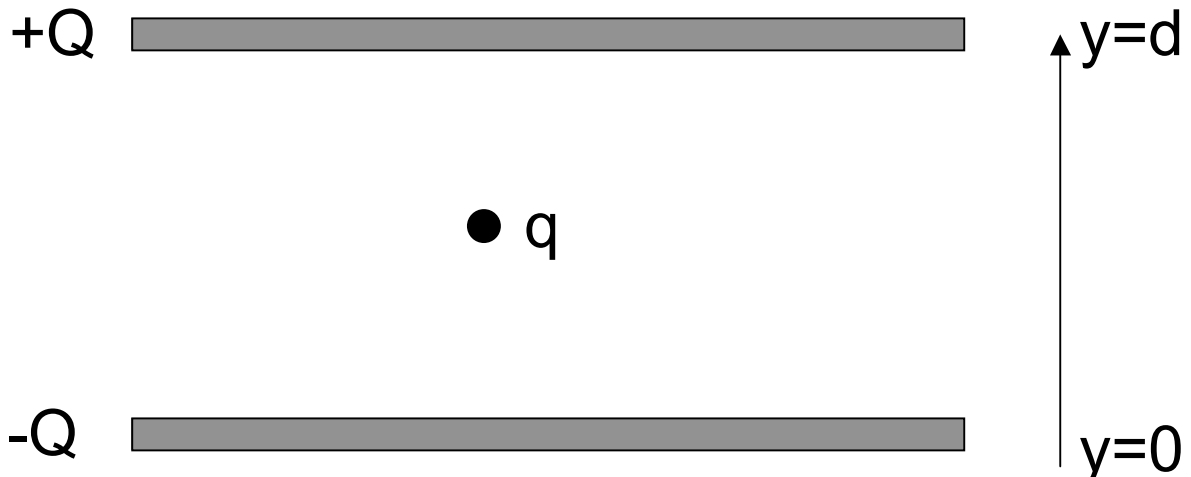


**Problem 4 (25 points)**

Shown below is the cross-section of two large parallel plates carrying charges  $+Q$  (top) and  $-Q$  (bottom). Each plate has area  $A$ . Vertically between the plates, a small charged particle with charge  $q$  and mass  $m$  is suspended at  $y=d/2$ , i.e. the force of gravity  $F_G = -m \cdot g$  and the electrostatic force on the particle cancel.

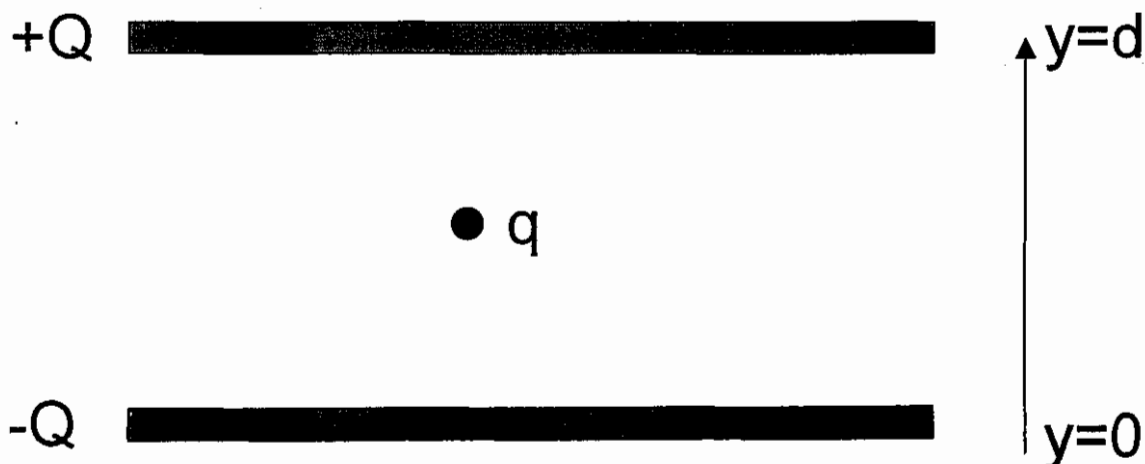
- (a) What is the sign of the small particles charge  $q$ ?
- (b) Determine  $q$  in terms of the other quantities given. Neglect fringe effects for the electric field created by the two plates.
- (c) Sketch the electric potential energy  $U_E$  of the charged particle as a function of  $y$  from  $y=0$  to  $y=d$ , assuming  $U_E = 0$  at  $y=0$ .
- (d) Sketch the total potential energy  $U_T$  of the particle as a function of  $y$  from  $y=0$  to  $y=d$ .
- (e) Sketch the electric potential  $V$  between the plates (ignore the charge  $q$ ) from  $y=0$  to  $y=d$ .



