the charge on particle B in terms of the charge on particle A?

A. $q_B = -3\,q_A$
B. $q_B = -9\,q_A$
C. $q_B = -1/3\,q_A$
D. $q_B = -1/9\,q_A$
E. None of the above.

3) (5 pts) Four point particles are fixed at the corners of a $0.01\text{m} \times 0.01\text{m}$ square, as shown. $Q_0 = 1.2 \times 10^{-9}\text{C}$. Find the x and y components of the electric field at the origin $(x, y) = (0,0)$.



A. $\vec{E}(0,0) = \left(+2.2 \times 10^5\ \frac{\text{N}}{\text{C}}\right)\hat{\imath} + \left(+2.2 \times 10^5\ \frac{\text{N}}{\text{C}}\right)\hat{\jmath}$

B. $\vec{E}(0,0) = \left(-1.5 \times 10^3\ \frac{\text{N}}{\text{C}}\right)\hat{\imath} + \left(-1.5 \times 10^3\ \frac{\text{N}}{\text{C}}\right)\hat{\jmath}$

C. $\vec{E}(0,0) = \left(-2.2 \times 10^5\ \frac{\text{N}}{\text{C}}\right)\hat{\imath} + \left(+2.2 \times 10^5\ \frac{\text{N}}{\text{C}}\right)\hat{\jmath}$

D. $\vec{E}(0,0) = \left(-2.2 \times 10^5\ \frac{\text{N}}{\text{C}}\right)\hat{\imath} + \left(+4.3 \times 10^5\ \frac{\text{N}}{\text{C}}\right)\hat{\jmath}$

E. $\vec{E}(0,0) = \left(+2.2 \times 10^5 \frac{\text{N}}{\text{C}}\right)\hat{\imath} + \left(-2.2 \times 10^5\ \frac{\text{N}}{\text{C}}\right)\hat{\jmath}$

The correct answer should be $\vec{E}(0,0) = \left(-4.3 \times 10^5\ \frac{\text{N}}{\text{C}}\right)\hat{\imath} + \left(+4.3 \times 10^5\ \frac{\text{N}}{\text{C}}\right)\hat{\jmath}$ so we gave credit to C and D, which had the x and y components in the correct directions.

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4) (5 pts) A very long thin wire with a uniform linear charge density λ is arranged horizontally on a table. A point particle with charge q and mass m remains at rest when placed distance d directly above the wire. Which of the following is an expression for q? Note that g is the acceleration due to gravity.

A. $q = d\sqrt{\frac{mg}{4\pi\epsilon_0}}$

B. $q = \frac{mg}{4\pi\epsilon_0}d^2$

C. $q = \lambda d$

D. $q = 2\pi\epsilon_0 mgd$

E. $q = \frac{2\pi\epsilon_0 mgd}{\lambda}$

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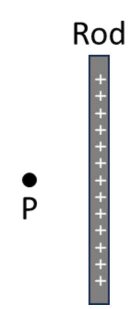
5) (5 pts) A rod has a total charge Q uniformly distributed along its length. Which of the following changes will increase the magnitude of the electric field at position P?



A. Make the rod longer without changing the total charge, Q.

B. Make the rod shorter without changing the total charge, Q.

C. Move the position P farther from the rod.

D. None of the above.

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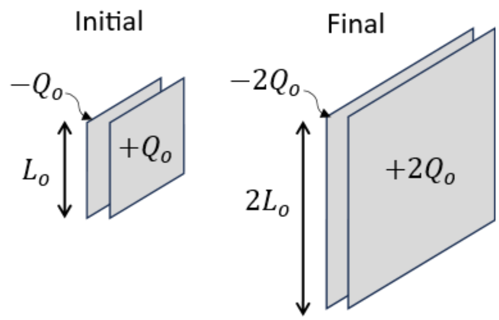
6) (5 pts) Initially a parallel-plate capacitor consists of two square plates each of side length L_o, and with charge $+Q_o$ on one plate and $-Q_o$ on the other plate. Then the sides of the plates are doubled and the amount of charge on both plates is doubled, as shown. Assuming the electric field is uniform between the plates of the capacitor and zero outside, how does the final electric field between the plates, E_f, compare to the initial electric field between the plates, E_o?



