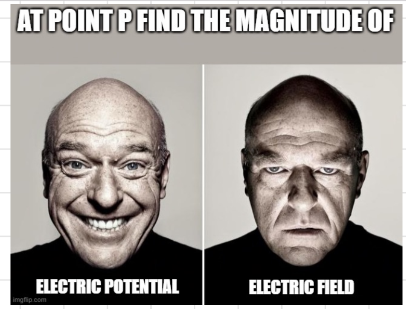
Electric Fields

A LEVEL

18 Electric fields

SOON =>



Learning outcomes

By the end of this topic, you will be able to:

18.1 Electric fields and field lines

1 understand that an electric field is an example of a field of force and define electric field as force per unit positive charge

2 recall and use $F = qE$ for the force on a charge in an electric field

3 represent an electric field by means of field lines

18.2 Uniform electric fields

1 recall and use $E = \Delta V/\Delta d$ to calculate the field strength of the uniform field between charged parallel plates

2 describe the effect of a uniform electric field on the motion of charged particles

18.3 Electric force between point charges

1 understand that, for a point outside a spherical conductor, the charge on the sphere may be considered to be a point charge at its centre

2 recall and use Coulomb's law $F = Q_1Q_2/(4\pi\varepsilon_0 r^2)$ for the force between two point charges in free space

18.4 Electric field of a point charge

1 recall and use $E = Q/(4\pi\varepsilon_0 r^2)$ for the electric field strength due to a point charge in free space

18.5 Electric potential

1 define the electric potential at a point as the work done per unit positive charge in bringing a small test charge from infinity to the point

2 recall and use the fact that the electric field strength at a point is equal to the negative of the potential gradient at that point

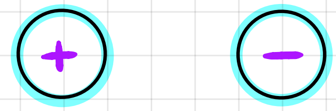
3 use $V = Q/(4\pi\varepsilon_0 r)$ for the electric potential in the field due to a point charge

4 understand how the concept of electric potential leads to the electric potential energy of two point charges and use $E_p = Qq/(4\pi\varepsilon_0 r)$

Electric Fields

- Charged Sphere
- Equipotential Surface
- Motion of Particles
- Radial Field
- Point Charge
- Test charge
- Uniform E. Fields
- E. Field Strength
- Lines of Force / Field lines
- Energy-interchange in Fields
- Electric Potential Energy

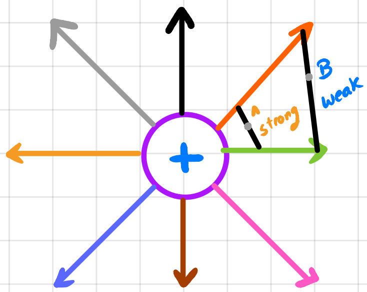
Electric field is an area around the charge. Where other charges experience electric force. (attractive/repulsive)



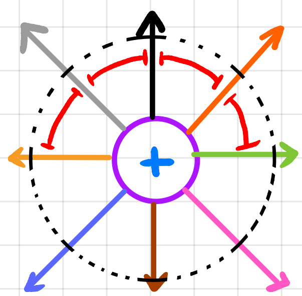
Around the charge electric field is represented by field lines

An isolated charge is called a point charge that creates a radial (spherically symmetric field)

i

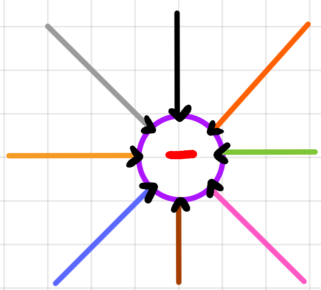


- Outwards
- Non-uniform (field lines not equally spaced)
- Radial Electric Field



Spherically Symmetric

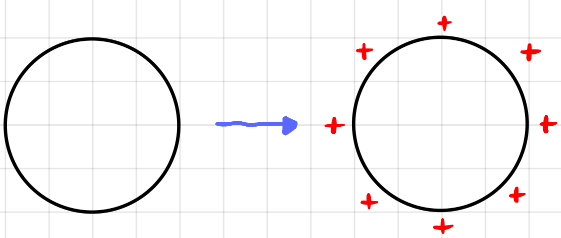
ii



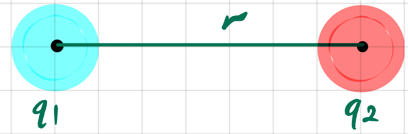
- Directed inwards
- Non uniform (field lines are not parralel)
- Radially inwards

Charged Body:-

A charged object/body has a uniformly spreading charge on its surface, due to mutual repulsion between likely charged particles.



