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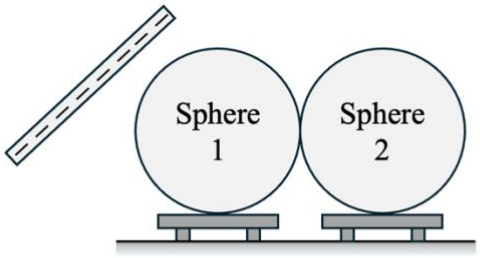
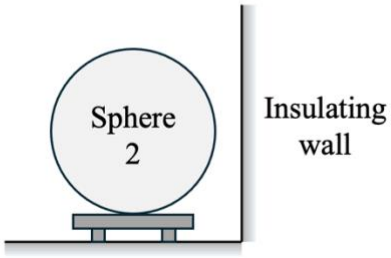
I. [60 pts] Multiple Choice (5 pts each): Mark your answer on BOTH the bubble sheet and this page.

1. [5 pts] Two identical and uncharged conducting spheres, 1 and 2, are initially in contact. The spheres are on insulating stands. Consider the following sequence:

   i. A negatively charged rod contacts sphere 1 and the rod is then removed.
   ii. Sphere 2 is then removed and brought into proximity but does not touch an insulating wall.



Step i

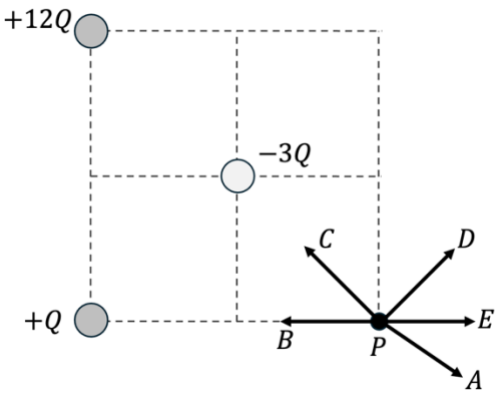


Step ii

   The electrostatic force on sphere 2 by the wall:

   A. points away from the wall.
   B. points toward the wall.
   C. points upward.
   D. is zero.
   E. There is not enough information

2. [5 pts] Three point charges ($+12Q, -3Q$ and $+Q$) are arranged as shown in the figure at right. A *positive* point charge is placed at point *P* in the lower right corner. Which arrow (A-E) best represents the direction of the net electric force on the *positive* point charge at point *P*?



   A. Arrow A
   B. Arrow B
   C. Arrow C
   D. Arrow D
   E. Arrow E

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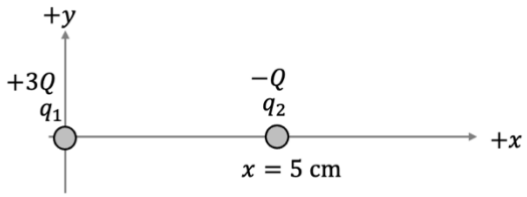
3. [5 pts] Two charges are placed along the x-axis, with charge $q_1 = 3Q$ at $x = 0$ and charge $q_2 = -Q$ at $x = 5$ cm. At what position should charge $q_3 = +25Q$ be placed such that the net force on q_1 is zero?



A. $x = 125$ cm

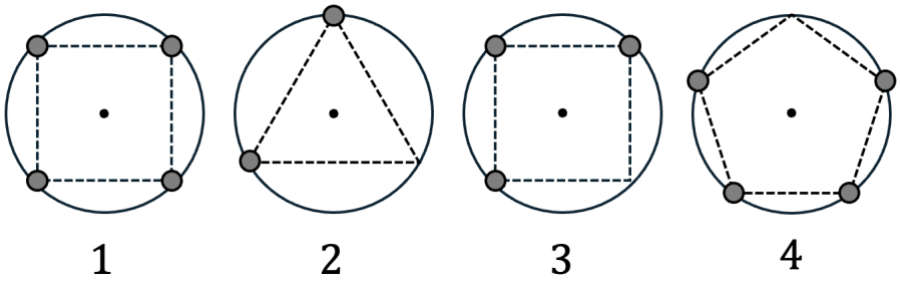
B. $x = 25$ cm

C. $x = -25$ cm

D. $x = 1.0$ cm

E. $x = -1.0$ cm

4. [5 pts] Consider the following configurations of point charges arranged around a circle at the corners of equilateral polygons. All charges have the same sign and magnitude, and some of the corners do not have a charge as shown. Rank the electric field magnitudes at the center of each circle (indicated by the small black dot), from smallest to largest. Treat each configuration as independent from the others.