A. $E_f = E_o$
B. $E_f = 2E_o$
C. $E_f = 4E_o$
D. $E_f = \frac{1}{2}E_o$
E. $E_f = \frac{1}{4}E_o$

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7) (5 pts) A particle with a mass of 1.6×10^{-14} kg and a charge of 3.2×10^{-9} C is launched from the negative plate toward the positive plate of a parallel-plate capacitor with an initial velocity of 4.0×10^{3} m/s. If the magnitude of the electric field between the plates of the capacitor is 2.5×10^{4} N/C, how far does the particle travel before coming to a momentary stop?

A. 3.2×10^{-3} m
B. 8.0×10^{-7} m
C. 1.6×10^{-3} m
D. 1.6×10^{-6} m
E. 4.0×10^{-7} m

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8) (5 pts) From the choices below identify the **one** combination of electric field, $\vec{E}$, area vector, $\vec{A}$, and resulting electric flux, Φ, that are physically consistent.

A. $\Phi = -250\,\frac{\text{N}\cdot\text{m}^2}{\text{C}}\,\hat{\jmath}$ $\quad \vec{E} = \left(+50\,\frac{\text{N}}{\text{C}}\right)\hat{\imath} + \left(-50\,\frac{\text{N}}{\text{C}}\right)\hat{\jmath}$ $\quad \vec{A} = +5\text{m}^2\,\hat{\jmath}$

B. $\Phi = 0\,\frac{\text{N}\cdot\text{m}^2}{\text{C}}$ $\quad \vec{E} = \left(+50\,\frac{\text{N}}{\text{C}}\right)\hat{\imath} + \left(-50\,\frac{\text{N}}{\text{C}}\right)\hat{\jmath}$ $\quad \vec{A} = +5\text{m}^2\,\hat{\jmath}$

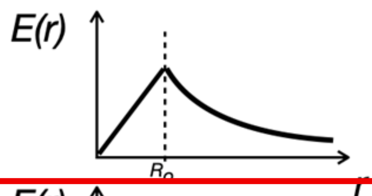
C. $\Phi = +500\,\frac{\text{N}\cdot\text{m}^2}{\text{C}}\,\hat{\jmath}$ $\quad \vec{E} = \left(+50\,\frac{\text{N}}{\text{C}}\right)\hat{\imath} + \left(+50\,\frac{\text{N}}{\text{C}}\right)\hat{\jmath}$ $\quad \vec{A} = +5\text{m}^2\,\hat{\jmath}$

D. $\Phi = +250\,\frac{\text{N}\cdot\text{m}^2}{\text{C}}$ $\quad \vec{E} = \left(+50\,\frac{\text{N}}{\text{C}}\right)\hat{\imath} + \left(-50\,\frac{\text{N}}{\text{C}}\right)\hat{\jmath}$ $\quad \vec{A} = +5\text{m}^2\,\hat{\imath}$

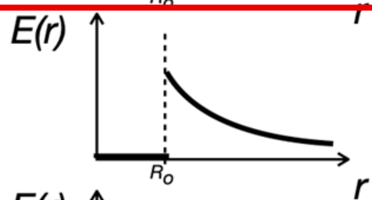
E. $\Phi = +250\,\frac{\text{N}\cdot\text{m}^2}{\text{C}}$ $\quad \vec{E} = \left(+50\,\frac{\text{N}}{\text{C}}\right)\hat{\imath} + \left(-50\,\frac{\text{N}}{\text{C}}\right)\hat{\jmath}$ $\quad \vec{A} = -5\text{m}^2\,\hat{\imath}$

9) (5 pts) A very long, uniformly charged, non-conducting cylinder has radius R_o. Which one of the following graphs shows the magnitude of the electric field as a function of the distance from the center of the cylinder, r?

