D2: Electric and Magnetic Fields

- Charges:

(+) (hole) (−) (electron)

- flow:

− ⟶ + Electron/charge flow

⟵ current flow

Conservation Of Charge

↳ In any charging process, no electrons are created or destroyed. Electrons are simply transferred from one material to another.

↳ Ways to charge:

- Friction
- Touching
- Induction (bring a charge close to low charge without touching)

↳ Device used for charging:

- Von de graaf
- Electroscope gold leaf

↳ Effects of charges:

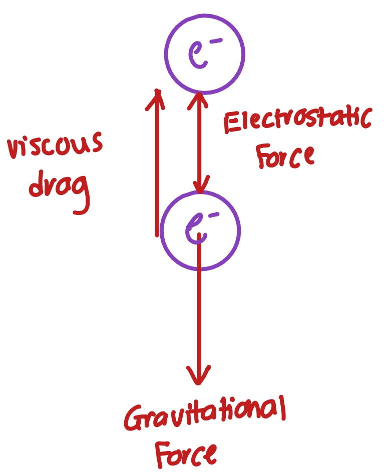
Same charges - repel
different charges - attract

↳ Types of Forces:

- Electrostatic Force (Held usually between charges)
- Electrical Force (when there's already flow of current)

Milikan's Experiment

↳ To determine the number of charge of an electron



1 electron carries : 1.6×10^{-19} C

1 coulomb carries : 6.25×10^{10} electrons

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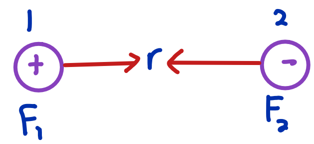
Electrostatic & Electric Force, Electric Field

- The smallest amount of -ve charge available is the charge of 1 electron.
  (This is strictly used in counting. For smaller values, use fractions. eg: $\frac{e^-}{3}$, $\frac{2}{5}e^-$, $\frac{5}{7}e^-$)
- The smallest amount of positive charge is the charge of 1 proton.
- Unit of a charge is Coulomb (C).
- Coulomb's law must must be between 2 charges.



Coulomb's Law

↳ Coulomb's law states that the electrostatic force (F) between 2 point charges (q_1 and q_2) is directly proportional to the product of their charges and inversely proportional to the square of the distance (r) between them.

$$F \propto q_1 q_2$$

$$F \propto \frac{1}{r^2}$$

$$F = \frac{k q_1 q_2}{r^2} \quad @ \quad F = \frac{q_1 q_2}{4\pi\epsilon_0 r^2}$$

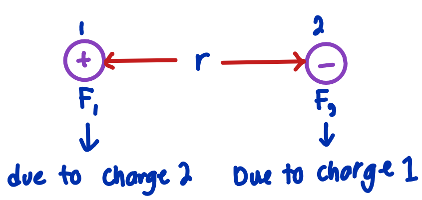
q : charge (C)

r : distance between 2 charges (m)

k : Coulomb's constant ($8.99 \times 10^9\ Nm^2C^{-2}$)

@ $k = \frac{1}{4\pi\epsilon_0}$

ϵ_0 : Permittivity for the free space ($8.5 \times 10^{-12}\ C^2m^{-2}N^{-1}$)



* If the are 3 or more charges, the overall force can be worked out using vector addition.

$$F_n = F_{n1} + F_{n2} + \dots$$

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Electric Field

↳ Force per unit positive point test charge (small charge), q

Q = Point charge

q = Test charge (sitting in the field)

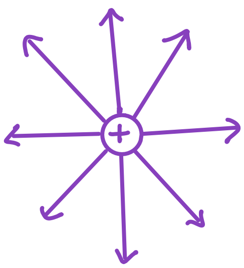
$\vec{E} = \frac{\vec{F}}{q} = \frac{kQ}{r^2}$ ↗ charge that produce the field

same

$g = \frac{GM}{r^2}$

[Radial] $E = \frac{Q}{4\pi\varepsilon_0 r^2}$ (Newton per coulomb, NC^{-1})

Rules to draw electric field



① lines evenly distributed

② lines touch the charge

③ atleast 6 lines

④ same length

if 2 times, [lines x 2]

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Electric Potential

↳ Electric potential, V is the potential energy per unit test charge (small charge)

@

↳ Work done per unit test charge (small charge) in bringing a unit positive charge from infinity to the point

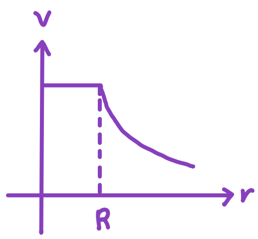
↳ V is a scalar quantity, so include signs in calculation

