Part I. [25 points] Two insulating plates, shown to the right, are both uniformly charged in such a way that the potential difference between them is $V_2 - V_1 = 20$ Volts (i.e. the right-hand plate is at a higher potential). The plates are separated by $d=0.1\text{m}$, and can be treated as infinitely large.

1. [4 points] What is the x-component of the electric field between the planes (the sign denotes the direction!).
   - A. -200 V/m
   - B. -2 V/m
   - C. 0 V/m
   - D. 2 V/m
   - E. 200 V/m

2. [4 points] An electron is released from rest on the inner surface of plate 1. What is its speed when it hits plate 2? The electron’s charge and mass are $-1.6 \times 10^{-19}\text{C}$ and $9.11 \times 10^{-31}\text{kg}$.
   - A. $32 \times 10^{-19}\text{m/s}$
   - B. $7.02 \times 10^{12}\text{m/s}$
   - C. $2.65 \times 10^{6}\text{m/s}$
   - D. $1.87 \times 10^{6}\text{m/s}$
   - E. None of the Above.

3. [4 points] Suppose there is a small hole in plate 2 so that the electron passes through. Which of the following best describes its subsequent motion?
   - A. It keeps moving at a constant velocity
   - B. It keeps moving to the right with increasing speed.
   - C. It slows down and stops a finite distance from plate 2.
   - D. It oscillates back and forth on either side of plate 2.
   - E. There is not enough information to tell.

4. [4 points] The difference between the charge densities on the two plates, $\sigma_2 - \sigma_1$, is given by (in $\text{C/m}^2$):
   - A. $\varepsilon_0(V_2 - V_1)/d$
   - B. $-\varepsilon_0(V_2 - V_1)/d$
   - C. $2\varepsilon_0(V_2 - V_1)/d$
   - D. $-2\varepsilon_0(V_2 - V_1)/d$
   - E. None of the above
A charged particle is fired horizontally between two large parallel plates, which are uniformly charged with equal and opposite charges. When the particle leaves the plates it has been deflected from the horizontal by an angle \( \theta \) (not small), as shown in the diagram below. (Ignore gravity and assume a uniform electric field exactly up to the edge of the plates).

5. [5 points] What happens to \( \theta \) if the charge on both plates is doubled?
   A. \( \theta \) is unchanged.
   B. \( \theta \) is doubled
   C. \( \tan \theta \) is doubled
   D. \( \tan \theta \) is quadrupled
   E. None of the above.

6. [4 points] Which of the following best represents the field lines between the two plates if the charge is negative?
   
   A) B)
   
   C) D)
   
   E)
Part II. [25 Points] Two charges, $5 \mu C$ and $-5 \mu C$, are placed at -9 cm and +9 cm along the x-axis, as shown to the right. A third $2 \mu C$ charge is fixed at the origin. A test charge is placed at +12 cm along the y-axis, with a value of $0.5 \mu C$. There is no gravity or friction in this problem. At time $t=0$, the test charge is released.

7. [7 points] In the box provided draw an arrow indicating the direction of acceleration the test charge after being released from the point as shown? And as time passes will the magnitude of the force increase, decrease, or remain the same. Explain.

The test charge will move away. Its magnitude will decrease.

$$|F| \propto \frac{1}{r^2}.$$ 

8. [10 points] Calculate the magnitude of the force felt by the test charge just after it is released.

**Forces due to $\pm 5 \mu C$ will cancel in y direction.**

$$F_y = \frac{1}{4 \pi \varepsilon_0} \frac{5 \mu C \cdot 0.5 \mu C}{r^2} = 0.625N$$

In $\dot{x}$ will be twice what it is due to one (the $\cos \Theta = \frac{dx}{r}$)

$$F_x = \frac{1}{4 \pi \varepsilon_0} \frac{5 \mu C \cdot 0.5 \mu C}{r^2} \frac{dx}{r} = 0.6 N$$

Magnitude is $\sqrt{F_x^2 + F_y^2} = 1.35 N$

9. [8 points] Describe where the test charge be placed such that it doesn’t experience any force. If there is no such place, state so explicitly.

If $2 \mu C$ missing, $x=0$.

Now, somewhere between $2 \mu C$ and $-5 \mu C$ charge.
Part III. [30 points] The figure shows a spherical ball and conducting shell. The inner plastic ball has a uniform charge density \( \rho \). 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 \( Q \).

10. [6 points] What is the charge density, \( \rho \), in terms of \( Q \) and \( R_{\text{inner}} \)?

11. [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.

12. [7 points] What is the magnitude of the electric field \( E(r) \) for \( R_{\text{inner}} < r < R_A \)?

13. [4 points] What is the magnitude of the electric field \( E(r) \) for \( R_A < r < R_B \)?

14. [7 points] What is the magnitude of the electric field \( E(r) \) for \( R_B < r \)?
IV. [20 points] A thin-walled plastic pipe of radius $a$ and length $3a$ is rubbed with fur so that it becomes uniformly charged on its outside surface. The charge per unit area on this surface is $+\sigma_o$.

A negative point charge $-q$ is placed at point $P$ on the axis of the pipe one third of the way from the top of the pipe as shown.

A. [5 pts] What is the direction of the force on the charge $-q$? If the magnitude of the force is equal to zero, state so explicitly. Explain.

*The net force on the point charge points down.* By symmetry, there will be no component of the force in the direction along the radius of the cylinder. A small ring of charge, such as that shown at right, will create an electric field along its axis that points as shown. This is because the components of the field in the horizontal direction will cancel due to the symmetry of the ring, leaving only the vertical components of the field. We can imagine the cylinder as a collection of such rings, and since more of the rings lie below the $-q$ charge than above it, the field at the charge will point upwards. Since the charge is negative, the force on it will point downwards.

B. [5 pts] What is the direction of the electric field at point $P$? If the magnitude of the field is equal to zero, state so explicitly. Explain.

Using the reasoning from question A, the electric field at point $P$ points up as shown on the diagram. Each small ring of charge will add to the electric field as previously discussed. Since there are more rings below point $P$ than above it, the net field at the point will point up.

Consider a thin strip of the pipe of height $\Delta y$ whose center is a distance $y$ below point $P$.

C. [5 pts] How much charge is on this thin strip of pipe? Show your work and briefly explain.

*The strip has charge density $+\sigma_o$ and height $\Delta y$. The total charge on the strip is given by the product of the charge density and the area of the strip. The area of the strip is:*

$$A = \text{Circumference} \times \text{Height} = 2\pi a \times \Delta y$$

*Therefore the total charge is:*

$$Q = \sigma_o \times A = 2\pi a \Delta y \sigma_o$$

D. [5 pts] The pipe is now cut into two pieces as shown at right. Rank the magnitudes of the surface charge densities of the original pipe ($\sigma_o$), of piece A ($\sigma_A$), and of piece B ($\sigma_B$). Explain. (Assume that the charge on the surface is not disturbed by the act of cutting the pipe.)

*The charge density is the total charge per unit of surface area. If you cut the cylinder in two separate pieces, the charge on each resulting cylinder will be less than the total charge on the initial cylinder; but the surface area of each piece will also be less than that of the entire cylinder by the same factor. So, the charge density will remain unchanged. Therefore, $\sigma_A = \sigma_B$. 