Coulomb's Law



$$\uparrow F = \frac{1}{4\pi\varepsilon_0 \downarrow} \cdot \frac{q_1 q_2}{r^2}$$

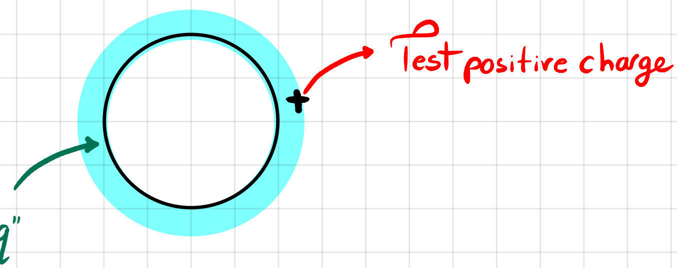
ε = Permitivity of a medium
$\varepsilon_0 = 8.85 \times 10^{-12}$ F/m

Coulombs law states that

$$F \propto \frac{q_1 q_2}{r^2}$$

The magnitude of force that two charged bodies exert on each other is directly proportional to the product of the charges, and inversely proportional to the square of distance between their centres.

Electric Field Strength : E



Electric field strength is the force exerted (by the exerted body) by unit charge of a test positive charge

At a point in the electric field of a charged body.

$$E = F/q$$

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

→ E is a vector quantity! NC^{-1} or Volts

i All the charge is uniformly distributed on the surface.

$E \propto 1/R_0^2$

ii For the region below the surface (of charged metal sphere) electric field strength is undefined and assumed to be zero

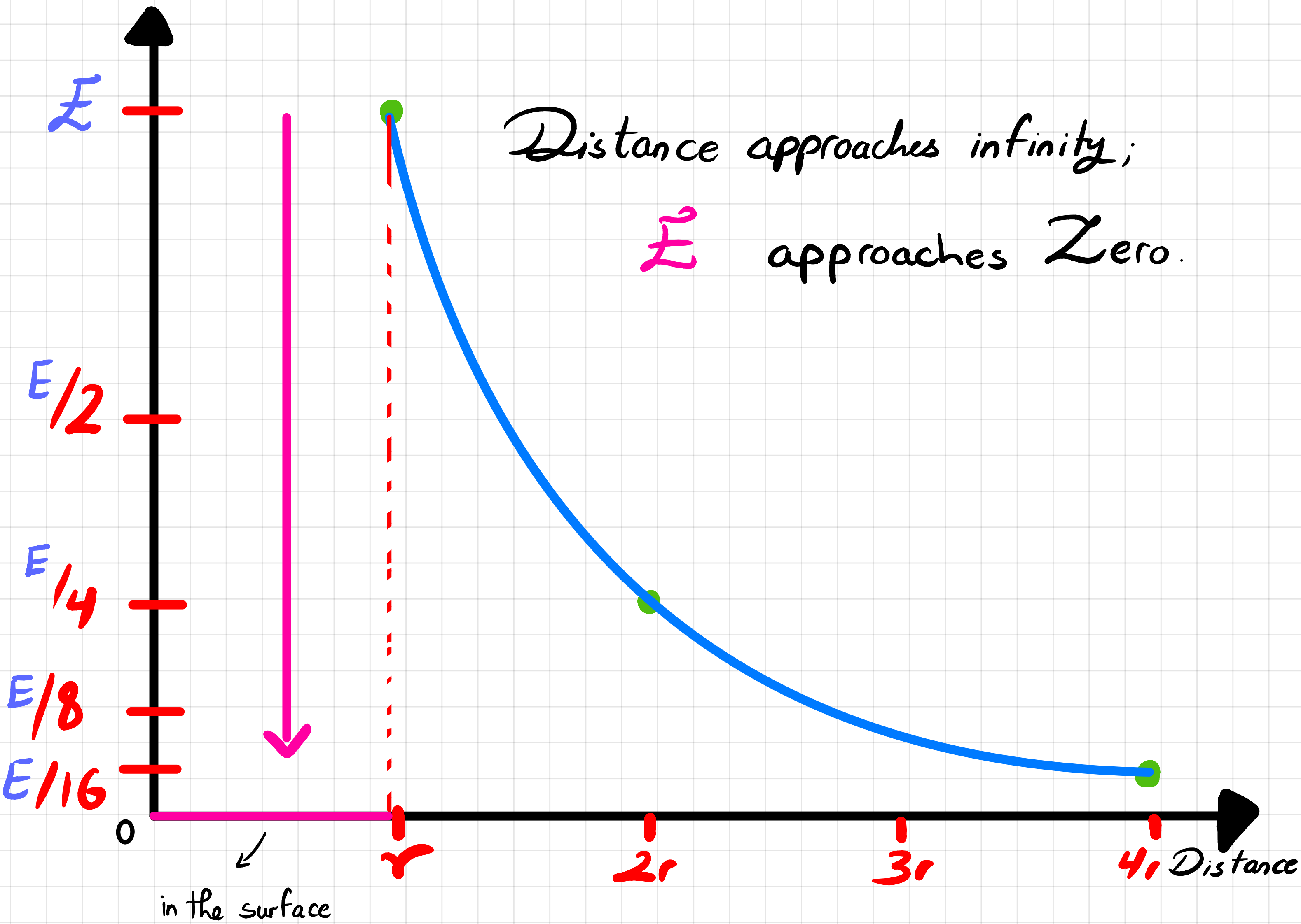
It follows inverse square law, (just like gravitation.)

