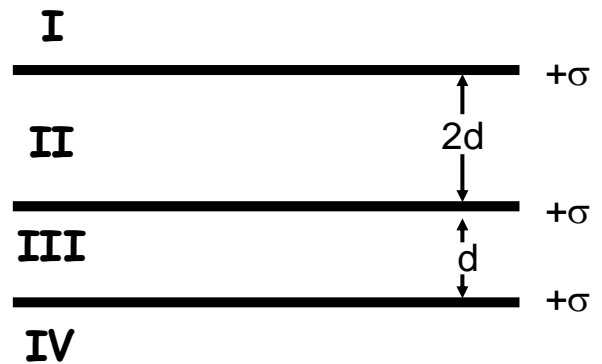


Part I. [14 points] Three equally charged, very large, thin plastic planes are arranged as shown in the figure. The top two are a distance $2d$ apart, the bottom two are a distance d apart. Each plane's surface charge density is a uniform $+\sigma$.



1. [4 points] What is the magnitude of the electric field 3.0 m above the upper plane (in region I):

- A. $\frac{\sigma}{2\epsilon_0}$
- B. $\frac{\sigma}{\epsilon_0}$
- C. $\frac{3\sigma}{2\epsilon_0}$
- D. $\frac{\sigma}{2\epsilon_0 d^2}$
- E. $\frac{9\sigma}{\epsilon_0 d^2}$

2. [4 points] What is the magnitude of the electric field half way between the upper two planes (in region II):

- A. $\frac{\sigma}{2\epsilon_0}$
- B. $\frac{\sigma}{\epsilon_0}$
- C. $\frac{3\sigma}{2\epsilon_0}$
- D. $\frac{3d\sigma}{2\epsilon_0}$
- E. $\frac{3\sigma}{2\epsilon_0 d^2}$

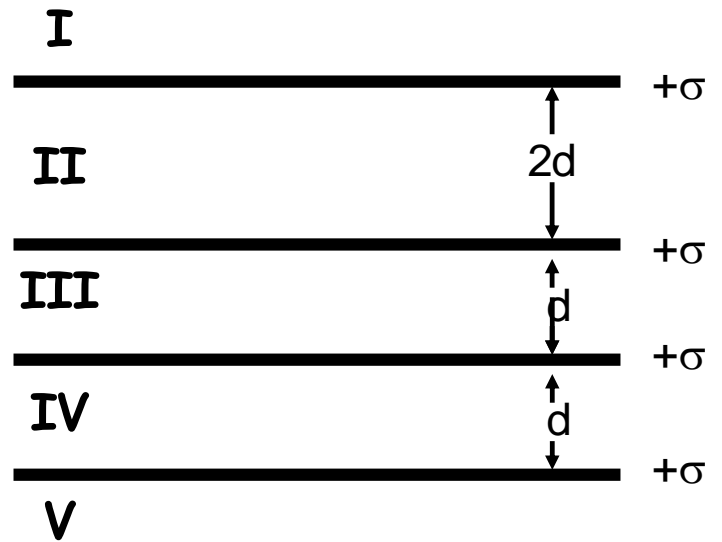
3. [3 points] In what region is the magnitude of the electric field zero?

- A. Region I
- B. Region II
- C. Region III
- D. Region IV
- E. None of the above

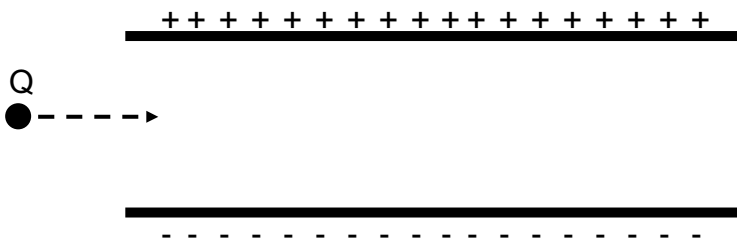
A fourth plane is added as shown in the figure.

4. [3 points] In what region is the magnitude of the electric field now zero?

- A. Region I
- B. Region II
- C. Region III
- D. Region IV
- E. None of the above



Part II. [24 points] A particle of mass m and charge Q moving at a speed of 5m/s enters a uniform electric field generated by two large plates. The upper plate is positively charged, and the lower plate is negatively charged. Gravity points towards the bottom of the page. In questions 5-6 the particle travels in a straight line through the middle of the two plates. Ignore any field effects at the edges of the plates.