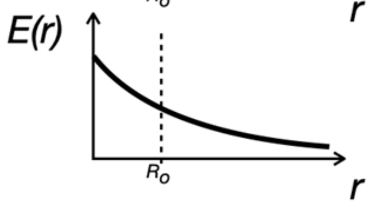
A.



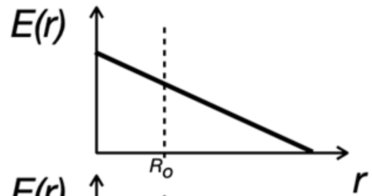
B.



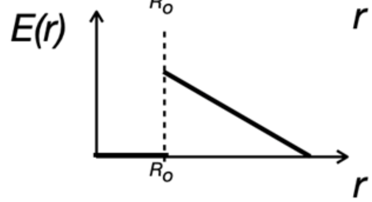
C.



D.



E.



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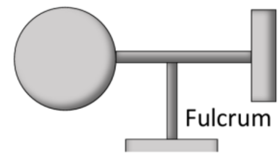
II. Lab multiple choice (15 points)

10) (5 pts) In lab A1, suppose that your lab teammate may have charged a metal sphere on a fulcrum and an acrylic rod while you are looking away. When you bring the rod close to the sphere, they are attracted to each other. Which of the following conclusions can you make based on this observation?



Conclusion i: The rod and the sphere are oppositely charged.
Conclusion ii: The sphere is neutral while the rod is charged.
Conclusion iii: The rod and the sphere are similarly charged.

A. Only conclusion i could be true.
B. Only conclusion iii could be true.
C. Either conclusion i or conclusion ii could be true but not conclusion iii.
D. Either conclusion ii or conclusion iii could be true but not conclusion i.
E. All of the conclusions, i, ii, and iii, could be true.

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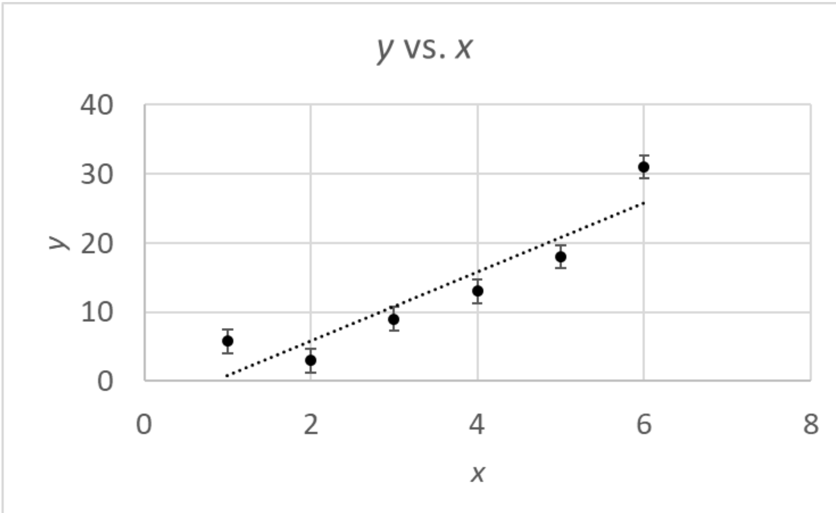
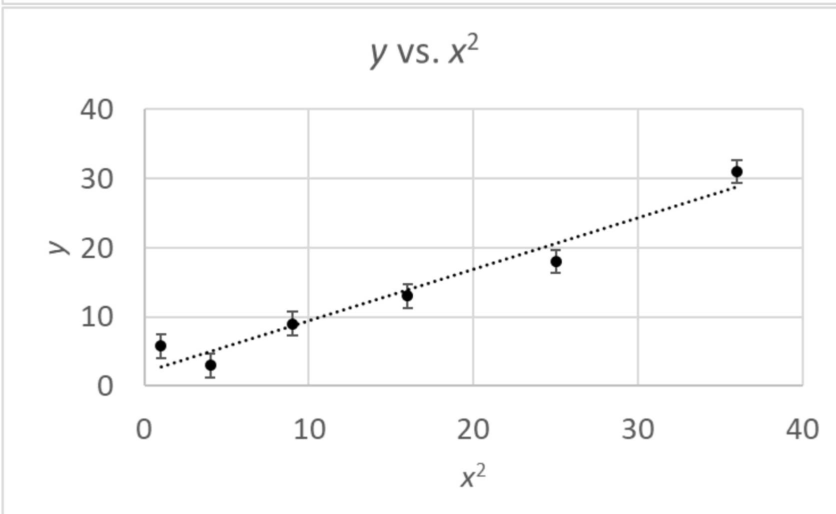
11) (5 pts) In the VR simulation each member of a team measures the force on a particle, and they obtain the following results: 0.56 N, 0.56 N, 0.56 N, and 0.56 N. Based on the rules for this course, which one of the following statements is most correct?

