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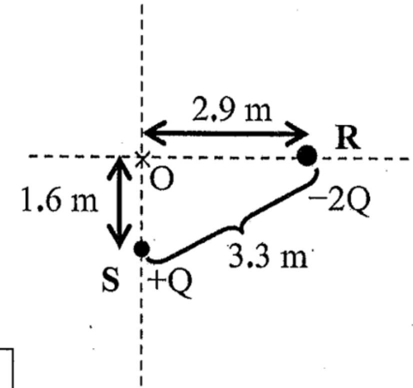
## I. Lecture Multiple Choice (45 pts)

Questions 1-5 are related to the following scenario.

Two point charges are fixed in place at points R and S as shown. The magnitude of $Q = 3.00$ μC. The dotted lines indicate horizontal and vertical coordinates, and the origin is labeled O.




1. [3 pts] Which choice best represents the direction of the electric force on the charge at S by the charge at R?

| ↗ | ↓ | ↑ | ↙ | none of these |
|---|---|---|---|---|
| **A** | **B** | **C** | **D** | **E** |

2. [3 pts] Which choice best represents the magnitude of this force?

   A. $9.0 \times 10^{-3}$ N

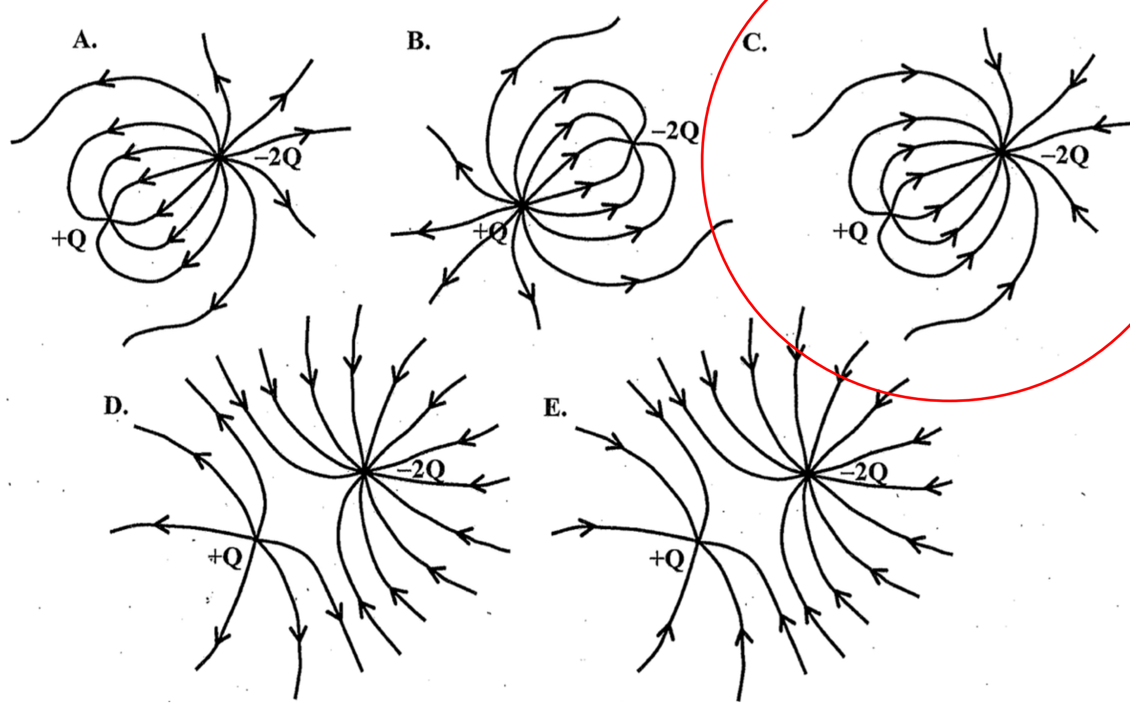
   B. $1.5 \times 10^{-2}$ N

   C. 4500 N

   D. $1.8 \times 10^{-2}$ N

   E. $7.2 \times 10^{-2}$ N

3. [3 pts] Which choice below best represents electric field lines for the above sources?