i) On the surface ; at r → E

ii) At 2r → $1/4^{th}$

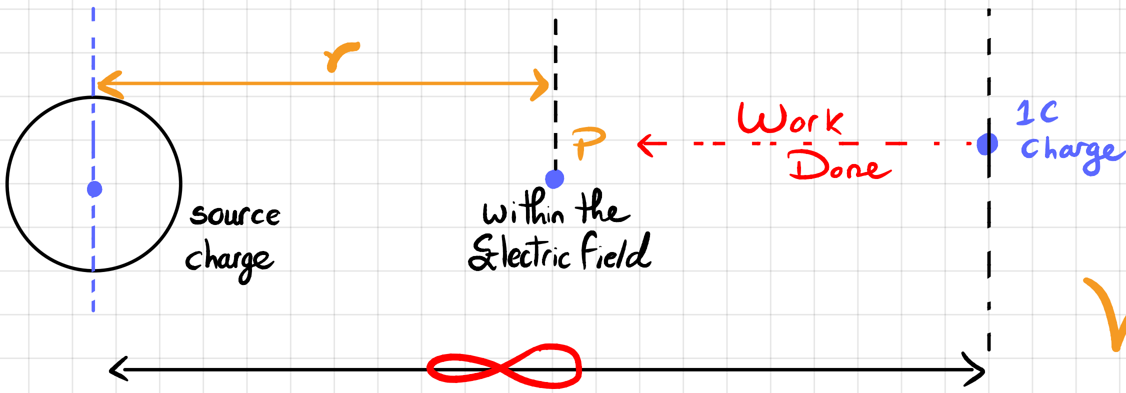
(iii) At 4r → $1/16^{th}$

How "E" varies... GRAPHICAL REPresentation



Electric Potential : (V)

Scalar JC^{-1}



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

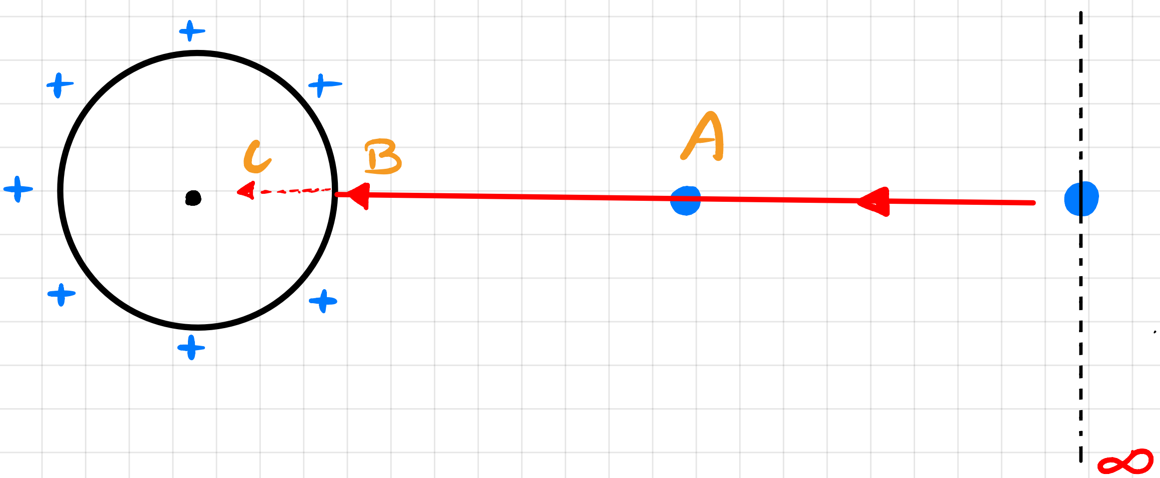
Electric potential at a point in an electric field is the work done in bringing a unit positive charge from infinity to that point in the field.

