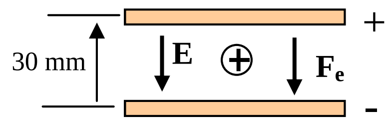
Chapter 25. Electric Potential

Work and Electric Potential Energy

25-1. An positively charged plate is 30 mm above a negatively charged plate, and the electric field intensity has a magnitude of 6×10^4 N/C. How much work is done BY the electric field when a +4-μC charge is moved from the negative plate to the positive plate?

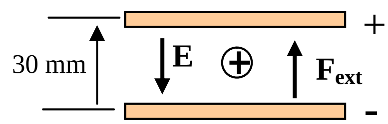
Work = Fd = qEd; F opposite to d makes work negative



$$\text{Work} = (4 \times 10^{-6}\text{ C})(6 \times 10^4\text{ N/C})(0.030\text{ m})$$

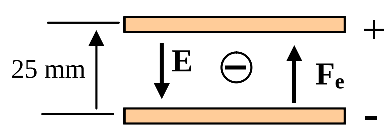
$Work = -7.20 \times 10^{-3}$ J; **$Work = -7.20$ mJ**

25-2. In Problem 25-1, how much work is done ON or against the electric field? What is the electric potential energy at the positive plate?



The displacement occurs against the electric force, so that work done ON the field due to outside UP force F_{ext} in same direction as the displacement. Since the field is in a position to do positive work when at the positive, plate, the electric potential energy is positive at that point: **$E_p = +7.20$ mJ.**

25-3. The electric field intensity between two parallel plates, separated by 25 mm is 8000 N/C. How much work is done BY the electric field in moving a –2-μC charge from the negative plate to the positive plate? What is the work done BY the field in moving the same charge back to the positive plate? *(Electric force with motion)*



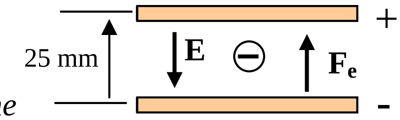
Work done BY field is positive, F_e with displacement.

$Work = qEd = (2 \times 10^{-6}\text{ C})(8000\text{ N/C})(0.025\text{ m})$ *Work done BY = Loss of electric energy.*

$Work = 4.00 \times 10^{-4}$ J Now, in coming back electric force opposes motion.

Work done BY field is negative: **$Work = -4.00 \times 10^{-4}$ J.**

25-4. In Problem 25-3, what is the potential energy when the charge is at (a) the positive plate and (b) the negative plate?

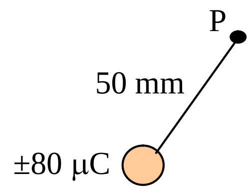


Remember, potential energy represents the work that the electric field can do when electric forces are free to act. When the –2 μC charge is at the positive plate, the E field can do no work, thus with reference to that point, $E_p = 0$.

(a) At + plate: $\boxed{E_p = 0}$ *No work can be done by the electric field.*

(b) At – plate, the field can do +work: $\boxed{E_p = +4.00 \text{ x } 10^{-4}\text{ J}}$

25-5. What is the potential energy of a +6 nC charge located 50 mm away from a +80-μC charge? What is the potential energy if the same charge is 50 mm from a –80-μC charge?



$$P.E. = \frac{kQq}{r} = \frac{(9 \text{ x } 10^9 \text{N}\cdot\text{m}^2/\text{C}^2)(+80 \text{ x } 10^{-6}\text{C})(6 \text{ x } 10^{-9}\text{C})}{0.050 \text{ m}}$$

$$\boxed{P.E. = 86.4 \text{ mJ}}$$

$$P.E. = \frac{kQq}{r} = \frac{(9 \text{ x } 10^9 \text{N}\cdot\text{m}^2/\text{C}^2)(-80 \text{ x } 10^{-6}\text{C})(6 \text{ x } 10^{-9}\text{C})}{0.050 \text{ m}}; \quad \boxed{P.E. = -86.4 \text{ mJ}}$$

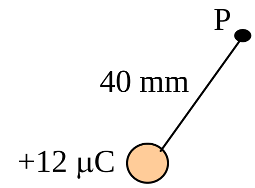
25-6. At what distance from a –7-μC charge will a –3-nC charge have a potential energy of 60 mJ? What initial force will the –3-nC charge experience?

$$P.E. = \frac{kQq}{r}; \quad r = \frac{kQq}{P.E.} = \frac{(9 \text{ x } 10^9 \text{N}\cdot\text{m}^2/\text{C}^2)(-7 \text{ x } 10^{-6}\text{C})(-3 \text{ x } 10^{-6}\text{C})}{0.060 \text{ J}}; \quad \boxed{r = 3.15 \text{ mm}}$$

$$F = \frac{kQq}{r^2} = \frac{(9 \text{ x } 10^9 \text{N}\cdot\text{m}^2/\text{C}^2)(-7 \text{ x } 10^{-6}\text{C})(-3 \text{ x } 10^{-9}\text{C})}{(3.15 \text{ x } 10^{-3})^2}; \quad \boxed{F = 19.0 \text{ N, repulsion}}$$

Note: This value can also be obtained from: $F = \dfrac{P.E.}{r}$

25-7. A +8-nC charge is placed at a point *P*, 40 mm from a +12-μC charge. What is the potential energy per unit charge at point *P* in joules per coulomb? Will this change if the 8-nC charge is removed?