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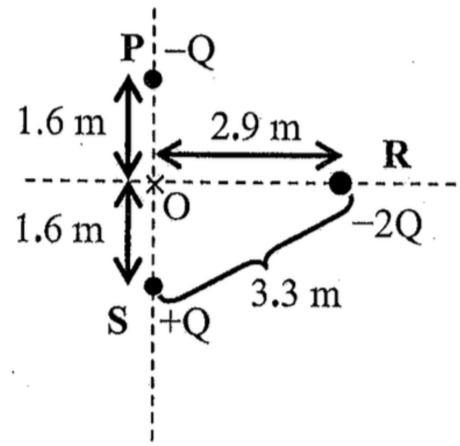
In questions 4-5, a third charge is now fixed in place at point P as shown. The magnitude of $Q = 3.00$ μC as before. The point labeled O is the origin.




4. [3 pts] Which choice below best represents the magnitude of the electric field at point O (the origin) due to these three source charges?

   A. $1.86 \times 10^4$ N/C

   B. $6.41 \times 10^3$ N/C

   C. $1.05 \times 10^4$ N/C

   D. $2.20 \times 10^4$ N/C

   E. None of these

5. [3 pts] Which choice below best represents the electric potential energy of this assembly of three charges?

   A. $+9.81 \times 10^{-2}$ J

   B. $+2.53 \times 10^{-2}$ J

   C. $-9.81 \times 10^{-2}$ J

   D. $-2.53 \times 10^{-2}$ J

   E. $-1.23 \times 10^{-1}$ $J$

6. [3 pts] A positively charged rod is brought near one side of an (initially) neutral metal ball, the other side of which is connected to ground. The rod does not touch the ball, and there are no sparks between them. The ground connection is then removed. After that, the rod is taken very far away. Which of the following statements is true?

   A. Electrons were transferred from ball to ground and the ball is now positively charged.

   B. Electrons were transferred from ground to ball and the ball is now positively charged.

   C. Electrons were transferred from ball to ground and the ball is now negatively charged.

   D. Electrons were transferred from ground to ball and the ball is now negatively charged.

   E. None of the above.

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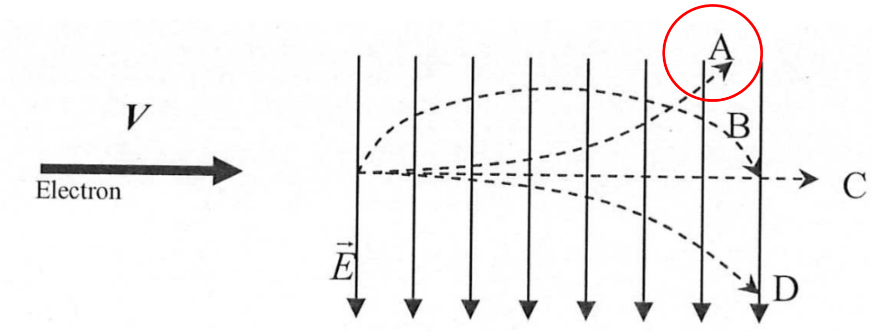
7. [3 pts] An *electron* moving with velocity $\boldsymbol{V}$ in the positive $x$-direction enters a region with a uniform electric field in the negative $y$-direction as shown. Which of the following paths A-D best represents the path of the electron?




8. [3 pts] A positively charged rod is brought near a conductor. You are not told the sign of the excess charge on the conductor (if any). When the conductor is in electrostatic equilibrium, which of following must be true? **Choose all that apply.**

   A. The total charge on the conductor must be zero.

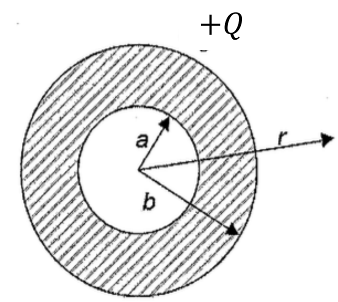
   B. The net electric field inside the conductor must be zero.