Electric potential is not always negative as depending on source charge (+/-) it can be either attractive or repulsive.

→ In a charged sphere :-

- For a charged sphere, there is no charge inside the sphere (charge lies on the surface)
- Hence it is assumed that inside the sphere, the electric potential remains constant

E = 0! no field inside



If a charge is moved beyond C i.e inside the sphere. there is no charge inside the sphere which could attract or repel.

Therefore, the amount of work required to move to C will be same as work done till D. As after C no extra work is required.

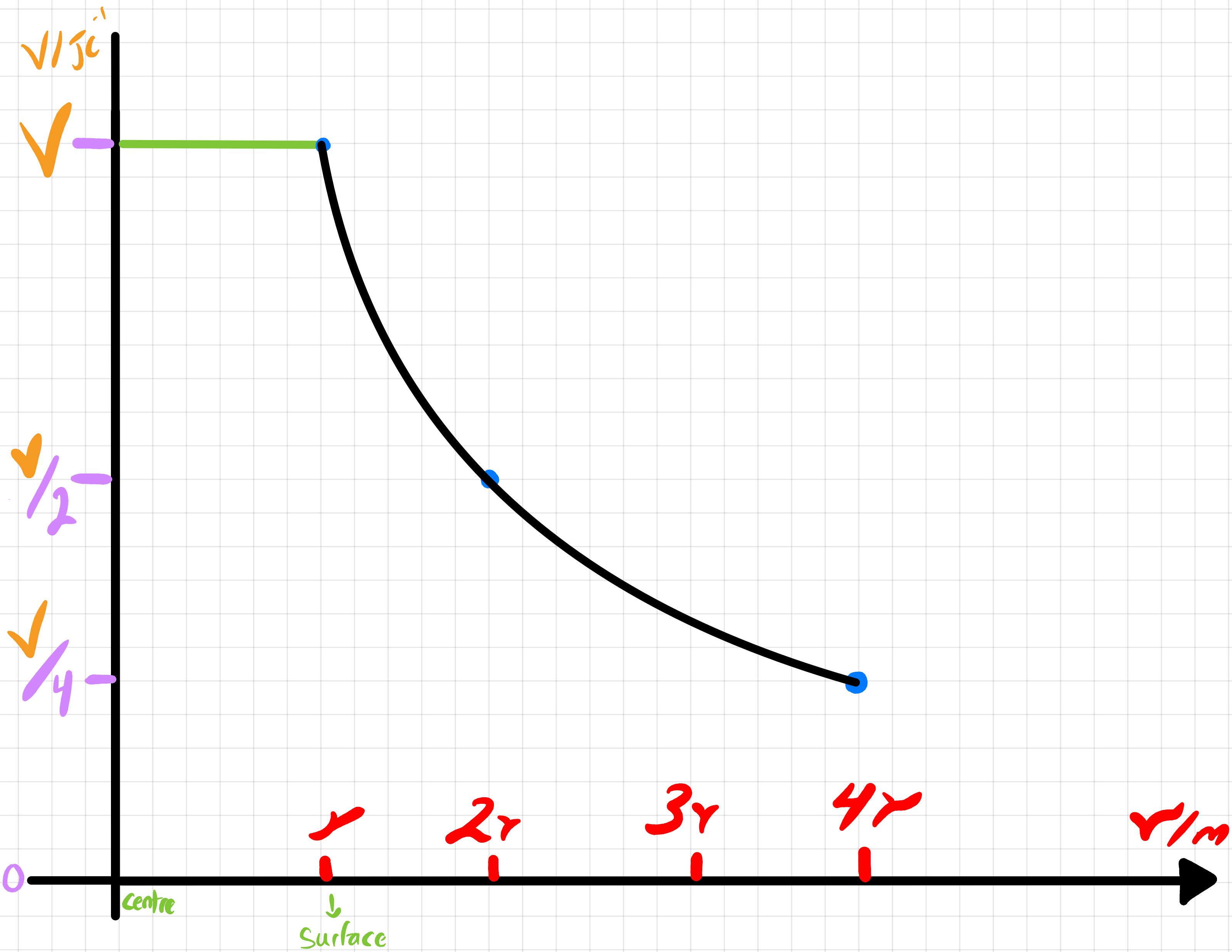
GRAPHICAL REPresentation (V vs r)

$$V = \frac{Q}{4\pi\varepsilon_0 r}$$ [Negative Inverse Relationship]