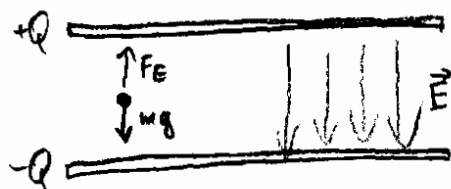
**Problem 4 (25 points)**

Shown below is the cross-section of two large parallel plates carrying charges  $+Q$  (top) and  $-Q$  (bottom). Each plate has area  $A$ . Vertically between the plates, a small charged particle with charge  $q$  and mass  $m$  is suspended at  $y=d/2$ , i.e. the force of gravity  $F_G = -m \cdot g$  and the electrostatic force on the particle cancel.

- (a) What is the sign of the small particles charge  $q$ ?
- (b) Determine  $q$  in terms of the other quantities given. Neglect fringe effects for the electric field created by the two plates.
- (c) Sketch the electric potential energy  $U_E$  of the charged particle as a function of  $y$  from  $y=0$  to  $y=d$ , assuming  $U_E = 0$  at  $y=0$ .
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- (e) Sketch the electric potential  $V$  between the plates (ignore the charge  $q$ ) from  $y=0$  to  $y=d$ .



# PROBLEM 4



the field is constant between the plates,

with  $E = \frac{\sigma}{\epsilon_0} = \frac{Q}{A\epsilon_0}$

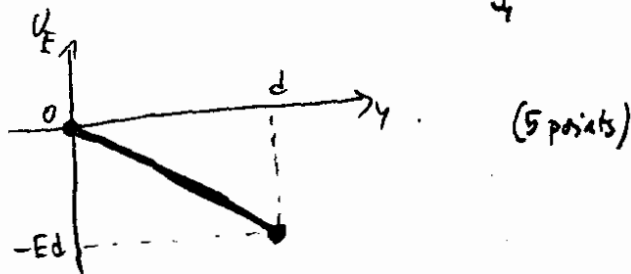
you can get it as a superposition of fields from two infinite plates

$$E = E_+ + E_- = \frac{\sigma}{2\epsilon_0} + \frac{\sigma}{2\epsilon_0} = \frac{\sigma}{\epsilon_0}$$

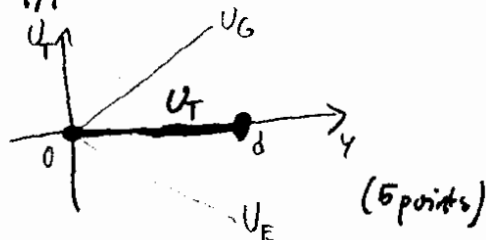
a) the charge must be attracted to the top plate, so it is negative (2 points)

b)  $F_E = F_G \dots E q = \frac{Q}{A\epsilon_0} q = -mg \dots$   $q = -\frac{mg A\epsilon_0}{Q}$  (8 points)

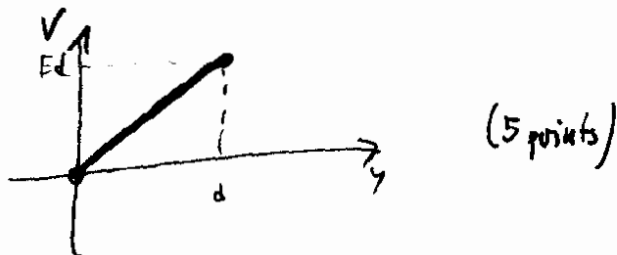
c) the potential energy in a constant field is linear.  $U(y) - U(0) = \int \vec{E} \cdot d\vec{r} = q E y$   
now  $q$  is negative, so we have



d) the potential energy due to gravity is  $U_G = mgy = (-Eq)y \dots$  it is exactly opposite to the potential energy in the electric field. So the total potential energy is constant



e) the potential between two plates is  $V(0) - V(y) = \int_0^y \vec{E} \cdot d\vec{r} = -Ey \dots$   $V(y) = V(0) + Ey$



You can get this also from  $V = \frac{U_E}{q}$  (now  $q$  was negative, so  $V$  has opposite slope)