5. [3 points] Which of the following is correct?

- A. $Q > 0$
- B. $Q < 0$
- C. $Q = 0$
- D. $Q > 0$ or $Q = 0$
- E. There isn't enough information to determine Q .

The mass of the particle is 5 g and the magnitude of the charge it carries is $5\text{ }\mu\text{C}$.

6. [5 points] What is the magnitude of the electric field?

- A. $9.8 \times 10^{-3}\text{ N/C}$
- B. $4.9 \times 10^{-2}\text{ N/C}$
- C. $9.8 \times 10^3\text{ N/C}$
- D. $2.0 \times 10^4\text{ N/C}$
- E. $4.9 \times 10^6\text{ N/C}$

The plates are separated by a distance of 2 cm , and the particle enters the plates in the middle. The plates are 3 m long. The charge on the plates is adjusted so that the magnitude of the electric field is $1 \times 10^6\text{ N/C}$. A different particle of mass m with the same charge and initial speed is shot through the center of the two plates. It is observed to have an acceleration of 0.1 m/s^2 in the $-y$ direction (towards bottom of page).

7. [5 points] What is the particle's mass?

- A. $3.0 \times 10^{-3}\text{ kg}$
- B. $5.0 \times 10^{-3}\text{ kg}$
- C. $1.0 \times 10^{-2}\text{ kg}$
- D. $5.1 \times 10^{-1}\text{ kg}$
- E. $5.0 \times 10^1\text{ kg}$

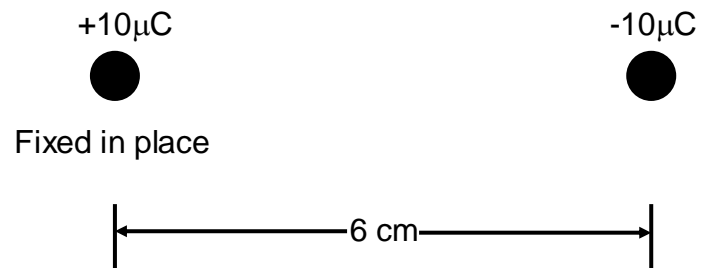
8. [4 points] How far from the left edge of the plates, in the horizontal direction, does the particle travel before it hits the lower plate?

- A. 0.50 m
- B. 1.0 m
- C. 1.6 m
- D. 2.2 m
- E. 230 m

For the final question in this problem consider two point charges separated by 6 cm. The left one is fixed, the right one is free to move. Each has a mass of 12 g.

9. [4 points] What is the magnitude of the instantaneous acceleration of the $-10\ \mu\text{C}$ charge?

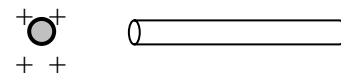
- A. $2.1\ \text{m/s}^2$
- B. $2.5 \times 10^2\ \text{m/s}^2$
- C. $2.1 \times 10^4\ \text{m/s}^2$
- D. $4.2 \times 10^4\ \text{m/s}^2$
- E. $4.7 \times 10^5\ \text{m/s}^2$



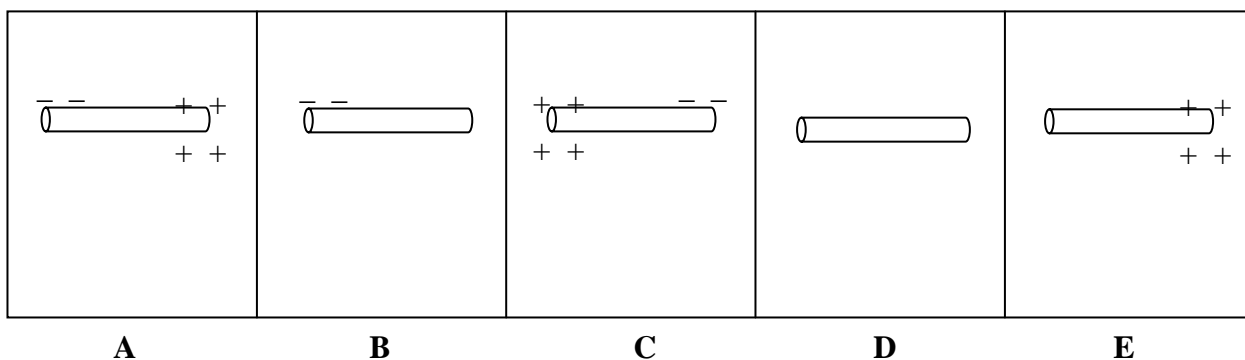
10. [3 points] The equation $x = x_0 + v_0t + \frac{1}{2}at^2$ cannot be applied to this configuration. Why?