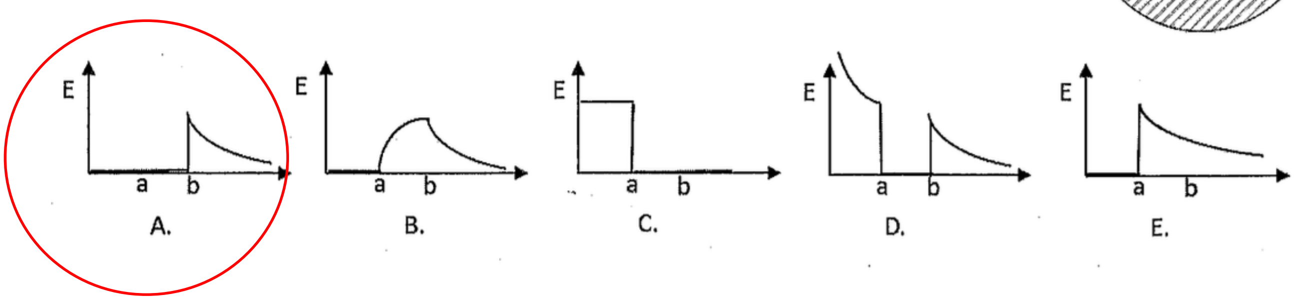
   C. Any charges on the conductor must be uniformly distributed.

   D. The electric field at the surface of the conductor is perpendicular to the surface.

   E. The charges in the conductor are at rest.

9. [3 pts] A conducting spherical shell of inner radius a and outer radius b has a net charge of $Q = +6\ \mu\text{C}$. Which of the plots below describes the radial component of the electric field as a function of distance from the center of the shell?



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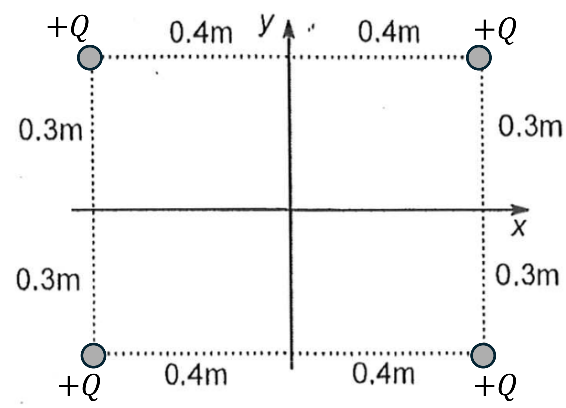
Use the diagram at right for the following two questions.

Four identical point charges with charge $Q = +6\ \mu\text{C}$ are placed at each corner of the rectangle shown at right.




10. [3 pts]What is the potential at the origin? Assume the potential is zero very far away.

    A. 0 V

    B. $107 \times 10^3$ V

    C. $345 \times 10^3$ V

    D. $432 \times 10^3$ V

    E. $604 \times 10^3\ V$

11. [3 pts] What would happen to a point charge placed at the origin? Assume the other charges are fixed in place.

    A. Neither a positive nor negative charge would move.

    B. A positive charge would move in the positive y direction and a negative charge would move in the negative y direction.

    C. A positive charge would move in the negative y direction and a negative charge would move in the positive y direction.

    D. A positive charge would move in the positive x direction and a negative charge would move in the negative x direction.

    E. A positive charge would move in the negative x direction and a negative charge would move in the positive x direction.

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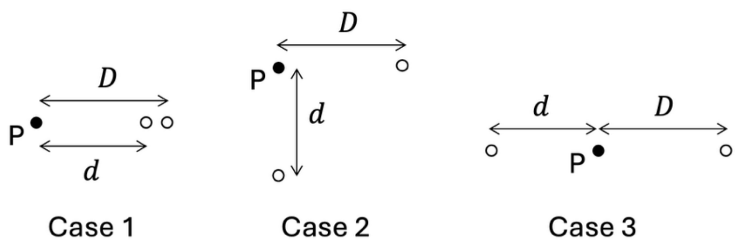
Use the following scenario for the next two problems.

The figure shows three arrangements of two protons (open circles), Case 1, 2 and 3. A point in space is indicated by the black dot and labeled P.




12. [3 pts] Rank the arrangements according to the magnitude of the net electric field at point R.

    A. Case 1 > Case 2 > Case 3

    B. Case 1 < Case 2 < Case 3

    C. Case 1 = Case 2 = Case 3

    D. Case 1 = Case 3 > Case 2

    E. Case 2 > Case 1 > Case 3

13. [3 pts] Rank the arrangements according to the amount of external work required to bring a third proton to point R from very far away. Assume the other protons are fixed in place.