$$P.E. = \frac{kQq}{r} = \frac{(9 \text{ x } 10^9 \text{N}\cdot\text{m}^2/\text{C}^2)(+12 \text{ x } 10^{-6}\text{C})(8 \text{ x } 10^{-9}\text{C})}{0.040 \text{ m}}$$

$$P.E. = 0.0216 \text{ J};$$

$$V = \frac{P.E.}{q} = \frac{0.0270 \text{ J}}{8 \text{ x } 10^{-9}\text{C}}; \quad \boxed{V = 2.70 \text{ x } 10^6 \text{ J/C}}; \quad \boxed{\text{No}}$$ *The P.E./q is a property of space.*

If another charge were placed there or if no charge were there, the P.E./q is the same.

25-8. A charge of +6 μC is 30 mm away from another charge of 16 μC. What is the potential energy of the system?

$$P.E. = \frac{kQq}{r} = \frac{(9 \text{ x } 10^9 \text{N}\cdot\text{m}^2/\text{C}^2)(+6 \text{ x } 10^{-6}\text{C})(16 \text{ x } 10^{-6}\text{C})}{0.030 \text{ m}}; \quad \boxed{P.E. = 28.8 \text{ J}}$$

25-9. In Problem 25-8, what is the change in potential energy if the 6-μC charge is moved to a distance of only 5 mm? Is this an increase or decrease in potential energy?

$(P.E.)_{30} = 28.8$ J *from previous example. Now assume charge is moved.*

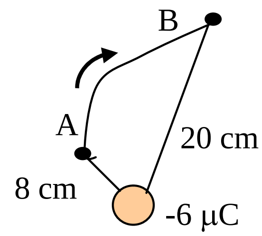
$$(P.E.)_5 = \frac{kQq}{r} = \frac{(9 \text{ x } 10^9 \text{N}\cdot\text{m}^2/\text{C}^2)(+6 \text{ x } 10^{-6}\text{C})(16 \text{ x } 10^{-6}\text{C})}{0.005 \text{ m}}; \quad (P.E.)_5 = 173 \text{ J}$$

Change in P.E. = 172. J – 28.8 J; $\boxed{\text{Change} = 144 \text{ J, increase}}$

25-10. A –3-μC charge is placed 6 mm away from a -9-μC charge. What is the potential energy? Is it negative or positive?

$$P.E. = \frac{kQq}{r} = \frac{(9 \text{ x } 10^9 \text{N}\cdot\text{m}^2/\text{C}^2)(-3 \text{ x } 10^{-6}\text{C})(-9 \text{ x } 10^{-6}\text{C})}{0.006 \text{ m}}; \quad \boxed{P.E. = +40.5 \text{ J}}$$

25-11. What is the change in potential energy when a 3-nC charge is moved from a point 8 cm away from a –6-μC charge to a point that is 20 cm away? Is this an increase or decrease of potential energy? *(Moves from A to B on figure.)*



$$(P.E.)_8 = \frac{kQq}{r} = \frac{(9 \text{ x } 10^9 \text{N}\cdot\text{m}^2/\text{C}^2)(-6 \text{ x } 10^{-6}\text{C})(3 \text{ x } 10^{-6}\text{C})}{0.08 \text{ m}}$$

$(P.E.)_8 = -2.025$ J, *(Negative potential energy)*

$$(P.E.)_{20} = \frac{(9 \text{ x } 10^9 \text{N}\cdot\text{m}^2/\text{C}^2)(-6 \text{ x } 10^{-6}\text{C})(3 \text{ x } 10^{-6}\text{C})}{0.20 \text{ m}} \qquad (P.E.)_{20} = -0.810 \text{ J},$$

Change = final – initial = -0.810 J – (-2.025 J); **Change in P.E. = +1.22 J, *increase***

25-12. At what distance from a –7-μC charge must a charge of –12 nC be placed if the potential energy is to be 9 x 10^{-5} J?

$$P.E. = \frac{kQq}{r}; \quad r = \frac{kQq}{P.E.} = \frac{(9 \text{ x } 10^9 \text{N}\cdot\text{m}^2/\text{C}^2)(-7 \text{ x } 10^{-6}\text{C})(-12 \text{ x } 10^{-9}\text{C})}{9 \text{ x } 10^{-5} \text{ J}};$$

r = 8.40 m

25-13. The potential energy of a system consisting of two identical charges is 4.50 mJ when their separation is 38 mm. What is the magnitude of each charge?

$$P.E. = \frac{kQq}{r} = \frac{kq^2}{r}; \quad q = \sqrt{\frac{r(P.E.)}{k}} = \sqrt{\frac{(0.038 \text{ m})(0.0045 \text{ J})}{(9 \text{ x } 10^9 \text{N}\cdot\text{m}^2/\text{C}^2)}};$$

q = 138 nC

Electric Potential and Potential Difference

25-14. What is the electric potential at a point that is 6 cm from a 8.40-μC charge? What is the potential energy of a 2 nC charge placed at that point?

$$V = \frac{kQ}{r} = \frac{(9 \text{ x } 10^9 \text{N}\cdot\text{m}^2/\text{C}^2)(8.40 \text{ x } 10^{-6}\text{C})}{0.06 \text{ m}}; \qquad V = 1.26 \text{ x } 10^6 \text{ V}$$