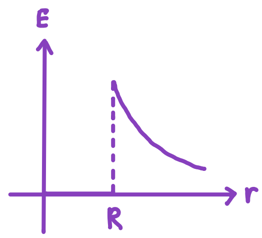
① $V = \frac{PE}{q}$ ② $V = \frac{W}{q}$ $\underbrace{③\ V = \frac{kQ}{r} \quad ④\ V = \frac{q}{4\pi\epsilon_0 r}}_{\text{Radial}}$ $\underbrace{⑤\ V = \frac{E}{d}}_{\text{parallel}}$

The Electric Potential of a Charged Conducting Sphere

↳ The electric potential at a radial distance of r away from the center of a sphere

- Electric potential inside sphere is constant
- Electric field inside sphere is 0 (because charges distributed evenly at the surface)

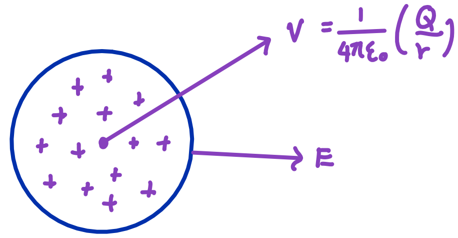




$$V = \frac{1}{4\pi\epsilon_0}\left(\frac{Q}{r}\right)$$

* Outside of sphere, the graphs obey:
  $V = \frac{1}{r}$, $E = \frac{1}{r^2}$

* At surface, V=R, the charges are uniformly distributed.



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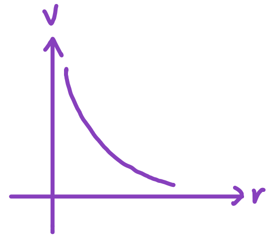
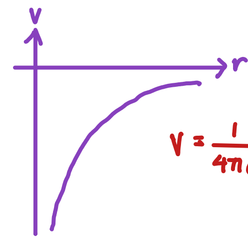
↳ Graph of electric potential due to point charge (big charge)

(i) single +ve charge

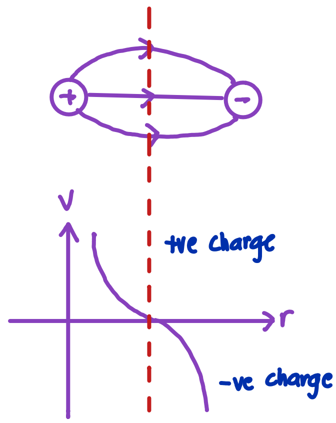


(ii) single -ve charge

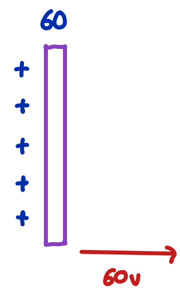


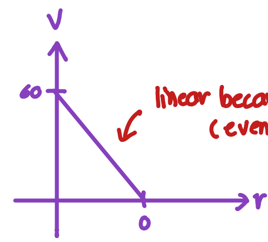
$V = \frac{1}{4\pi\epsilon_0}\left(\frac{Q}{r}\right)$ when $Q<0$

(ii) 2 unlike charges



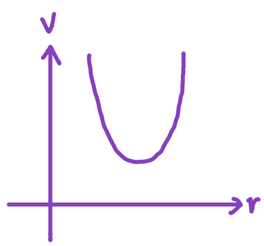
(iv) Parallel plates

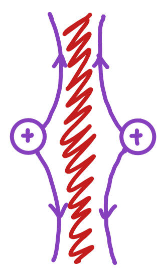




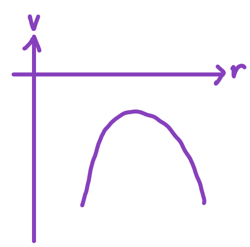
linear because field lines are parallel (evenly distributed)

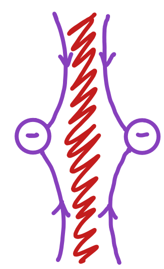
(v) 2 like-charges (+ve)





(vi) 2 like-charges (-ve)





↳ If several charges all contribute to the total potential at a point, it can be calculated by adding up the individual potentials due to the individual charges (include signage, no direction)

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Equipotential

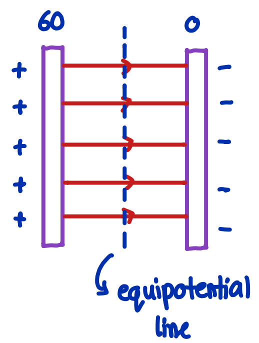
↳ Regions in space where the electric potential of a charge distribution has a constant value.