- A. It is only applicable to forces due to gravity.
- B. It is only applicable to constant forces.
- C. The forces felt by each charge are equal but opposite.
- D. Both charges must be free to move, not just one.
- E. It is Friday.

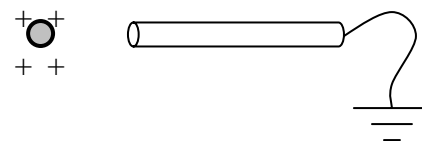
Part III. [12 points] A small, lightweight ball with net charge $Q = +30 \mu\text{C}$ is placed at rest near one end of a long uncharged rod as shown. The ball *never* touches the rod. There are no other objects nearby. Assume that the rod is made of *metal* for questions 11 through 14.



11. [3 points] Which choice best describes the behavior of the ball?
- A. The ball is electrically repelled by the rod, and moves to the left.
 - B. The ball is electrically attracted to the rod, and moves to the right.
 - C. The ball feels no electric force, and remains at rest.
 - D. The ball is at first repelled by, but then attracted to the rod.
 - E. The ball exerts a force on the rod, but the ball feels no force at all and does not move.
12. [3 points] Which diagram best represents the distribution of electric charge on the rod? Remember that the charged ball is to the left end of the rod in each figure:



13. [3 points] A wire is now connected from ground to the end of the rod opposite the ball. Which choice best describes the charge distribution on the rod?

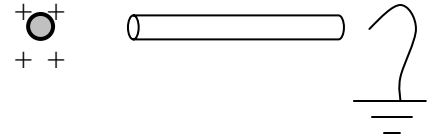


- A. The rod is electrically neutral (uncharged), because the ball never touched it.
- B. The rod has a net positive charge, because electrons were able to escape down the wire to the ground.
- C. The rod has a net negative charge, because some electrons were able to enter the rod by traveling up the ground wire.
- D. The rod has more negative charge on its left end, but more positive charge on its right end, and hence is electrically neutral.
- E. All mobile charges have left the rod through the ground wire, so the material has changed from a conductor to an insulator.

last

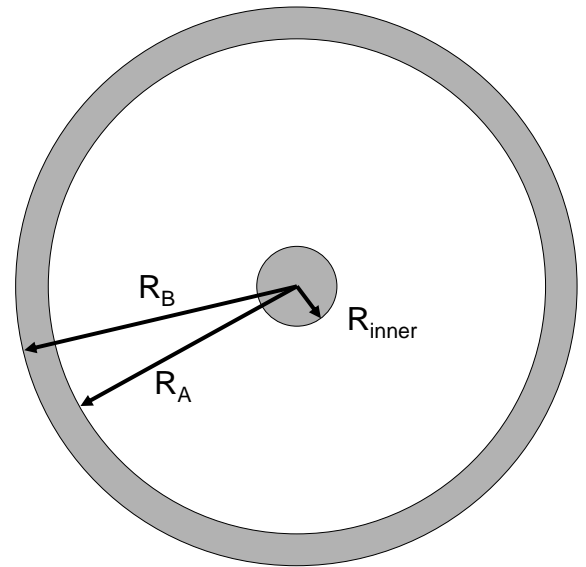
first

14. [3 points] The ground wire is now carefully removed, and then the charged ball is removed, leaving only the rod in place. Which diagram now best represents the distribution of electric charge on the rod?



A	B	C	D	E

Part IV. [30 points] The figure shows a spherical ball and conducting shell. The inner plastic ball has a uniform charge density ρ . The total charge in the inner ball is Q ($Q > 0$). The space between the inner ball and the conducting shell and also outside the conducting shell is a vacuum. The outer shell is charged with an additional Q .



15. [6 points] What is the charge density, ρ , in terms of Q and R_{inner} ?

16. [6 points] What is the total charge present on the inner surface of the conducting shell ($r=R_A$)? The outer surface of the conducting shell ($r=R_B$)? Explain.

17. [7 points] What is the magnitude of the electric field $E(r)$ for $R_{\text{inner}} < r < R_A$?

18. [4 points] What is the magnitude of the electric field $E(r)$ for $R_A < r < R_B$?

19. [7 points] What is the magnitude of the electric field $E(r)$ for $R_B < r$?