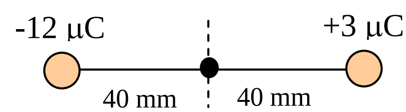
$P.E. = qV = (2 \text{ x } 10^{-9} \text{ C})(1.26 \text{ x } 10^6 \text{ V})$; **P.E. = 2.52 mJ**

25-15. Calculate the potential at point *A* that is 50 mm from a –40-μC charge. What is the potential energy if a +3-μC charge is placed at point A?

$$V = \frac{kQ}{r} = \frac{(9 \text{ x } 10^9 \text{N}\cdot\text{m}^2/\text{C}^2)(-40 \text{ x } 10^{-6}\text{C})}{0.050 \text{ m}}; \quad \boxed{V = -7.20 \text{ x } 10^6 \text{ V}}$$

$$\text{P.E.} = qV = (3 \text{ x } 10^{-6} \text{ C})(-7.2 \text{ x } 10^6); \quad \boxed{\text{P.E.} = -21.6 \text{ J}}$$

25-16. What is the potential at the midpoint of a line joining a –12-μC charge with a +3-μC charge located 80 mm away from the first charge?

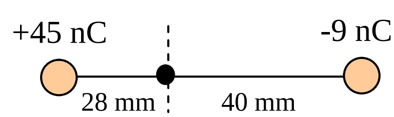


$$V = \sum \frac{kQ}{r} \quad \textit{(Net potential is algebraic sum)}$$

$$V = \sum \frac{kQ}{r} = \frac{(9 \text{ x } 10^9 \text{N}\cdot\text{m}^2/\text{C}^2)(-12 \text{ x } 10^{-6}\text{C})}{0.040 \text{ m}} + \frac{(9 \text{ x } 10^9 \text{N}\cdot\text{m}^2/\text{C}^2)(+3 \text{ x } 10^{-6}\text{C})}{0.040 \text{ m}}$$

$$V = -2.70 \text{ x } 10^6 \text{ V} + 0.675 \text{ x } 10^6 \text{ V}; \quad V = -2.025 \text{ x } 10^6 \text{ V}; \quad \boxed{V = -2.02 \text{ MV}}$$

25-17. A +45-nC charge is 68 mm to the left of a –9-nC charge. What is the potential at a point located 40 mm to the left of the –9-nC charge?



Find potential due to each charge, then add:

$$V = \sum \frac{kQ}{r} = \frac{(9 \text{ x } 10^9 \text{N}\cdot\text{m}^2/\text{C}^2)(45 \text{ x } 10^{-9}\text{C})}{0.028 \text{ m}} + \frac{(9 \text{ x } 10^9 \text{N}\cdot\text{m}^2/\text{C}^2)(-9 \text{ x } 10^{-9}\text{C})}{0.040 \text{ m}}$$

$$V = +14.5 \text{ x } 10^3 \text{ V} + (-2.025 \text{ x } 10^3 \text{ V}); \quad \boxed{V = +12.4 \text{ kV}}$$

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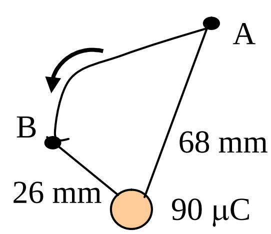
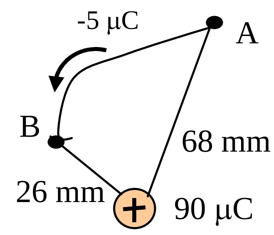
*25-18. Points A and B are 68 mm and 26 mm away from a 90-μC charge. Calculate the potential difference between points A and B? How much work is done BY the electric field as a -5-μC charge moves from A to B?



$$V_B = \frac{(9 \text{ x } 10^9 \text{N}\cdot\text{m}^2/\text{C}^2)(90 \text{ x } 10^{-6}\text{C})}{0.026 \text{ m}}; \quad V_B = 3.115 \text{ x } 10^7 \text{ V}$$

*25-18. (Cont.) $V_A = \dfrac{(9 \text{ x } 10^9 \text{N}\cdot\text{m}^2/\text{C}^2)(90 \text{ x } 10^{-6}\text{C})}{0.068 \text{ m}}$;



$V_A = 1.19 \text{ x } 10^7$ V; $V_B = 3.115 \text{ x } 10^7$ V

$V_B - V_A = 3.115 \text{ x } 10^7 \text{ V} - 1.19 \text{ x } 10^7$ V; **$\Delta V = 1.92 \text{ x } 10^7$ V**

Note that the potential INCREASES because B is at a higher potential than A

Now for the field: $(\text{Work})_{AB} = q(V_A - V_B) = (-5 \text{ x } 10^{-6} \text{ C})(1.19 \text{ x } 10^7 \text{ V} - 3.119 \text{ x } 10^7 \text{ V})$;

$\text{Work}_{AB} = +96.2$ mJ; *The field does positive work on a negative charge.*

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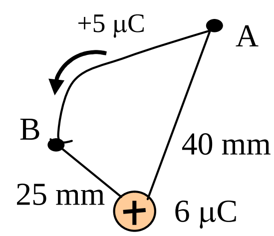
*25-19. Points A and B are 40 mm and 25 mm away from a +6-μC charge. How much work must be done against the electric field (by external forces) in moving a +5-μC charge from point A to point B?