A. $E_2 < E_3 < E_4 < E_1$

B. $E_1 < E_2 < E_3 < E_4$

C. $E_1 < E_4 < E_3 < E_2$

D. $E_2 = E_3 = E_4 < E_1$

E. $E_1 < E_2 = E_3 = E_4$

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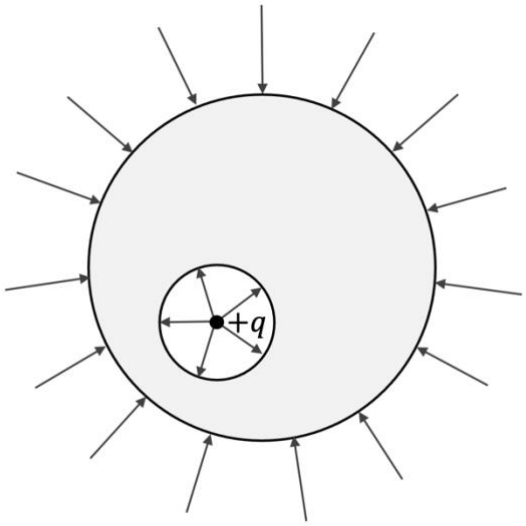
5. [5 pts] A conducting sphere has unknown charge Q. A known charge $+q$ is placed in a spherical void as shown above. What is the unknown charge Q?



A. $+q$

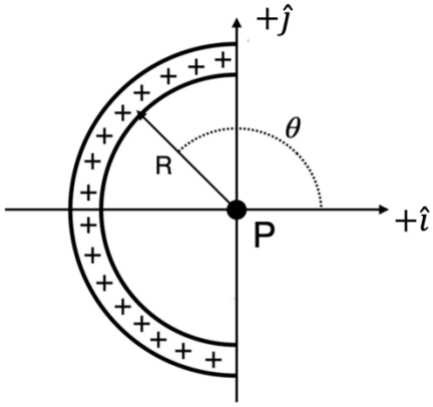
B. $-q$

C. $-3q$

D. $+4q$

E. $-4q$

6. [5 pts] A thin semi-circular conductor carries a charge of $+Q$. The charge is uniformly distributed, and you can neglect the thickness of the conductor. Which of the following expressions of the electric field at point P is correct?



A. $k\frac{Q}{\pi R^2}\int_{-\pi/2}^{\pi/2}\cos(\theta)\,d\theta\hat{\imath}$

B. $k\frac{Q}{\pi R^2}\int_{-\pi/2}^{\pi/2}\sin(\theta)\,d\theta\hat{\jmath}$

C. $k\frac{Q}{\pi R}\int_{-\pi/2}^{\pi/2}\cos(\theta)\,d\theta\hat{\imath}$

D. $k\frac{Q}{\pi R^2}\int_{-\pi/2}^{\pi/2}\sin(\theta)\,d\theta\hat{\imath} + k\frac{Q}{\pi R^2}\int_{-\pi/2}^{\pi/2}\cos(\theta)\,d\theta\hat{\jmath}$

E. None of the above

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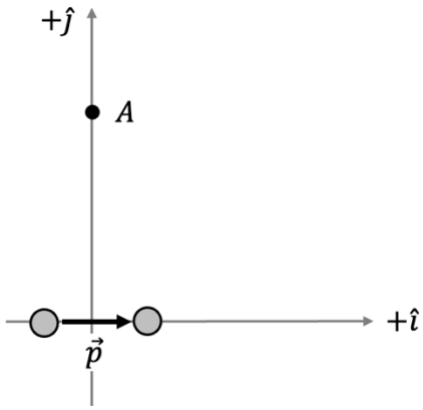
7. [5 pts] A dipole is centered on the origin as shown, with a dipole moment $\vec{p}$ that points along the *x*-axis. What is the electric field of the dipole at point *A* on the *y*-axis? Point *A* is far away from the dipole.



   A. $-k\frac{p}{|y|^3}\hat{\imath}$

   B. $+k\frac{p}{|y|^3}\hat{\imath}$

   C. $-k\frac{2p}{|y|^3}\hat{\imath}$

   D. $+k\frac{p}{|y|^3}\hat{\jmath}$

   E. None of the above

8. [5 pts] The electric force due to a uniform external electric field causes a torque of magnitude 10.0×10^{-9} N · m on an electric dipole oriented at 30.0 degrees from the direction of the external field. The dipole moment of the dipole is 7.00×10^{-12} C · m. What is the magnitude of the external electric field?