    A. Case 1 > Case 2 > Case 3

    B. Case 1 < Case 2 < Case 3

    C. Case 1 = Case 2 = Case 3

    D. Case 1 = Case 3 > Case 2

    E. Case 2 > Case 1 > Case 3

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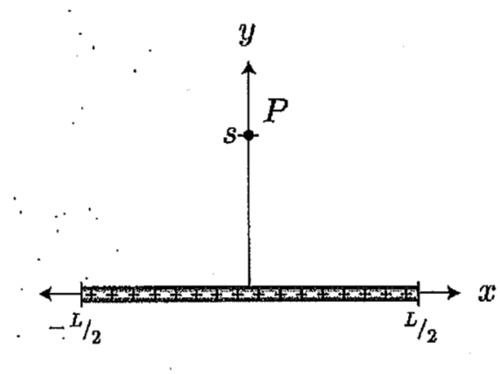
Use the following scenario for the next two problems.

Consider a thin rod of length $L$ with total charge $Q > 0$ uniformly spread along it as shown. The rod lies along the $x$-axis and is centered at the origin. Point $P$ is on the $+y$-axis a distance $s$ above the origin.




14. [3 pts] In which direction is the electric field at point $P$?

A. $+\hat{x}$

B. $-\hat{x}$

C. $+\hat{y}$

D. $-\hat{y}$

E. Not enough information.

15. [3 pts] In the limit $s \gg L$ (point $P$ is far away from the rod), which of these formulas is the best estimate for the magnitude of the electric field at point $P$?

A. $E_p \sim \frac{kQ}{s^2}$

B. $E_p \sim \frac{kQ}{s}$

C. $E_p \sim \frac{kQ^2}{s^2+L^2}$

D. $E_p \sim \frac{kQ}{sL}$

E. $E_p \sim \frac{2kQ}{sL}$

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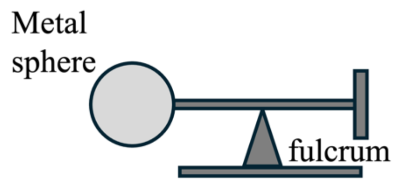
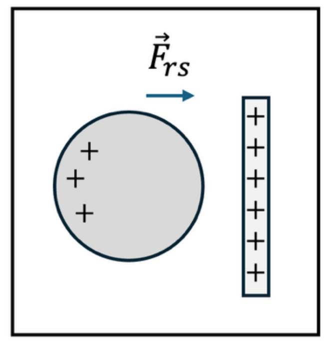
## II. Lab multiple choice (15 pts)

16. [4 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.




A student, David, draws the top-view diagram at right to show the excess charge distribution on the sphere and rod, in addition to the direction of the force by the rod on the metal sphere, $\vec{F}_{rs}$. Which of the following statements that identify errors in the diagram do you agree with, if any?




I. The sphere cannot be attracted to the rod.

II. The sphere and the rod must have opposite types of excess charge.

III. The excess charge on the sphere must be on right side of the sphere.

A. Statement I only

B. Statement II only

C. Statement III only

D. Statement II and III

E. I disagree with all of the above statements.

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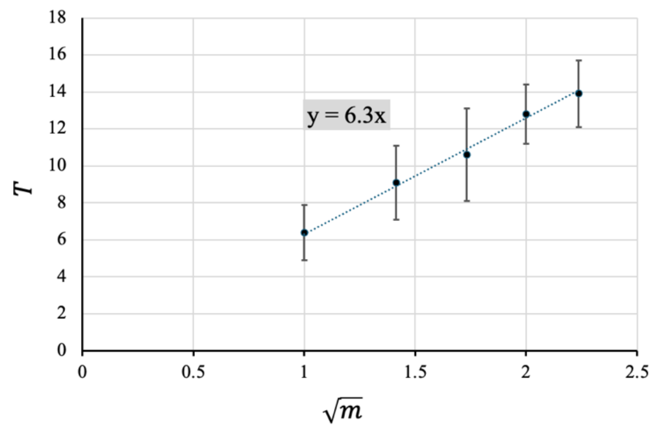
17. [4 pts] A lab team is testing a model that relates quantities $T$ and $m$. They form the plot shown at right by correctly following the rules discussed in the Phys 122 labs. Which of the following statements are correct? Select all that apply.