$V_A = \dfrac{(9 \text{ x } 10^9 \text{N}\cdot\text{m}^2/\text{C}^2)(6 \text{ x } 10^{-6}\text{C})}{0.040 \text{ m}}$; $V_A = 1.35 \text{ x } 10^6$ V

$V_B = \dfrac{(9 \text{ x } 10^9 \text{N}\cdot\text{m}^2/\text{C}^2)(6 \text{ x } 10^{-6}\text{C})}{0.025 \text{ m}}$; $V_B = 2.16 \text{ x } 10^6$ V

$(\text{Work})_{AB} = q(V_A - V_B) = (+5 \text{ x } 10^{-6} \text{ C})(1.35 \text{ x } 10^6 \text{ V} - 2.16 \text{ x } 10^6 \text{ V})$; **$Work_{AB} = +4.05$ J**

Note: The work BY the field is negative, because the motion is against the field forces.

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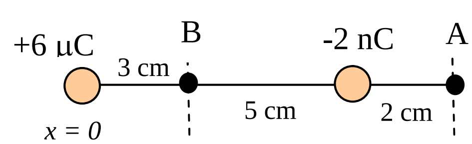
*25-20. A +6 μC charge is located at x = 0 on the x-axis, and a -2-μC charge is located at x = 8 cm. How much work is done BY the electric field in moving a –3-μC charge from the point x = 10 cm to the point x = 3 cm?

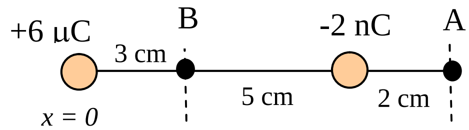


$V_A = \Sigma \dfrac{kQ}{r}$; $V_B = \Sigma \dfrac{kQ}{r}$

$V_A = \dfrac{(9 \text{ x } 10^9 \text{N}\cdot\text{m}^2/\text{C}^2)(6 \text{ x } 10^{-6}\text{C})}{0.10 \text{ m}} + \dfrac{(9 \text{ x } 10^9 \text{N}\cdot\text{m}^2/\text{C}^2)(-2 \text{ x } 10^{-6}\text{C})}{0.020 \text{ m}}$; $V_A = -360$ kV

*25-20. (Cont.) V_A = -360 V

$$V_B = \Sigma \frac{kQ}{r}$$

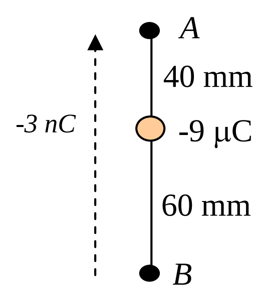


$$V_B = \frac{(9 \text{ x } 10^9 \text{N}\cdot\text{m}^2/\text{C}^2)(6 \text{ x } 10^{-6}\text{C})}{0.030 \text{ m}} + \frac{(9 \text{ x } 10^9 \text{N}\cdot\text{m}^2/\text{C}^2)(-2 \text{ x } 10^{-6}\text{C})}{0.050 \text{ m}}; \quad V_B = 1440 \text{ kV}$$

$(\text{Work})_{AB} = q(V_A - V_B) = (-3 \text{ x } 10^{-6} \text{ C})(-360 \text{ kV} - 1440 \text{ kV})$; $\boxed{Work_{AB} = +5.40 \text{ J}}$

Challenge Problems

25-21. Point A is 40 mm above a –9-μC charge and point B is located 60 mm below the same charge. A –3-nC charge is moved from point B to point A. What is the change in potential energy?



$$(P.E.)_A = \frac{kQq}{r} = \frac{(9 \text{ x } 10^9 \text{N}\cdot\text{m}^2/\text{C}^2)(-9 \text{ x } 10^{-6}\text{C})(-3 \text{ x } 10^{-9}\text{C})}{0.040 \text{ m}}$$

$$(P.E.)_B = \frac{kQq}{r} = \frac{(9 \text{ x } 10^9 \text{N}\cdot\text{m}^2/\text{C}^2)(-9 \text{ x } 10^{-6}\text{C})(-3 \text{ x } 10^{-9}\text{C})}{0.060 \text{ m}}$$

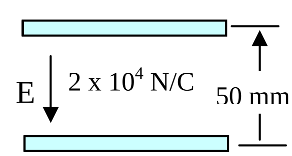
$(\text{P.E.})_A = 6.075 \text{ x } 10^{-3}$ J; $(\text{P.E.})_B = 4.05 \text{ x } 10^{-3}$ J; $\Delta E_p = 6.075 \text{ mJ} - 4.05 \text{ mJ}$

$\boxed{\Delta E_p = 2.02 \text{ mJ};}$ *The potential energy increases.*

25-22. Two parallel plates are separated by 50 mm in air. If the electric field intensity between the plates is 2 x 10^4 N/C, what is the potential difference between the plates?

$$E = \frac{V}{d}; \quad V = Ed = (2 \text{ x } 10^4 \text{N/C})(0.05 \text{ m})$$

$\boxed{V = 1000 \text{ V}}$



25-23. The potential difference between two parallel plates 60 mm apart is 4000 volts. What is the electric field intensity between the plates?