(i) If r is made TWICE then becomes HALF

(ii) If r is made THRICE then becomes $1/3^{rd}$

(iii) If r is made 4 TIMES then becomes $1/4^{th}$

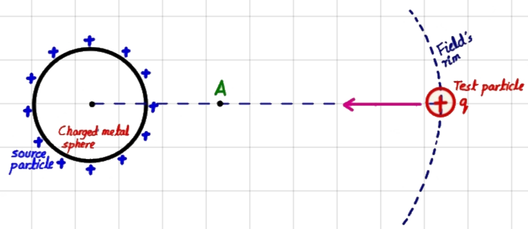


Sign of Electric Potential

V can be either + or −

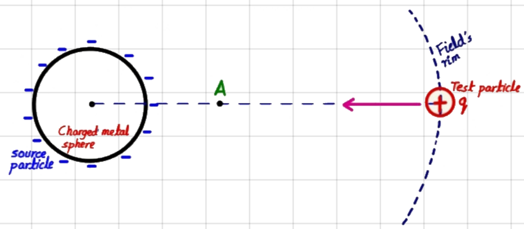
Workdone against the field is +ve

Workdone along the field is −ve



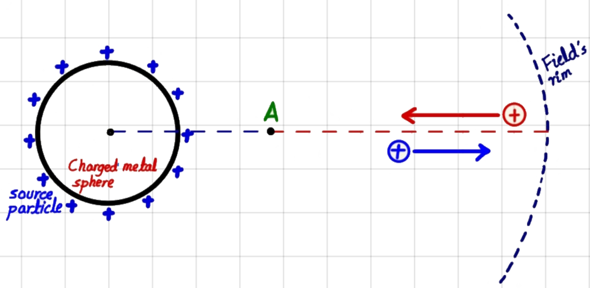
+ve work

work done against field which causes an increase in potential energy of system.



−ve work

work done by field



Work against field

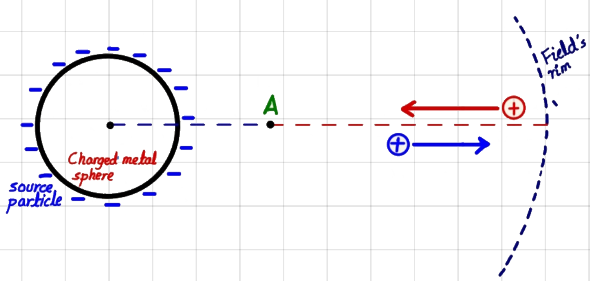
+ve work

EPE increasing

Work by the field

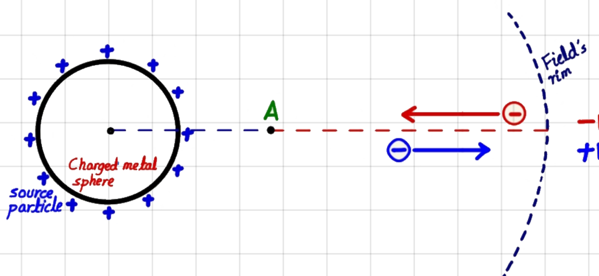
−ve work

EPE decreasing



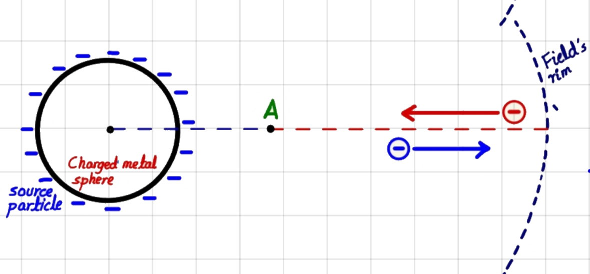
−ve work

+ve work



−ve work

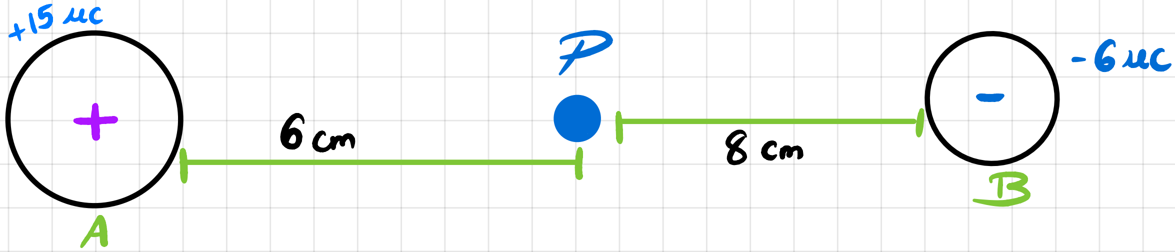
+ve work



+ve work

−ve work

Concept of:- Resultant V b/w Two charges



Find resultant Electric Potential at P due to both charges

We will find Electric Potential due to each charge at P, then add them to get the resultant