Equipotential surface → Meant for 3D
Equipotential line → Meant for 2D

↳ The potential difference between any 2 points on the surface is zero

$$\Delta V = \frac{\Delta W}{q}$$

↳ An equipotential surface must be perpendicular to the electric field at any point



* At least 3 equipotential line

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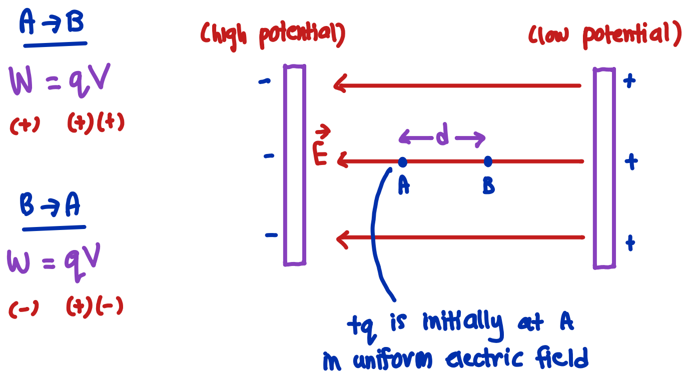
Electric Potential Difference

↳ Suppose a charge +q moves between point A and B through a distance, d in a uniform electric field.



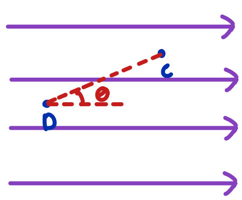
- Moving from A to B requires work (move against the field)
- q increase in potential
- Work done by the charge
- The work will be positive, because charge do the work
- If B→A, Charge lose potential, field do the work, work is negative
- In order to move +q from A to B, external force must be applied to the charge equal to :

$$F = Eq$$

- The work done to move the charge:

$$W = F \cdot d = (Eq) \cdot d$$

- If a charge moves at angle (θ) to an electric field, the work done to move the charge :



$$W = F \cdot d = (Eq) \cdot d \cos\theta$$

- Electrical potential difference between 2 points in an electric field is defined as the work done in moving a positive test charge (small charge) from the point at lower potential to the point at higher potential.

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Potential difference between 2 points = energy difference per unit charge

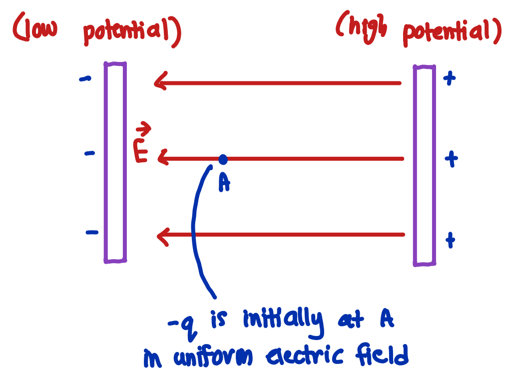
$$\Delta V = \frac{\Delta PE}{q} = \frac{\Delta W}{q}$$

(unit : V / JC^{-1})

* When dealing with atomic scale, Joule is too big to use for a unit of energy. A useful unit is the electrovolt (eV)

$$1\,eV = 1\,V \times 1.6 \times 10^{-19}\,C$$
$$= 1.6 \times 10^{-19}\,J$$

↳ suppose q is -ve



$$W = qV$$
$$(-) \quad (-)(+)$$

- q accelerate to positive plate, work is negative, fields do the work

Relationship between electric potential, V and electric field, E

- The effect of any charge distribution can be described either in terms of electric field or in terms of electric potential.
- The relation for the case (example) of a uniform electric field such as between parallel plates.
- The work done to move a +ve charge q from A to B is :

$$W = qV_{AB}$$

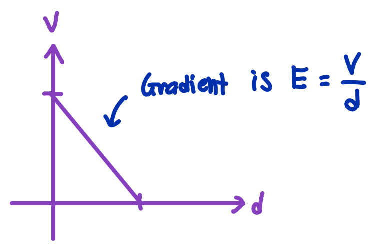
But :

$$W = F \cdot d = (Eq) \cdot d \quad (d = \text{distance})$$

So :

$$E = \frac{V_{AB}}{d}$$

(E - uniform)
(unit : Vm^{-1})



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Electric Potential Energy

- A charge has a result of its position in an electric field.
- When a charge is placed in an eletric field, it will feel the force
- The charge will move around (work will be done)
- The charge will either gain or lose electrical potential energy.
- If moves against the field, the charge does the work, gain potential (vice versa)

PE of the test charge's that moves in a point charge's field.

$$PE = \Delta W = \frac{kQq}{r} = Vq$$

Potential of the charge from the one who produce the field (point charge),

$$V = \frac{kQ}{r}$$

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