$$E = \frac{V}{d} = \frac{4000\text{ V}}{0.060\text{ m}};\quad \boxed{E = 66.7\text{ kV/m}}$$

25-24. If an electron is located at the plate of lower potential in Problem 25-23, what will be its kinetic energy when it reaches the plate of higher potential. What is the energy expressed in electronvolts? (*Work done on electron equals its change in kinetic energy.)*

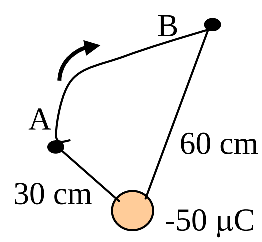
$$\tfrac{1}{2}mv^2 = qEd = (1.6 \text{ x } 10^{-19}\text{ J})(66{,}700\text{ V/m})(0.060\text{ m}) = 6.40 \text{ x } 10^{-16}\text{ J}$$

$$\tfrac{1}{2}(9.11 \text{ x } 10^{-31}\text{ kg})v^2 = 6.40 \text{ x } 10^{-16}\text{ J};\quad \boxed{v = 3.75 \text{ x } 10^{7}\text{ m/s}}$$

25-25. Show that the potential gradient V/m is equivalent to the unit N/C for electric field.

$$1\frac{\text{V}}{\text{m}}\left(\frac{1\text{ J/C}}{1\text{ V}}\right)\left(\frac{1\text{ N m}}{1\text{ J}}\right) = 1\frac{\text{N}}{\text{C}}$$

25-26. What is the difference in potential between two points 30 and 60 cm away from a –50-μC charge? $\Delta E_p = V_A - V_B$



$$V_{AB} = \frac{(9 \text{ x } 10^9 \text{N}\cdot\text{m}^2/\text{C}^2)(-50 \text{ x } 10^{-6})}{0.030\text{ m}} - \frac{(9 \text{ x } 10^9 \text{N}\cdot\text{m}^2/\text{C}^2)(-50 \text{ x } 10^{-6})}{0.060\text{ m}}$$

$$V_{AB} = -1.50 \text{ x } 10^{7}\text{ V} - (-7.50 \text{ x } 10^{6}\text{ J});\quad \boxed{\Delta V_{AB} = -7.50 \text{ x } 10^{6}\text{ J}}$$

25-27. The potential gradient between two parallel plates 4 mm apart is 6000 V/m. What is the potential difference between the plates?

$$V = Ed = (6000\text{ V/m})(0.004\text{ m});\quad \boxed{V = 24.0\text{ V}}$$

25-28. The electric field between two plates separated by 50 mm is 6 x 10^5 V/m. What is the potential difference between the plates?

$$V = Ed = (600{,}000 \text{ V/m})(0.005 \text{ m}); \quad \boxed{V = 3 \text{ kV}}$$

25-29. What must be the separation of two parallel plates if the field intensity is 5 x 10^4 V/m and the potential difference is 400 V?

$$V = Ed; \quad d = \frac{V}{E} = \frac{400 \text{ V}}{50{,}000 \text{ V/m}}; \quad \boxed{d = 8.00 \text{ mm}}$$

25-30. The potential difference between two parallel plates is 600 V. A 6-μC charge is accelerated through the entire potential difference. What is the kinetic energy given to the charge?

$$\Delta E_k = Work = qV; \quad \Delta E_k = (6 \times 10^{-6} \text{ C})(600 \text{ V}); \quad \boxed{\Delta E_k = 3.60 \text{ mJ}}$$

25-31. Determine the kinetic energy of an alpha particle (+2e) that is accelerated through a potential difference of 800 kV. Give the answer in both electronvolts and joules.

$$\Delta E_k = \text{Work} = qV; \quad \Delta E_k = (2e)(8 \times 10^5 \text{ V}); \quad \boxed{\Delta E_p = 1.60 \text{ MeV}}$$

$$\Delta E_k = \text{Work} = qV; \quad \Delta E_k = 2(1.6 \times 10^{-19} \text{ C})(8 \times 10^5 \text{ V}); \quad \boxed{\Delta E_p = 2.56 \times 10^{-13} \text{ J}}$$

25-32. A linear accelerator accelerates an electron through a potential difference of 4 MV, What is the energy of an emergent electron in electronvolts and in joules?

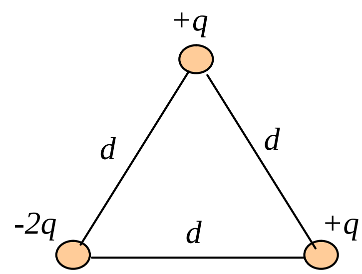
$$\Delta E_k = qV = (1 \text{ e})(4 \times 10^6 \text{ V}); \quad \boxed{\Delta E_k = 4.00 \text{ MeV}}$$

$$\Delta E_k = qV = (1.6 \times 10^{-19} \text{ J})(4 \times 10^6 \text{ V}); \quad \boxed{\Delta E_k = 6.40 \times 10^{-13} \text{ J}}$$

25-33. An electron acquires an energy of 2.8 x 10^{-15} J as it passes from point A to point B. What is the potential difference between these points in volts?

$$\Delta E_k = qV; \quad (1.6 \times 10^{-19} \text{ C})V = 2.8 \times 10^{-15} \text{ J}; \quad \boxed{V = 17.5 \text{ kV}}$$

*25-34. Show that the total potential energy of the three charges placed at the corners of the equilateral triangle shown in Fig. 25-11 is given by:



$$\frac{-kq^2}{d}$$

First find the work required to bring the two +q's together.

