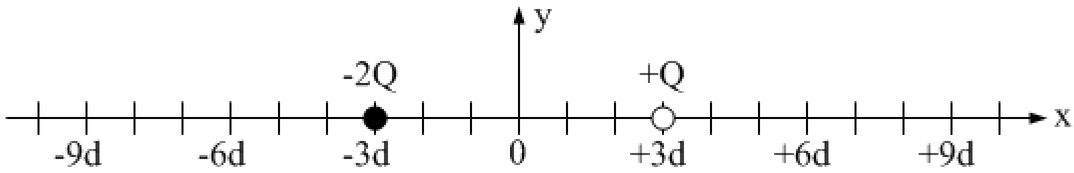
PROBLEM 1 – 10 points

Two charges are placed on the x-axis. The charge at x = -3d has a charge of –2Q, while the charge at +3d has a charge of +Q.



[2 points] (a) The net electric potential due to the two charges is zero at at least one location on the x-axis near the two charges. In which region(s) is there such a point on the x-axis, where the net electric potential is zero a finite distance from the charges? **Select all that apply.**

[   ] to the left of the –2Q charge

[**X**] between the charges

[**X**] to the right of the +Q charge

Because one charge has twice the magnitude of the other we're looking for locations twice as far from the –2Q charge as from the +Q charge. There is one such location between the charges and another to the right of the +Q charge.

[5 points] (b) Determine the location of one such point on the x-axis near the charges where the net electric potential is zero.

Between the charges:

$$V_1 + V_2 = 0$$

$$\frac{k(-2Q)}{x-(-3d)} + \frac{kQ}{3d-x} = 0$$

$$\frac{2}{x+3d} = \frac{1}{3d-x}$$

$6d - 2x = x + 3d$ **, so** $3d = 3x$ **and** $x = +d$

To the right of the +Q charge:

$$V_1 + V_2 = 0$$

$$\frac{k(-2Q)}{x-(-3d)} + \frac{kQ}{x-3d} = 0$$

$$\frac{2}{x+3d} = \frac{1}{x-3d}$$

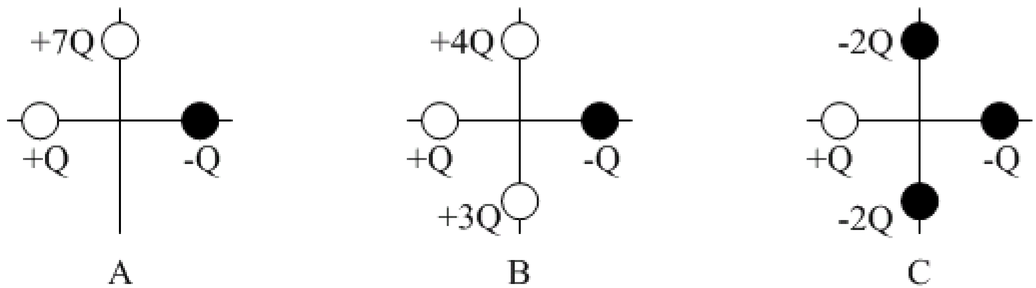
$2x - 6d = x + 3d$ **, so** $x = +9d$

[3 points] (c) Are there any points near the charges, **but not on the x-axis**, where the net electric potential due to the point charges is zero? Explain.

Yes, there are plenty of such points. Potential is a scalar, so there is no direction to worry about. Every point that is twice as far from the –2Q charge as it is from the +Q charge will work. There is an oval equipotential line, passing through x = +d and x = +9d that connects all of these points.

PROBLEM 2 – 15 points

Three configurations of point charges are shown. Each charge is located a distance d from the origin. In each case the origin is located at the intersection of the axes. The electric potential from a single charge is defined to be zero an infinite distance from the charge, and the electric potential associated with two charges is also defined to be zero when the charges are infinitely far apart.



[4 points] (a) **In configuration A**, imagine that the +Q and –Q charges are placed at the locations shown, and then the +7Q charge is brought into the picture and placed at its location. Does bringing in the +7Q charge cause the potential energy of configuration A to increase, decrease, or stay the same? Briefly explain.

The potential energy stays the same. The +7Q charge interacting with the +Q charge has a positive potential energy, while the interaction of the +7Q charge interacting with the –Q charge has a negative potential energy. These have the same magnitude because the distances involved are equal.