i E.P (V_A) at "P" due to A

$$V_A = +\frac{Q}{4\pi\varepsilon_0 r} = +\frac{15\times10^{-6}}{4\pi\varepsilon_0(6\times10^{-2})} \longrightarrow V_A = +2.25\times10^{6}\ jc^{-1}$$

ii E.P (V_B) at "P" due to B

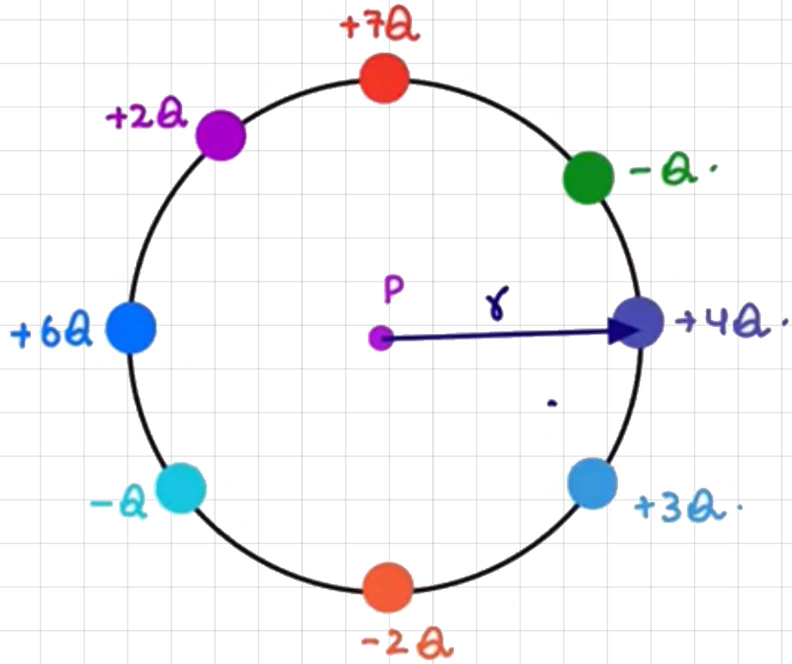
$$V_B = -\frac{Q}{4\pi\varepsilon_0 r} = -\frac{6\times10^{-6}}{4\pi\varepsilon_0(8\times10^{-2})} \longrightarrow V_B = -6.75\times10^{5}\ jc^{-1}$$

$$V_{resultant} = V_A + V_B$$

$$+2.25\times10^{6} + (-6.75\times10^{5})$$

$$V_{resultant} = 1575000\ jc^{-1}$$

Ex:



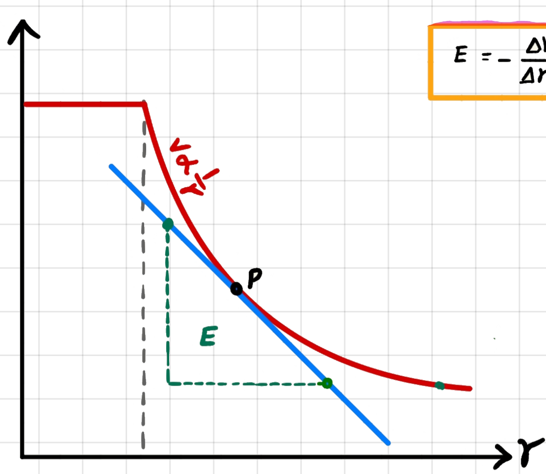
Every charge is equidistant from P. Find Resultant Potential

