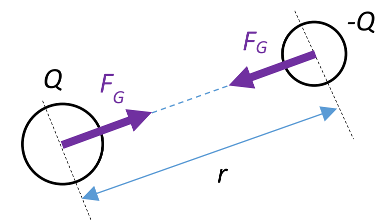
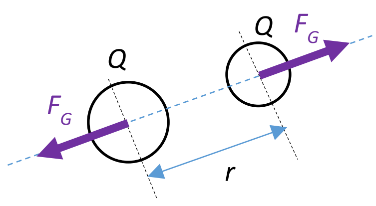
**Electric Fields**

**Coulomb's law of Electrostatic Force** – The magnitude of the electrostatic force between two point charges is directly proportional to the product of the charges and inversely proportional to the square of their separation.

**Electric Potential Energy** – work done by an external agent on the charge in moving the charge from infinity to that point.



Opposite charges attract



Like charges repel

$$F_E = \frac{qQ}{4\pi\varepsilon_0 r^2} \qquad E = \frac{Q}{4\pi\varepsilon_0 r^2}$$

$$E = \frac{F_G}{q} \qquad F_E = qE$$

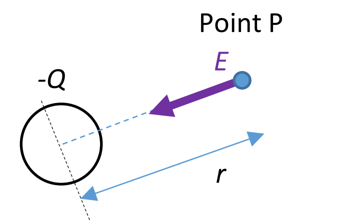
$$F_E = -\frac{dU}{dr} \qquad U = -\int_\infty^r F_E\,dr \qquad E = -\frac{dV}{dr} \qquad V = -\int_\infty^r E\,dr$$

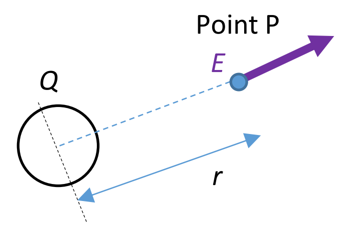
$$U = \frac{qQ}{4\pi\varepsilon_0 r} \qquad V = \frac{Q}{4\pi\varepsilon_0 r}$$

$$V = \frac{U}{q} \qquad U = qV$$

Note:

- May not need negative sign for charges in $F_E$ and $E$ (Vectors)
- Must sub in respective negative signs for charges in $U$ and $V$.




**Electric Field Strength, *E*** – at a point in an electric field is the electric force per unit positive charge acting on a stationary test charge placed at that point.

**Electric Potential, *V*** – work done **per unit** positive charge by an external agent in moving a point charge from infinity to that point.

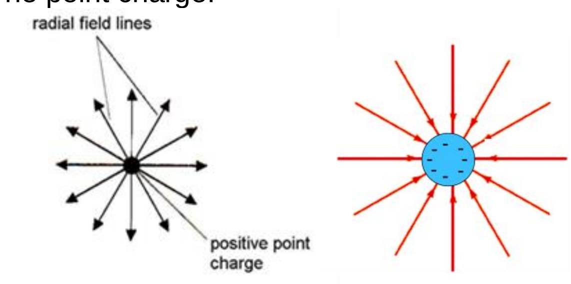
**Field Lines**

- Tangent of the lines points in the direction of the force on a positive test charge
- Point in the direction of decreasing electric potentials
- Closer lines indicate larger *E*
- No two lines intersect one another
- Perpendicular to Equipotential Lines/Surfaces

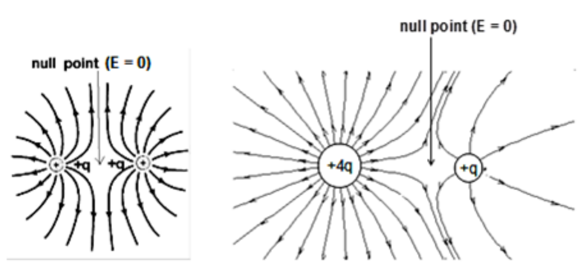
**Equipotential Lines**

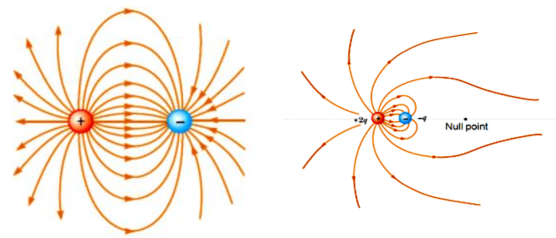
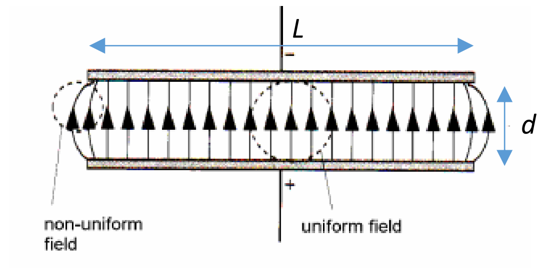
- All points along a line has the same electric potential
- No work done when moving a mass along a equipotential line
- Perpendicular to Field Lines

One point charge:



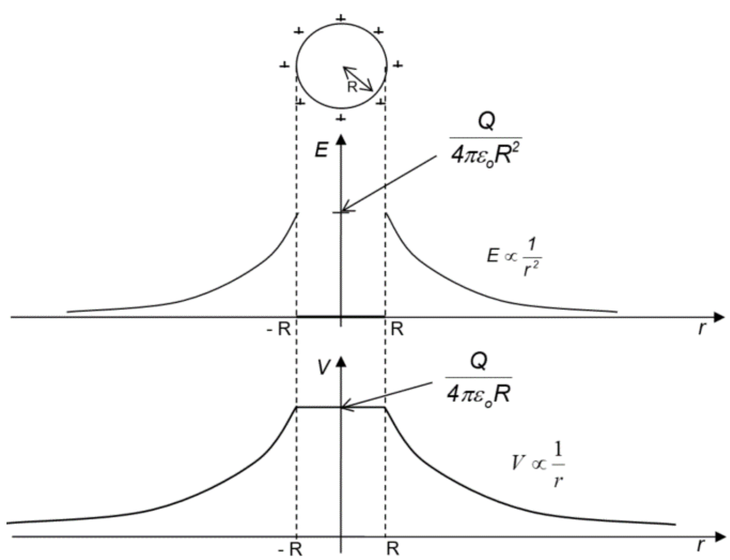

Two like point charges



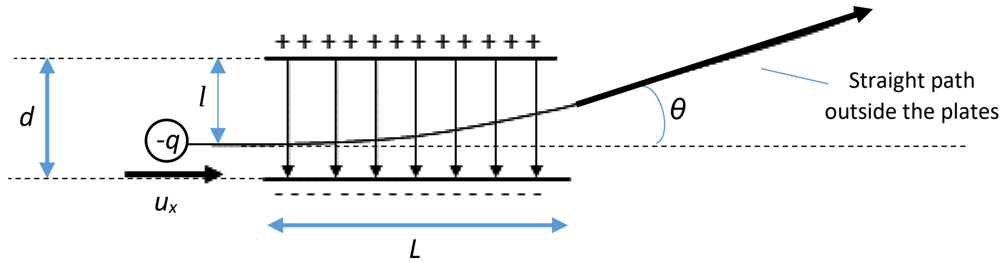
| | |
|---|---|
| | Two unlike point charges<br><br> |
| **In between parallel plates,**<br>Electric is uniform, assuming *d* << *L*<br><br><u>Electric Field Strength,</u><br>$E = \frac{\Delta V}{d}$<br><u>Electric Force on a charge *q*,</u><br>$F = qE = q\frac{\Delta V}{d}$<br><u>Work Done / Change in EPE</u><br>$W = q\Delta V$ | Parallel Plates:<br><br><br>Electric field between parallel charged plates<br>*Usually assume field in between plates to be uniform. Non-uniform field at the edges are usually ignored in calculation. |

**Electric Field Strength and Potential in Conductors:**

- $E$ is zero but $V$ maybe non-zero within a conductor.
  - Because net charges will distribute over the surface of (but not within) the conductor.
    - Charge density is larger at region of smaller radius of curvature
- Since $E$ = 0, and $E = -dV/dr$, there is no change in potential → equipotential throughout the conductor. (Note: same potential does not mean zero potential)



## Projectile Motion of a Charge Moving in Between Parallel Plates




| | | |
|---|---|---|
| <u>Force on charge *-q*</u> | $F = q\frac{\Delta V}{d}$, upward | |
| <u>Acceleration on charge *-q*</u> | $a_y = \frac{F}{m} = \frac{q\Delta V}{md}$ | |
| <u>Equations of Motion</u><br>• $u_x$ remains constant<br>• Applicable only within plates, in the uniform field | y-directions | x-direction |
| | $s_y = u_y t + \frac{1}{2}a_y t^2$ | $s_x = u_x t$ |
| | $v_y^{\ 2} = u_y^{\ 2} + 2a_y s_y$ | $v_x^{\ 2} = u_x^{\ 2}$<br>$v_x = u_x$ |
| | $v_y = u_y + a_y t$ | |
| <u>Final Velocity</u> | $\vec{v} = \vec{u}_x + \vec{v}_y$<br>$v = \sqrt{u_x^{\ 2} + v_y^{\ 2}}$ | |
| <u>Time of Flight (Time within Plates)</u> | $t_f = \frac{L}{u_x}$, $t$ = 0 when charge just enter plates | |
| <u>Angle of deflection, *θ*</u> | At time $t_f$ just after leaving the plates,<br>$\theta = tan^{-1}\frac{v_y}{u_x}$ | |
| <u>Will charge hit plate or leave the plates?</u> | At time $t_f$ just after leaving the plates,<br>$s_y > l$ → hits plate<br>$s_y \leq l$ → leaves plate<br>$s_y = l$ → *just* nice leave plate | |
| <u>Conservation of Energy</u><br>• Electric Potential Energy converted to Kinetic Energy of the charge | $\frac{1}{2}mv_f^{\ 2} - \frac{1}{2}mv_i^{\ 2} = -q\Delta V_{s_y} = qEs_y$ | |