A. The quantity $T$ was the dependent variable.

B. The quantity $m$ was the dependent variable.

C. The following expression relates the two quantities: $T \propto m$.

D. The following expression relates the two quantities: $T = C\sqrt{m} + d$, where $C$ and $d$ are constants.

E. The largest mass used in the experiment is ~2.2 times larger than the smallest mass.

18. [4 pts] As part of Lab A2, a group measures the force exerted on a negative charge when it is placed 0.70 m from a positive charge. They carry out three trials and tabulate their data as shown. Which of the following best estimates of the force are consistent with the rules in this class:

| Trial | Force (N) |
|---|---|
| 1 | 5.38 |
| 2 | 5.25 |
| 3 | 5.62 |

I. $(5.417 \pm 0.188)$ N

II. $(5.42 \pm 0.19)$ N

III. $(5.4 \pm 0.2)$ N

A. I. only

B. II. only

C. III. only

D. I. and III. only

E. II. and III. only

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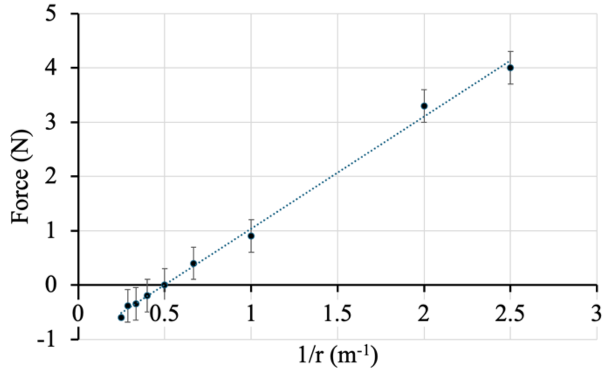
19. [3 pts] In Lab A3, students measured the force, $F$, on a minty particle, while varying the distance, $r$, from another minty particle. The students defined a positive reading on their force meter as an attractive force and a negative reading as a repulsive force. After they had gathered their data, they formed the plot shown at right. Which statement(s) below is consistent with the data in the graph?




A. The students use the separation distance as their independent variable and vary the distance in steps of 0.75 m.

B. The students use the separation distance as their dependent variable and vary the distance in steps of 0.25 m.

C. The minty particles exert a force on one another that is approximately zero when the particles are separated by 0.5 m.

D. When the separation distance is 0.4 m, the force between the particles is attractive.

E. None of these statements are consistent with this graph.

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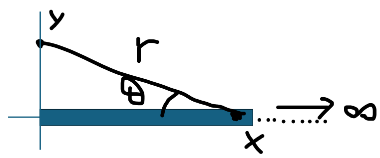
## III. Lecture free response (25 pts)

20. [6 pts] A uniformly charged thin rod lies along the *x*-axis from $x = 0$ to $x = \infty$. The rod has linear charge density $+\lambda$. In the space below, write down an integral that represents the *y*-component of the electric field at a location along the $y$ axis. You should express the integral in terms of *x*, *y*, $\lambda$, Coulomb's constant *k*, and any other constants. Include the bounds of integration. **You do not need to evaluate the integral.** Show your work.

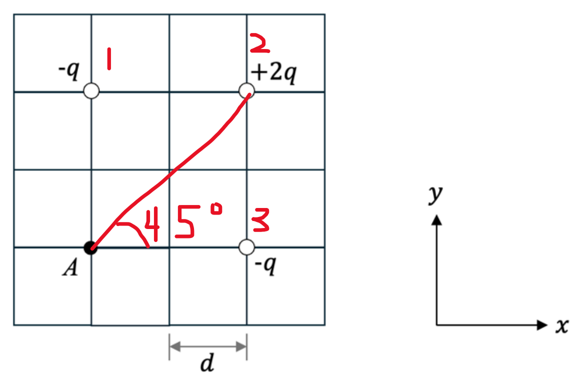
*The infinitesimal charge dq on a small length dx of the rod at location (x, 0) is $dq = \lambda dx$. We want to calculate the electric field at a location (0, y). The distance from the charge dq to the point of interest is $r = \sqrt{x^2 + y^2}$.*