$\therefore$ we can add all the charges $\quad Q_{TOTAL} = +18Q$

Resultant "V" at P will be $\quad V_P = \dfrac{18Q}{4\pi\varepsilon_0 r}$

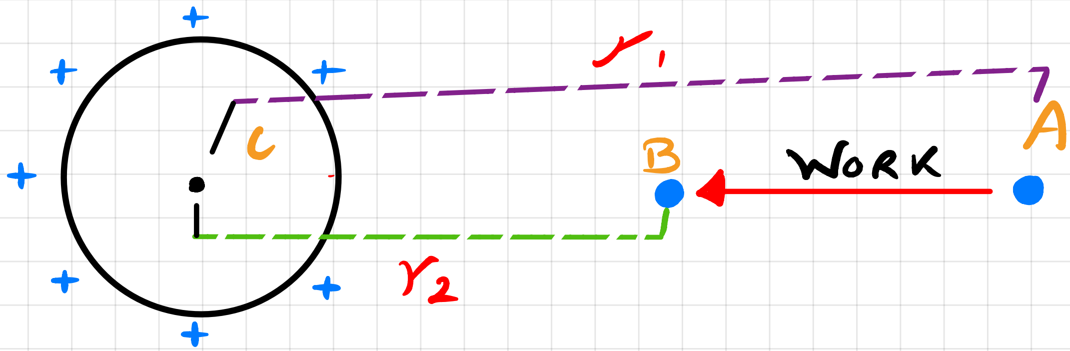
Electric Field Strength : E

Electric force experienced by a unit +ve charge



$\boxed{E = -\frac{\Delta V}{\Delta r}}$ → gradient of V against r

Concept Of Workdone in Electric Field $\boxed{q \times \Delta V}$



To find workdone to move from A to B

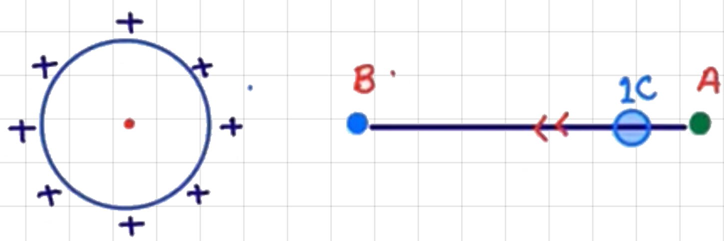
i. Find electric potential at A "V_A"

ii. Find electric potential at B "V_B"

iii. Find change in electric potential $\Delta V = V_B - V_A$

iv. Workdone required can be found as $W = q \times \Delta V$

Note: If the particle moved is of 1C then work done is

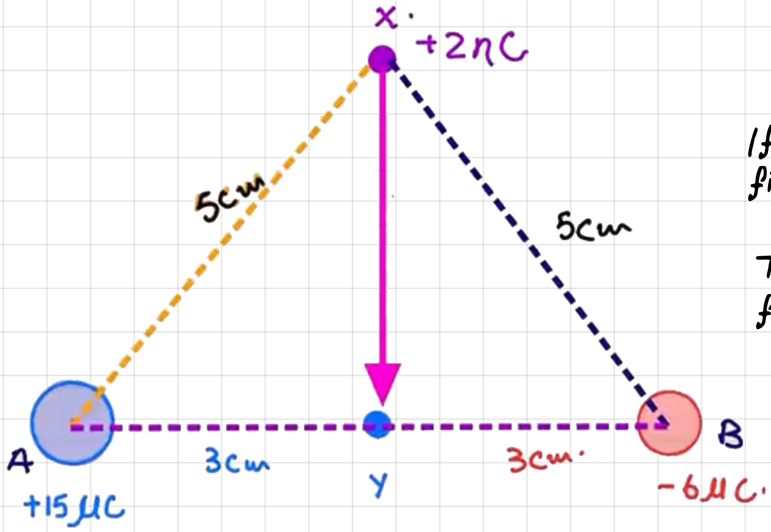


work = $q \times \Delta V$

$= 1 \times \Delta V$

$\boxed{\text{work} = \Delta V}$

In this situation, the work done will be same as change in electric potential
But the work done will be stored as electric potential energy.



If a charge of +2nc is moved from X to Y find work done to move the charge.

To calculate work done to move charge from X to Y we follow these steps

i Find V at X (V_x)

$$V_x = V_A + V_B$$

$$V_x = \frac{+15\times10^{-6}}{4\pi\varepsilon_0(5\times10^{-2})} + \left(\frac{-6\times10^{-6}}{4\pi\varepsilon_0(5\times10^{-2})}\right) \longrightarrow 1.6\times10^{6}\,jc^{-1}$$

ii Find V at Y (V_y)

$$V_y = V_A + V_B$$

$$V_y = \frac{+15\times10^{-6}}{4\pi\varepsilon_0(3\times10^{-2})} + \left(\frac{-6\times10^{-6}}{4\pi\varepsilon_0(3\times10^{-2})}\right) \longrightarrow 2.7\times10^{6}\,jc^{-1}$$