A. There is no uncertainty in their measurements.
B. There is a random uncertainty of 0.005 N.
C. There is an instrumental uncertainty of 0.005 N.

12) (5 pts) You measure y at various values of x. The top graph shows y vs. x, and the bottom graph shows y vs. x^2. Each graph has a linear best-fit line.





Suppose that you are testing two models.
Model 1: $y = mx + b$
Model 2: $y = mx^2 + b$

Based on these graphs, what can you conclude?

A. The data supports only Model 1.
B. The data supports only Model 2.
C. The data supports both Models 1 and 2.
D. The data does not support either Model 1 or Model 2.
E. We do not have enough information to conclude anything.

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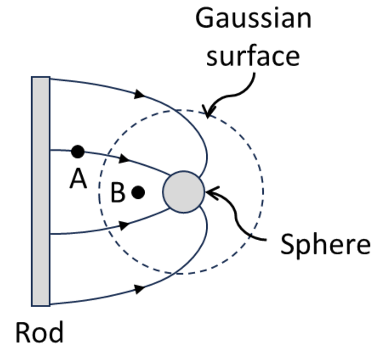
III. Lecture free response (25 points)

Use the following scenario for the next three questions.

A charged rod and a charged sphere are placed next to each other and held in place. The figure on the right shows the electric field lines.



13) (5 pts) Is the electric field at point A *greater than*, *less than*, or *equal to* that at point B? Explain your reasoning.

Less than. The magnitude of the electric field is related to the spacing between electric field lines with greater magnitude where the spacing is closer, and the spacing between field lines at A is less than that at B.

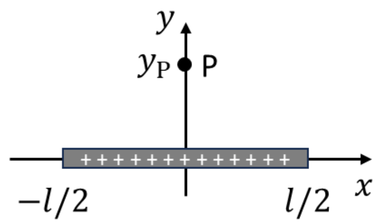
14) (5 pts) Is the absolute value of the charge on the rod *greater than*, *less than*, or *equal to* the absolute value of the charge on the sphere? Explain your reasoning.

Equal to. Electric field lines start on positive charges and end on negative charges. All the field lines that start on the rod end on the sphere, so there must be as much positive charge on the rod as there is negative charge on the sphere.

15) (6 pts) If the charged rod were removed would the flux through the Gaussian surface *increase*, *decrease* or *remain the same*? Explain your reasoning.

Remain the same. Gauss's law states that the flux through a closed surface is given by $\Phi_e = \frac{Q_{\text{in}}}{\epsilon_0}$. If the rod is removed the charged enclosed by the Gaussian surface does not change, so the flux through the surface does not change.