*The electric field strength due to the small charge dq is therefore $dE = \frac{k\lambda dx}{x^2+y^2}$. The y component of this vector is $dE_y = sin\theta dE = \frac{y}{\sqrt{x^2+y^2}} dE$, where $\theta$ is shown above. The final step is to add up (integrate) the contributions to the electric field from each infinitesimal charge dq from $x = 0$ to $x = \infty$. So we get*

$$E_y(y) = \int dE_y = \int_0^{\infty} \frac{k\lambda y dx}{(x^2 + y^2)^{3/2}}$$

21. [9 pts] Three point charges are fixed at the corners of a square as shown of side 2*d* where $q = 5\mu C$ and $d = 15$ cm as shown. Find the x and y components of the electric field at point *A*. Show your work and write your answers in the spaces below.




*The y component of the electric field at point A is the sum of the y components of the field from each point charge. The electric field from charge 1 is in the +y direction, and the field from charge 2 has a component in the -y direction. The field from charge 3 is only in the x direction. So the y component of the electric field at point A is*

$$E_y = \frac{kq}{(2d)^2} - \frac{2kq}{(2d)^2 + (2d)^2} sin45° = 1.46 \times 10^5 \text{ N/C}$$

*By symmetry about the line y=x, the x component has the same magnitude and sign as the y component, so $E_x = 1.46 \times 10^5$ N/C.*

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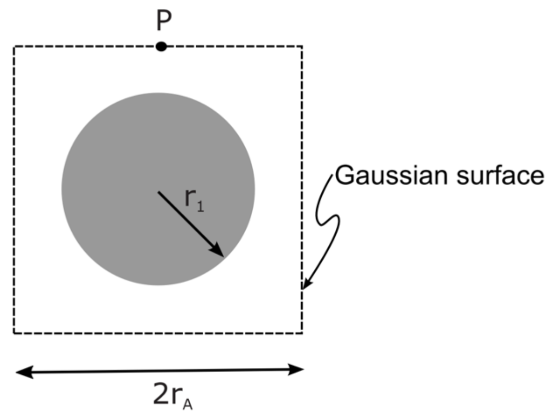
The next two questions are related to the following scenario.

A positive charge $q_1$ is uniformly distributed on an **insulating sphere** with radius $r_1$. Consider a cubical Gaussian surface with sides of length $2r_A$ centered on the sphere, as shown.




22. [5 pts] In terms of the variables given and fundamental constants, what is the electric flux through **one side** of the cubical Gaussian surface? Explain.

*According to Gauss' law, the net flux through the closed surface is* $\Phi_{Net} = \frac{Q_{inside}}{\epsilon_o} = \frac{q_1}{\epsilon_o}$*. Since the cubical surface has six sides and is centered on the uniformly charged sphere, by symmetry the flux through one side of the surface should be equal to one sixth of the net flux.*

$$\Phi_{one\ side} = \frac{\Phi_{Net}}{6} = \frac{q_1}{6\epsilon_o}$$

23. [5 pts] Could you use Gauss' law and the Gaussian surface to calculate the electric field at point P? Briefly explain your reasoning.

*In order to calculate the electric field at point P, we need a Gaussian surface that allows us to simplify the flux integral in Gauss' law,* $\oint \vec{E} \cdot d\vec{A}$*. While the cubical surface does have discrete rotational symmetry, this symmetry does not match the spherical symmetry of the charge distribution. Since the electric field will not have the same magnitude and will not form the same angle with the area vectors at each point on the surface, we* ***cannot*** *simplify the flux integral to calculate the electric field at point P.*

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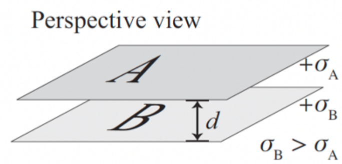
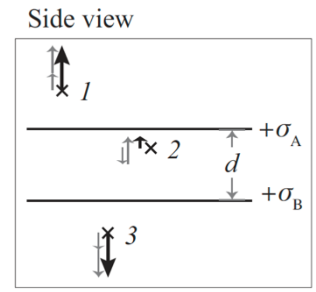
## IV. Tutorial free response (15 pts)

The figure at right shows a small portion of two parallel, infinite sheets of positive surface charge densities $+\sigma_A$ and $+\sigma_B$. The sheets are a distance *d* apart. The surface charge density of sheet B is greater than that of sheet A (*i.e.,* $\sigma_B > \sigma_A$).