   A. 200 NC^{-1}

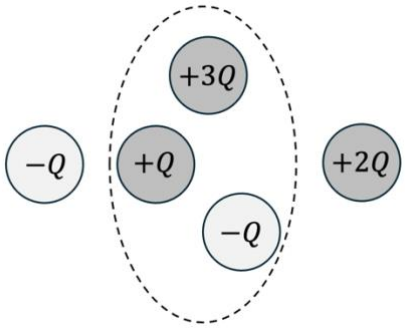
   B. 570 NC^{-1}

   C. 1650 NC^{-1}

   D. 2860 NC^{-1}

   E. None of the above

9. [5 pts] In the electric field line diagram for the charge arrangement shown in the figure, eight field lines emanate from the object of charge +1*Q*. What is the field line flux through the closed surface indicated by the dashed line?



   A. -24
   B. +8
   C. +24
   D. +32
   E. Not enough information

10. [5 pts] A positively charged hollow sphere of radius 1.00 m has a uniform surface charge density of 10.0 nC/m^2. Determine the magnitude of the electric field at a distance of 1.20 m from the center of the sphere.

   A. 78 N/C
   B. 145 N/C
   C. 785 N/C
   D. 880 N/C
   E. None of the above

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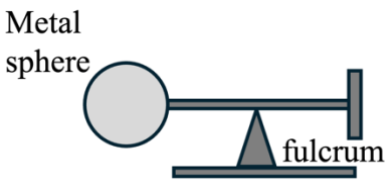
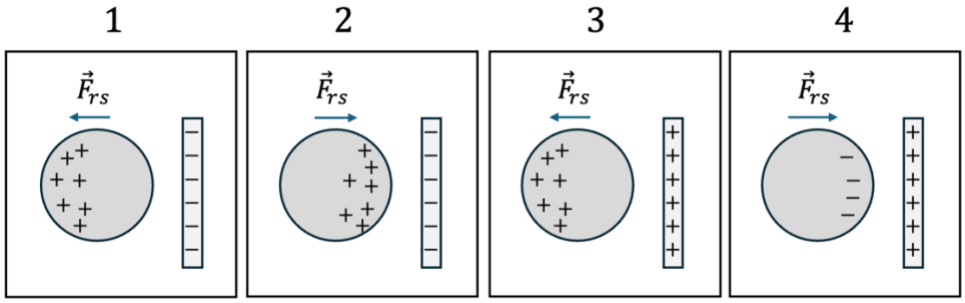
11. [5 pts] An initially uncharged metal sphere is placed on a fulcrum, as shown. The metal sphere is charged by scraping an insulating rod along the surface of the sphere (the rod had previously been rubbed with a cloth). The rod is charged again and brought close to the sphere but does not touch the sphere. The type of material the rod and cloth are made of is not known.



Consider the four diagrams below which show possible excess charge distributions on the sphere and rod, in addition to the direction of the force by the rod on the metal sphere, $\vec{F}_{rs}$. The diagrams are top view diagrams. Which of these diagrams illustrates a physically possible scenario?



A. Diagram 1 only

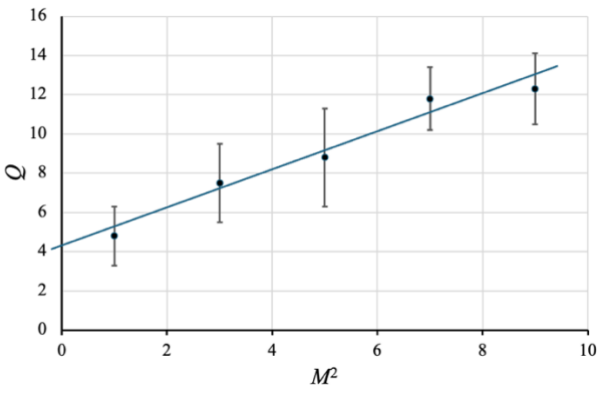
B. Diagram 2 only

C. Diagram 3 only

D. Diagrams 1 and 3

E. Diagrams 2 and 4

12. [5 pts] A student has formed the graph of quantity Q versus the square of quantity M (M^2). They have also drawn the best-fit line on the graph. Which of the following is true?