16) (9 pts) A thin rod lies on the x axis between $x = -l/2$ and $x = l/2$. Charge q is uniformly distributed along the length of the rod. Consider point P which is at y_P on the y axis. Set up an integral in terms of variables given and constants that calculates the y component of the electric field at point P, $E_{P,y}$. You do not need to evaluate the integral, i.e. you only need to fill in the parts within the parentheses in the expression below.



$$E_{\mathrm{P},y} = \int_{(-l/2)}^{(l/2)} \left(K \frac{q}{l} \frac{1}{(x^2 + y_{\mathrm{P}}^2)} \frac{y_{\mathrm{P}}}{\sqrt{x^2 + y_{\mathrm{P}}^2}} \right) d(x)$$

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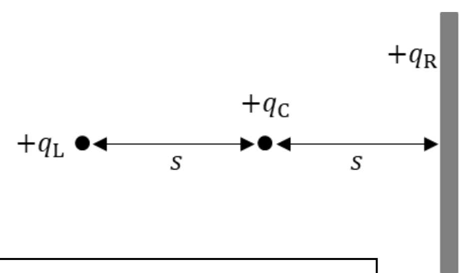
IV. Tutorial free response (15 points)

Use the following scenario for the next three questions.

17) (5 pts) A charged rod is placed near a neutral metal ball. The rod does not touch the ball, and there is no spark between them. Does the ball exert any electric force on the rod? If so, explain the mechanism and state whether the force is attractive or repulsive. If not, explain why not.

The ball exerts an **attractive force** on the rod. The electrons in the metal ball are free to move as the ball is a conductor. When the charged rod is brought near the metal ball, the free electrons move such that the surface on the ball closer to the rod is charged oppositely from rod, and the surface on the ball farther away from the rod is similarly charged to the rod since like charges repel, and opposite charges attract. Since electric force depends on distance (the closer, the stronger), the attraction between the rod and the "near" surface of the ball is stronger than the repulsion between the rod and the "far" surface on the ball. This causes overall attractive force between the rod and the ball.

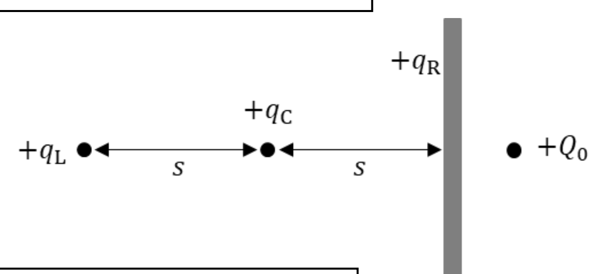
18) (6 pts) A particle with a positive charge $+q_C$ is placed equidistant between another particle with a positive charge $+q_L$ on the left and the center of a uniformly charged rod with a total positive charge $+q_R$ on the right as shown. If the net force acting on the center charge is zero, is q_L *greater than*, *less than*, or *equal to* q_R? Explain your reasoning.



Charged rod

Less than. The force due to the left particle is to the right as the positive charge repels the positive charge at the center. The force due to the rod is to the left for a similar reason. So, for the net force on the center charge to be zero, the magnitudes of these forces must be equal. For the force due to the rod, we can calculate the force on $+q_C$ by splitting the rod into small charge elements dq along the rod. Consider the force on $+q_C$ due to each dq, and vector sum all the force vectors. Most dq's in the rod are farther from $+q_C$ than the left particle (at distance s). This means that the magnitude of $+q_L$ must be less than the sum of the magnitudes of dq's, $+q_R$. The charge elements dq's on the rod away from the center result in force that has a vertical component that cancels with another force that is resulted from dq that is the same distance from the center on the other side on the rod. Due to this cancelation, we can conclude that $+q_L$ must be less than the sum of the magnitudes of dq's, $+q_R$.

19) (4 pts) Suppose that you add another particle with a positive charge $+Q_0$ to the right of the rod in the scenario described in Q18, as shown. After introducing this new charge, does the net force on the center charge with $+q_C$ *point to the right*, *point to the left*, or *remain zero*? Explain your reasoning.



Charged rod

Points to the left. The original net force was zero. The force due to the new particle points to the left because similar charges repel. The new net force is the vector sum of the original net force plus this new force to the left, so the new net force is to the left.