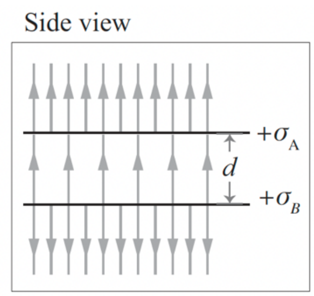



24. [3 pts] On the side-view diagram at right, draw *vectors* with their tails at each "x" to represent the net electric field at points *1, 2,* and *3, (*$|\vec{E}_1|$, $|\vec{E}_2|$, $|\vec{E}_3|$,*).* Your drawing should be qualitatively correct in both magnitude and direction. Explain.



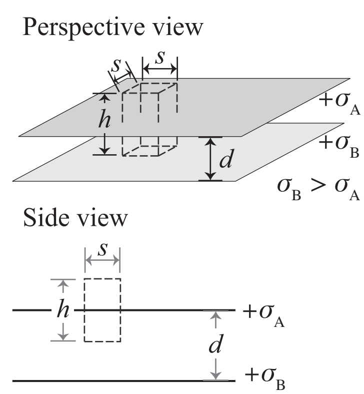

*The electric field from an infinite positively charged sheet is directed away from the sheet, and its magnitude is independent of distance from the sheet but proportional to the charge density. The electric field due to each sheet is shown in gray on the diagram at right. By superposition, the net electric field (shown in black) is the sum of the electric fields due to each sheet.*

25. [4 pts] On the side-view diagram at right, draw *electric field lines* to represent the net electric field above, between, and below the sheets. Your drawing should be qualitatively correct in both magnitude and direction. Explain.




*From question 24, the magnitude of the net electric field is the same in the two regions outside of the sheets, and larger than that between the sheets. In the field line representation, the density of field lines represents the magnitude of the net electric field, while the arrows indicate its direction. (Note that field lines start on positive charges, but can end only on negative charges.)*

An imaginary closed surface with sides *h, s,* and *s* is shown at right.




26. [4 pts] Evaluate the quantity $\oint \vec{E} \cdot d\vec{A}$ over the surface in terms of the magnitudes $|\vec{E}_1|$, $|\vec{E}_2|$, $|\vec{E}_3|$, and/or other relevant quantities. (Your expression should not contain any charge densities.) Explain and show your work.

*Flux is non-zero only on the "upper" and "lower" sides, each of which have area* $s^2$. *(Elsewhere,* $\vec{E}$ *and* $d\vec{\vec{A}}$ *are perpendicular, corresponding to a dot product of zero.) On these two sides,* $\vec{E}$ *is constant, so the flux can be written* $\vec{E}_1 \cdot \vec{A}_{upper}$ *for the upper side and for* $\vec{E}_2 \cdot \vec{A}_{lower}$ *the lower side. (The area vectors have magnitudes* $s^2$ *and point outward from the surface.) Since* $\vec{E}_1$ *and* $\vec{A}_{upper}$ *are parallel but* $\vec{E}_2$ *and* $\vec{A}_{lower}$ *are anti-parallel, the net flux is* $s^2\left(|\vec{E}_1| - |\vec{E}_2|\right)$.

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27. [4 pts] Use the given imaginary surface and Gauss' law to find an expression for $\sigma_A$ in terms of the magnitudes $|\vec{E}_1|$, $|\vec{E}_2|$, $|\vec{E}_3|$, and/or other relevant quantities. Explain and show your work.

*Gauss's law can be written as* $\oint \vec{E} \cdot d\vec{A} = q_{enc}/\varepsilon_0$. *From question 26,* $\oint \vec{E} \cdot d\vec{A} = s^2\left(|\vec{E}_1| - |\vec{E}_2|\right)$. *The enclosed charge is* $q_{enc} = \sigma_A s^2$. *Thus, solving for the charge density,* $\sigma_A = \varepsilon_0\left(|\vec{E}_1| - |\vec{E}_2|\right)$. *(Note that this expression indicates the charge density is positive, as expected.)*