A. Quantity Q is proportional to quantity M.

B. Quantity Q is proportional to quantity M^2.

C. Quantity Q is linearly related to quantity M.

D. Quantity Q is linearly related to quantity M^2.

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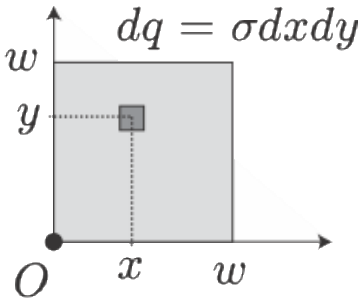
II. Lecture long-answer questions (20 points total)

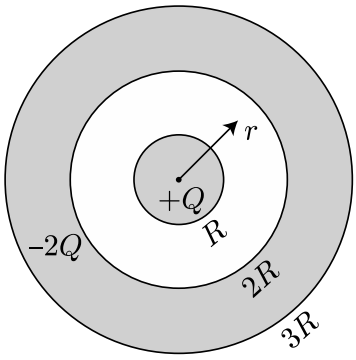
13. [4 pts] Consider a uniformly-charged square, charge density σ and side length w, positioned as shown. Set up the integral to compute the E field vector at the origin O, but **do not compute it!**

    Provide the **numerators** and **denominators** for the integral below. Your answer should depend only on x and y. Show your work.



$$\vec{E}_O = k\sigma \int_0^w dx \int_0^w dy \; \frac{\qquad\qquad}{\qquad\qquad}\hat{x} + \frac{\qquad\qquad}{\qquad\qquad}\hat{y}$$

For the next **4** problems, consider a spherical conductor, charge $+Q$, in the center of a spherical shell, charge $-2Q$. The geometrical parameters are defined in the figure. Assume $Q > 0$.



14. [4 pts] Draw field lines (SOLID lines) representing the electric field.

15. [4 pts] Draw a Gaussian surface (DASHED lines) that can be used to compute the E field at radius r for $R < r < 2R$.

16. [4 pts] What is the charge density, σ, at $r = 3R$? Show your work for full credit.

$\sigma =$

17. [4 pts] Calculate the electric field at $r = 4R$. Show your work for full credit.

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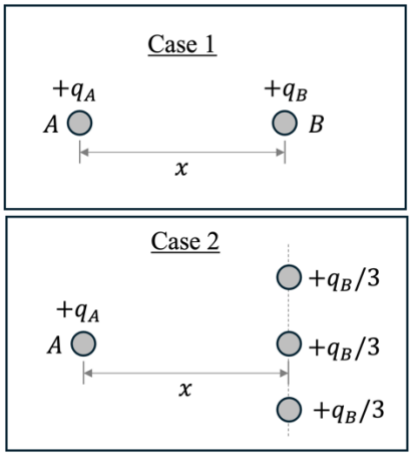
III. Tutorial and lab long answer questions (20 points total)

Use this context for questions 18 and 19.

Two experiments involve charged particles: In case 1, two positively charged particles, A and B are held a distance *x* apart as shown. The magnitude of the charge on particle A is *greater than* the magnitude of the charge on particle B ($|q_A| > |q_B|$).

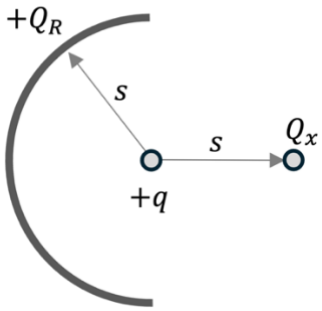


In case 2, particle B is replaced by three identical particles of charge $q_B/3$ that lie along a line as shown.

18. [5 pts] In case 1, is the magnitude of the electric force on particle A *greater than*, *less than*, or *equal to* the magnitude of the electric force on particle B? Explain.

19. [5 pts] Is the magnitude of the net electric force on particle A in case 2 *greater than*, *less than*, or *equal to* the magnitude of the electric force on particle A in case 1? Explain.

A thin semicircular rod has a total charge $+Q_R$ uniformly distributed along it. A positive point charge $+q$ and a charge (Q_x) of unknown sign and unknown magnitude are placed as shown. The $+q$ charge is equidistant from Q_x and from all points on the rod. It is known that the net force on the positive point charge $+q$ is zero.



20. [5 pts] What is the *sign* of the charge Q_x and is the magnitude of charge ($|Q_x|$) *greater than, less than,* or *equal to* the magnitude of the charge on the rod ($|Q_R|$)? Explain your reasoning.

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21. [5 pts] In Lab A2, a group places two charges 0.50 m apart and measures the force on one of the charges. They repeat the experiment three times and tabulate their data as shown. The students report the best estimate of the force as (4.0 ± 0.1) N.

Trial	Force (N)
1	3.52
2	3.46
3	3.68

Have the students made any errors? If yes, state so explicitly and describe what value they should report and why. If not, explain why their reported value is correct.