[4 points] (b) **In configuration B**, what is the electric potential at the origin because of the four charges? You can express this in terms of k, Q, and d.

$$V = +\frac{kQ}{d} - \frac{kQ}{d} + \frac{4kQ}{d} + \frac{3kQ}{d} = +\frac{7kQ}{d}$$

[3 points] (c) Rank the three configurations based on the electric potential at the origin due to the charges, from largest to smallest.

[ ] A>B>C [ ] A>C>B [**X**] A=B>C [ ] B>A>C
[ ] B>C>A [ ] C>A>B [ ] C>B>A [ ] C>A=B

Both configurations A and B have a net potential at the origin of $V = +\frac{7kQ}{d}$ **while configuration C has a potential at the origin of** $V = -\frac{4kQ}{d}$**.**

[4 points] (d) In one, and only one, of the configurations the total potential energy is negative. Which configuration is this?

[**X**] A [ ] B [ ] C

Briefly explain your answer: **Add up all the** $U = \frac{kq_1q_2}{r}$ **terms, one for each pair of charges, to get for configuration A:** $U = \frac{kQ(-Q)}{2d} + \frac{kQ(7Q)}{r} + \frac{k(-Q)(7Q)}{r} = \frac{-kQ^2}{2d}$**. Doing the same thing for the other configurations results in positive answers.**

PROBLEM 2 – 15 points (1 point for each answer in the table)

A parallel-plate capacitor, with air between the plates (dielectric constant = 1) is charged by being connected to a battery that has a voltage of V_0. Then, a series of steps is carried out, as shown below. For each step, fill in the table with the potential difference across the capacitor, in terms of V_0; the capacitance, in terms of the initial capacitance, C_0; the charge stored in the capacitor, in terms of the initial charge Q_0; the magnitude of the uniform electric field in the capacitor, in terms of the initial value E_0; and the stored electric energy, in terms of the initial energy U_0. The values after step 1 are shown, as an example.

Step 1: After the wires connecting the battery to the capacitor are removed, the distance between the capacitor plates is doubled.

Step 2: After completing step 1, a dielectric, with a dielectric constant of 3, is placed in the capacitor, completely filling the space between the plates.

Step 3: After completing step 2, the battery is re-connected to the capacitor.

Step 4: After completing step 3, the dielectric is removed from the capacitor.

	Potential difference	Capacitance	Charge	Field	Energy
Initially	V_0	C_0	Q_0	E_0	U_0
1. Wires removed, then distance is doubled	$2\,V_0$	$\frac{C_0}{2}$	Q_0	E_0	$2\,U_0$
2. Dielectric inserted	$\frac{2V_0}{3}$	$\frac{3C_0}{2}$	Q_0	$\frac{E_0}{3}$	$\frac{2U_0}{3}$
3. Battery re-connected	V_0	$\frac{3C_0}{2}$	$\frac{3Q_0}{2}$	$\frac{E_0}{2}$	$\frac{3U_0}{2}$
4. Dielectric removed	V_0	$\frac{C_0}{2}$	$\frac{Q_0}{2}$	$\frac{E_0}{2}$	$\frac{U_0}{2}$

Show work here.

2. (a) Charge stays the same. (b) Capacitance increases by a factor of 3. (c) Using $\Delta V=Q/C$, the potential difference decreases by a factor of 3.
(d) Using $E = \Delta V/d$, the electric field decreases by a factor of 3.
(e) Using $U = 0.5Q^2/C$, the energy decreases by a factor of 3 (other energy equations give this answer, too.)

3. (a) Potential difference returns to the initial value, increasing by a factor of 3/2. (b) Capacitance stays the same. (c) Using $Q = C\Delta V$, the charge increases by a factor of 3/2.
(d) Using $E = \Delta V/d$, the electric field increases by a factor of 3/2. (e) Using $U = 0.5C(\Delta V)^2$, the energy increases by a factor of 9/4 (other energy equations give this answer, too.)

4. (a) Potential difference stays the same. (b) Capacitance decreases by a factor of 3. (c) Using $Q = C\Delta V$, the charge decreases by a factor of 3.
(d) Using $E = \Delta V/d$, the electric field stays the same.
(e) Using $U = 0.5C(\Delta V)^2$, the energy decreases by a factor of 3 (other energy equations give this answer, too.)