Part I. [26 Points] Consider the two charged infinite planes spaced a distance \( d = 2 \text{m} \) apart. The left plane has a +\( \sigma \), and the right plane of −\( \sigma \). \( \sigma \) is 50\( \mu \text{C/m}^2 \).

Ignore \( P \) for questions 1-5.

1. [5 points] We place a free electron exactly half way between the plates. What is the \( x \)-component of the force it experiences (positive is to the right in the picture)?
   
   \[ \text{A. } -7.2 \times 10^{-13} \text{ N} \]
   \[ \text{B. } 1.17 \times 10^{-12} \text{ N} \]
   \[ \text{C. } -4.52 \times 10^{-13} \text{ N} \]
   \[ \text{D. } -1.13 \times 10^{-13} \text{ N} \]
   \[ \text{E. } 0 \text{ N} \]

2. [5 points] And what is the \( y \)-component of the force it experiences (positive is vertical in the picture)?
   
   \[ \text{A. } 7.2 \times 10^{-13} \text{N} \]
   \[ \text{B. } 1.8 \times 10^{-14} \text{N} \]
   \[ \text{C. } 1.44 \times 10^{-13} \text{N} \]
   \[ \text{D. } 0 \text{ N} \]

3. [3 points] If we increase the separation of the plates, \( d \), to 4\( \text{m} \), what will the \textit{magnitude} force on the electron be in the \( x \) direction now?
   
   \[ \text{A. Larger than it was before} \]
   \[ \text{B. The same as before} \]
   \[ \text{C. Less than before} \]

4. [3 points] And the \( y \)-component of the force?
   
   \[ \text{A. Larger than it was before} \]
   \[ \text{B. The same as before} \]
   \[ \text{C. Less than before} \]

5. [5 points] We now place a second charge, \( q = 100\mu \text{C} \), 1\( \text{m} \) vertically above the electron we have been discussing (see \( P \) in the figure). At the point we first release the free electron from the center, what is the \textit{x-component} of the force?
   
   \[ \text{A. } -7.2 \times 10^{-13} \text{ N} \]
   \[ \text{B. } 1.17 \times 10^{-12} \text{ N} \]
   \[ \text{C. } -4.52 \times 10^{-13} \text{ N} \]
   \[ \text{D. } -1.13 \times 10^{-13} \text{ N} \]
   \[ \text{E. } 0 \text{ N} \]

6. [5 points] And the \( y \)-component?
   
   \[ \text{A. } 1.8 \times 10^{-14} \text{N} \]
   \[ \text{B. } 1.44 \times 10^{-13} \text{N} \]
   \[ \text{C. } 0 \text{ N} \]
   \[ \text{D. } 7.2 \times 10^{-13} \text{N} \]
   \[ \text{E. } -1.13 \times 10^{-13} \text{N} \]
Part II. [25 points] Two infinitely long nonconducting thin parallel planes are separated by a distance d. Both have a surface charge density $\pm \sigma$. Small sections of these planes are shown below.

7. [7 points] Draw field lines for the electric field above, between, and below the two planes.

![Field Lines Diagram]

8. [5 points] A dipole (with a charge of $+q$ on one end, and $-q$ on the other, as shown below) is held in each of the three regions, I, II, and III. Draw the orientation of the dipole after it has reached an equilibrium position in each region. Be sure to indicate which are the plus and minus ends of the dipole. Draw an arrow from the center of the dipole indicating the net force it experience in each region as well. If the net force is zero indicate explicitly.

![Dipole Diagram]

9. [4 points] In what region would the force of gravity be counter acted by the electric force? Gravity points towards the bottom of the page!

10. [9 points] Calculate the value of $\sigma$ such that the electron will remain stationary in the region found in problem 9 ($m_e = 9.11 \times 10^{-31}$ kg, $g=9.8$ m/s$^2$, $e=-1.6 \times 10^{-19}$ C).
Part III. [27 Points] For this problem, consider the two ping-pong balls shown in the figure, suspended at the end of a 20 cm wire. Each aluminized ping-pong ball has a mass of 5 grams, and has a radius of 1.5 cm. Initially, they hang so that each suspending metal wire is vertical, and the sides of the balls just touch. When a charged rod is touched to the top plate and withdrawn, a total charge of \(-Q\) is transferred to the apparatus, and the balls separate by 2 cm (as shown in the figure).

11. [10 points] Below are two side views of the aluminized ping-pong balls. On the left draw the electric field lines (include direction). Ignore any effects due to the supporting wires or stand and polarization. On the right side, clearly label all the forces (free-body diagram).

12. [12 points] Calculate the total charge \(Q\) in Coulombs. Again; ignore any effects due to the wires and treat the balls as point charges for this calculation.

13. [5 points] By what factor would you have to change \(Q\) so that the balls were separated by 7 cm?