Then add the extra work to bring the –2q charge to each q:

$$P.E. = \sum \frac{kQq}{r} = \frac{kqq}{d} + \frac{k(-2q)q}{d} + \frac{k(-2q)q}{d} \;; \qquad P.E. = \frac{kq^2}{d} - \frac{2kq^2}{d} - \frac{2kq^2}{d} = \frac{-3kq^2}{d}$$

$$\boxed{P.E. = \frac{-3q^2}{d}}$$

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*25-35. Assume that q = 1 μC and d = 20 mm. What is the potential energy of the system of charges in Fig. 25-11.

$$P.E. = \frac{-3q^2}{d} = \frac{-3(1 \text{ x } 10^{-6}\text{C})^2}{0.020 \text{ m}}; \quad \boxed{\text{P.E.} = 1.50 \text{ x } 10^{-10} \text{ J}}$$

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*25-36. The potential at a certain distance from a point charge is 1200 V and the electric field intensity at that point is 400 N/C. What is the distance to the charge, and what is the magnitude of the charge?

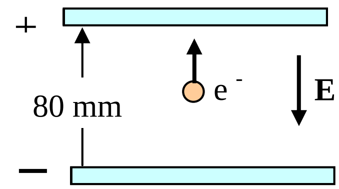
$$V = \frac{kQ}{r} = 1200 \text{ V}; \quad r = \frac{kQ}{1200 \text{ V}}; \quad E = \frac{kQ}{r^2} = 400 \text{N/C}$$

$$E = \frac{kQ}{(k^2Q^2/(1200 \text{ V})^2} = \frac{(1200 \text{ V})^2}{kQ}; \quad \frac{1.44 \text{ x } 10^6\text{V}^2}{(9 \text{ x } 10^9 \text{N} \cdot \text{m}^2/\text{C}^2)Q} = 400 \text{ N/C}$$

$$Q = \frac{1.44 \text{ x } 10^6 \text{N/C}}{(9 \text{ x } 10^9 \text{N} \cdot \text{m}^2/\text{C}^2)(400 \text{ N/C})}; \quad \boxed{Q = 400 \text{ nC}}$$

$$r = \frac{kQ}{1200 \text{ V}} = \frac{(9 \text{ x } 10^9 \text{N} \cdot \text{m}^2/\text{C}^2)(4.00 \text{ x } 10^{-9}\text{C})}{1200 \text{ V}}; \quad \boxed{r = 3.00 \text{ m}}$$

*25-37. Two large plates are 80 mm apart and have a potential difference of 800 kV. What is the magnitude of the force that would act on an electron placed at the midpoint between these plates? What would be the kinetic energy of the electron moving from low potential plate to the high potential plate?



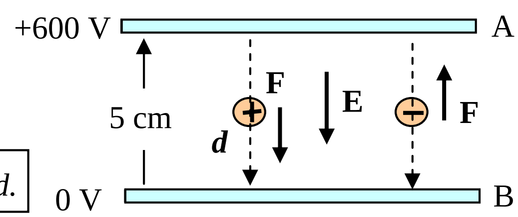
$$F = qE = \frac{qV}{d} = \frac{(1.6 \text{ x } 10^{-19}\text{J})(8 \text{ x } 10^{5}\text{V})}{0.080 \text{ m}}; \quad \boxed{F = 1.6 \text{ x } 10^{-12} \text{ N}}$$

$Work = qV = ½mv^2$; $E_k = (1.6 \text{ x } 10^{-19} \text{ C})(8 \text{ x } 10^{5} \text{ V})$

$$\boxed{\Delta E_k = 1.28 \text{ x } 10^{-13} \text{ J}}$$

Critical Thinking Problems

25-38. Plate A has a potential that is 600 V higher than Plate B which is 50 mm below A. A +2-μC charge moves from plate A to plate B? What is the electric field intensity between the plates? What are the sign and magnitude of the work done by the electric field? Does the potential energy increase or decrease? Now answer the same questions if a –2-μC charge is moved from A to B?



First find the field E between the plates:

$$E = \frac{V}{d} = \frac{600 \text{ V}}{0.050 \text{ m}}; \quad \boxed{E = 12{,}000 \text{ V/m}, \textit{ downward.}}$$

*When a <u>positive</u> charge moves with the field, the work is <u>positive</u>, since **F** and **d** are <u>same</u>.*

*When a <u>negative</u> charge moves with **E**, the work is <u>negative</u>, since **F** and **d** are <u>opposite</u>*

(a) $Work = q\,\Delta V = (2 \text{ x } 10^{-6} \text{ C})(600 \text{ V} - 0 \text{ V})$; $\boxed{Work = 1.20 \text{ mJ, positive work}}$

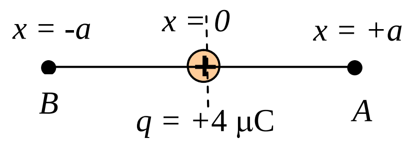
The field does work, so the +2-μC *charge loses energy;* $\boxed{\textit{P.E. decreases}}$

(b) $Work = q\,\Delta V = (-2 \text{ x } 10^{-6} \text{ C})(600 \text{ V} - 0 \text{ V})$; $\boxed{Work = -1.20 \text{ mJ, negative work}}$

The field does negative work, so the -2-μC *charge gains energy;* $\boxed{\textit{P.E .increases}}$

25-39. Point A is a distance $x = +a$ to the right of a +4-μC charge. The rightward electric field at point A is 4000 N/C. What is the distance a ? What is the potential at point A? What are the electric field and the potential at the point $x = -a$. Find the electric force and the electric potential energy when a –2-nC charge is placed at each point?

$$E_A = \frac{kq}{a^2}; \quad a^2 = \frac{kq}{E_A} = \frac{(9 \text{ x } 10^9 \text{N}\cdot\text{m}^2/\text{C}^2)(4 \text{ x } 10^{-6}\text{C})}{4000 \text{ N/C}}$$



$$a = \sqrt{9.00 \text{ m}^2} \qquad \boxed{a = 3.0 \text{ m}}$$

$$V_A = \frac{kQ}{a} = \frac{(9 \text{ x } 10^9 \text{N}\cdot\text{m}^2/\text{C}^2)(4 \text{ x } 10^{-6}\text{C})}{3.00 \text{ m}}; \qquad \boxed{V_A = 12.0 \text{ kV}}$$

$$E_B = \frac{kq}{a^2} = \frac{(9 \text{ x } 10^9 \text{N}\cdot\text{m}^2/\text{C}^2)(4 \text{ x } 10^{-6}\text{C})}{(3.00 \text{ m})^2}; \qquad \boxed{E_B = 4000 \text{ N, } \textit{to the left}}$$

$$V_B = \frac{kQ}{a} = \frac{(9 \text{ x } 10^9 \text{N}\cdot\text{m}^2/\text{C}^2)(4 \text{ x } 10^{-6}\text{C})}{3.00 \text{ m}}; \qquad \boxed{V_A = 12.0 \text{ kV}}$$

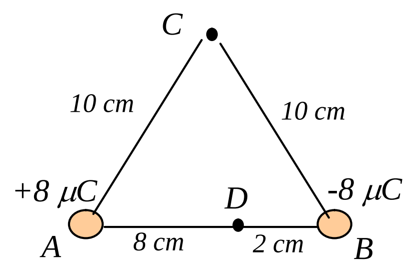
$$F_A = qE_A = (-2 \text{ x } 10^{-9} \text{ C})(+4000 \text{ N/C}); \qquad \boxed{F_A = -8 \text{ x } 10^{-6} \text{ N, } \textit{leftward}}$$

$$(P.E.)_A = qV_A = (-2 \text{ x } 10^{-9} \text{ C})(12{,}000 \text{ V}); \qquad \boxed{(\text{P.E.})_A = 8.00 \text{ x } 10^{-6} \text{ J}}$$

$$F_B = qE_B = (-2 \text{ x } 10^{-9} \text{ C})(-4000 \text{ N/C}); \qquad \boxed{F_A = +8 \text{ x } 10^{-6} \text{ N, } \textit{rightward}}$$

$$(P.E.)_B = qV_B = (-2 \text{ x } 10^{-9} \text{ C})(12{,}000 \text{ V}); \qquad \boxed{(\text{P.E.})_A = 8.00 \text{ x } 10^{-6} \text{ J}}$$

*25-40. Points A, B, and C are at the corners of an equilateral triangle that is 100 mm on each side. At the base of the triangle, a +8-μC charge is 100 mm to the left of a –8-μC charge. What is the potential at the apex C? What is the potential at a point D that is 20 mm to the left of the –8-μC charge? How much work is done by the electric field in moving a +2-μC charge from point C to point D?



$$V_C = \frac{(9 \times 10^9 \mathrm{N \cdot m^2/C^2})(8 \times 10^{-6}\mathrm{C})}{0.10 \mathrm{~m}} + \frac{(9 \times 10^9 \mathrm{N \cdot m^2/C^2})(-8 \times 10^{-6}\mathrm{C})}{0.10 \mathrm{~m}}; \quad \boxed{V_C = 0}$$

$$V_D = \frac{(9 \times 10^9 \mathrm{N \cdot m^2/C^2})(8 \times 10^{-6}\mathrm{C})}{0.08 \mathrm{~m}} + \frac{(9 \times 10^9 \mathrm{N \cdot m^2/C^2})(-8 \times 10^{-6}\mathrm{C})}{0.02 \mathrm{~m}}; \quad \boxed{V_D = -2.70 \mathrm{~MV}}$$

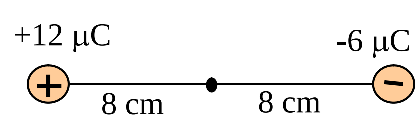
$$(Work)_{CD} = qV_{CD} = (+2 \times 10^{-6} \mathrm{~C})\,[0 - (-2.70 \times 10^{6} \mathrm{~V})] \quad \boxed{(Work)_{CD} = 5.40 \mathrm{~J}}$$

---

*25-41. Two charges of +12 and –6-μC are separated by 160 mm. What is the potential at the midpoint A of a line joining the two charges? At what point B is the electric potential equal to zero?

$$V_A = \frac{(9 \times 10^9 \mathrm{N \cdot m^2/C^2})(12 \times 10^{-6}\mathrm{C})}{0.08 \mathrm{~m}} + \frac{(9 \times 10^9 \mathrm{N \cdot m^2/C^2})(-6 \times 10^{-6}\mathrm{C})}{0.08 \mathrm{~m}}; \quad \boxed{V_A = 675 \mathrm{~kV}}$$

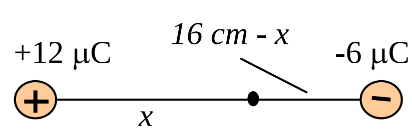
$$V_B = \frac{(9 \times 10^9 \mathrm{N \cdot m^2/C^2})(12 \times 10^{-6}\mathrm{C})}{\mathrm{x}} + \frac{(9 \times 10^9 \mathrm{N \cdot m^2/C^2})(-6 \times 10^{-6}\mathrm{C})}{16 \mathrm{~cm - x}} = 0$$



$$\frac{12 \times 10^{-6}\mathrm{C}}{x} = \frac{6 \times 10^{-6}\mathrm{C}}{(16 \mathrm{~cm} - x}$$

$$2(16 \mathrm{~cm} - x) = x;$$

$\boxed{x = 10.7 \text{ cm } \textit{from the } +12\text{-}\mu\text{C } \textit{charge}}$



*25-42. For the charges and distances shown in Fig. 25-12, find the potential at points A, B, and C? How much work is done BY the electric field in moving a +2-μC charge from C to A? How much work is done in moving a –2-μC charge from B to A?

$$V_A = \frac{(9 \text{ x } 10^9 \text{N}\cdot\text{m}^2/\text{C}^2)(-6 \text{ x } 10^{-9}\text{C})}{0.03 \text{ m}} + \frac{(9 \text{ x } 10^9 \text{N}\cdot\text{m}^2/\text{C}^2)(+4 \text{ x } 10^{-9}\text{C})}{0.03 \text{ m}}; \quad \boxed{V_A = -600 \text{ V}}$$

$$V_B = \frac{(9 \text{ x } 10^9 \text{N}\cdot\text{m}^2/\text{C}^2)(-6 \text{ x } 10^{-9}\text{C})}{0.09 \text{ m}} + \frac{(9 \text{ x } 10^9 \text{N}\cdot\text{m}^2/\text{C}^2)(+4 \text{ x } 10^{-9}\text{C})}{0.03 \text{ m}}; \quad \boxed{V_B = +600 \text{ V}}$$

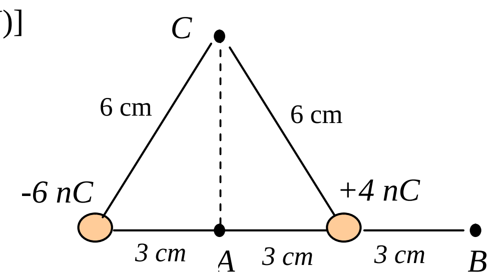
$$V_B = \frac{(9 \text{ x } 10^9 \text{N}\cdot\text{m}^2/\text{C}^2)(-6 \text{ x } 10^{-9}\text{C})}{0.06 \text{ m}} + \frac{(9 \text{ x } 10^9 \text{N}\cdot\text{m}^2/\text{C}^2)(+4 \text{ x } 10^{-9}\text{C})}{0.06 \text{ m}}; \quad \boxed{V_C = -300 \text{ V}}$$

$(Work)_{CA} = q(V_A - V_C) = (2 \text{ x } 10^{-6} \text{ C})[-300 \text{ V} - (-600 \text{ V})]$

$$\boxed{Work = +6 \text{ x } 10^{-4} \text{ J}}$$

$(Work)_{CA} = (-2 \text{ x } 10^{-6} \text{ C})[600 \text{ V} - (-600 \text{ V})]$

$$\boxed{Work = -2.4 \text{ x } 10^{-3} \text{ J}}$$



*25-43. The horizontal plates in Millikan's oil-drop experiment are 20 mm apart. The diameter of a particular drop of oil is 4 μm, and the density of oil is 900 kg/m³. Assuming that two electrons attach themselves to the droplet, what potential difference must exist between the plates to establish equilibrium? [Volume of a sphere = $4\pi R^3/3$]

$$Vol. = \frac{4\pi(0.02 \text{ m})^3}{3} = 33.5 \text{ x } 10^{-18}\text{m}^3; \quad \rho = \frac{m}{V}; \quad m = \rho V$$

$$m = (900 \text{ kg/m}^3)(33.5 \text{ x } 10^{-18} \text{ m}^3) = 3.016 \text{ x } 10^{-14} \text{ kg};$$

$$qE = mg; \quad q\left(\frac{V}{d}\right) = mg; \quad V = \frac{mgd}{q}$$

$$V = \frac{(3.016 \text{ x } 10^{-14}\text{kg})(9.8 \text{ m/s}^2)(0.02 \text{ m})}{2(1.6 \text{ x } 10^{-19}\text{C})}; \quad \boxed{V = 18.5 \text{ kV}}$$