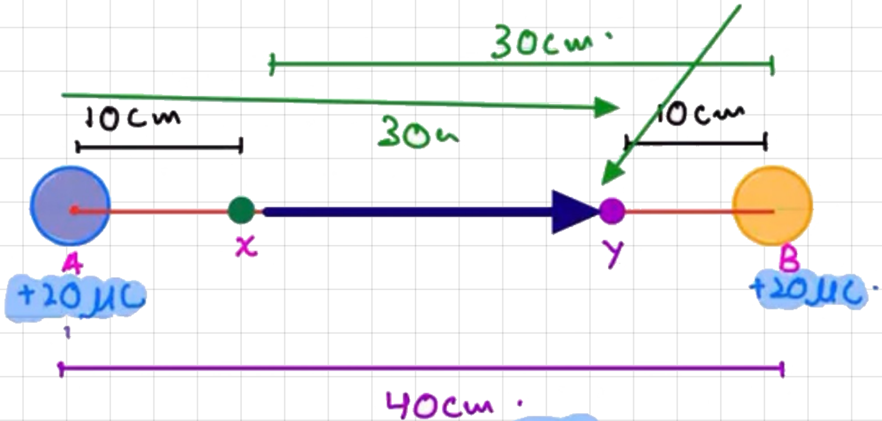
iii Now find ΔV

$$\Delta V = V_y - V_x \longrightarrow 1.1\times10^{6}\,jc^{-1}$$

iv Now finally workdone

$$\text{WORK} = q \times \Delta V$$

Ex:



If a charge of +2nC is moved from X to Y find the work done ($W = \Delta V \times q$)

Potential at X $V_X = V_A + V_B$

$$\frac{+20\times10^{-6}}{4\pi\varepsilon_0(10\times10^{-2})} + \frac{20\times10^{-6}}{4\pi\varepsilon_0(30\times10^{-2})} \rightarrow 2.4\times10^{6}\, jc^{-1}$$

Potential at Y $V_Y = V_A + V_B$

$$V_Y = \frac{+20\times10^{-6}}{4\pi\varepsilon_0\times(30\times10^{-2})} + \frac{+20\times10^{-6}}{4\pi\varepsilon_0\times(10\times10^{-2})} \rightarrow 2.4\times10^{6}\, jc^{-1}$$

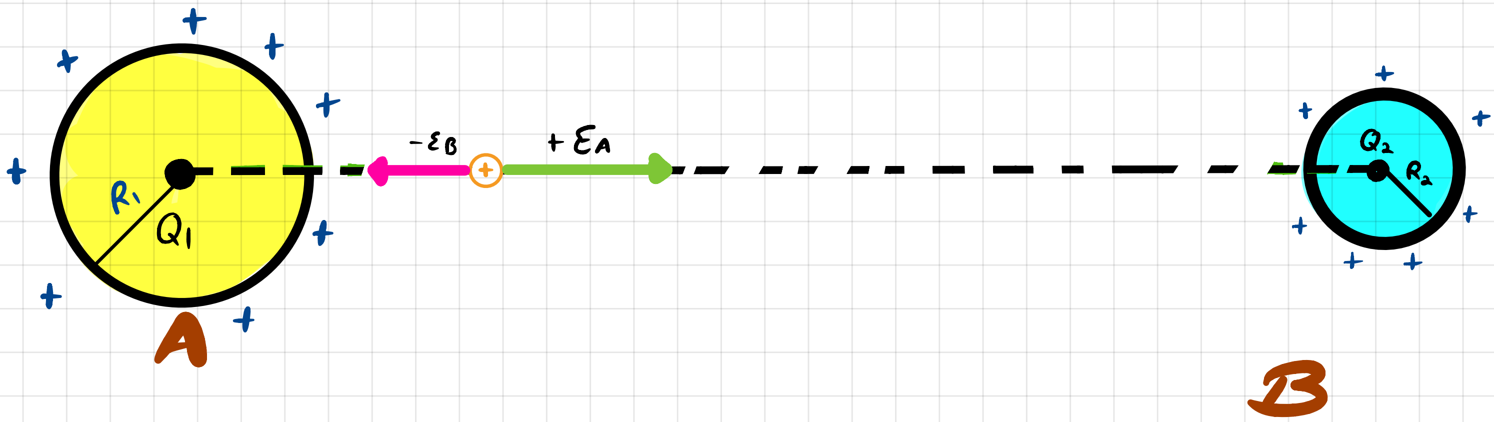
$\Delta V = 0$ Work $= 0$

Combined Electric Field

Electric field strength is a vector quantity and at any point to find resultant, vector method of adding is applied

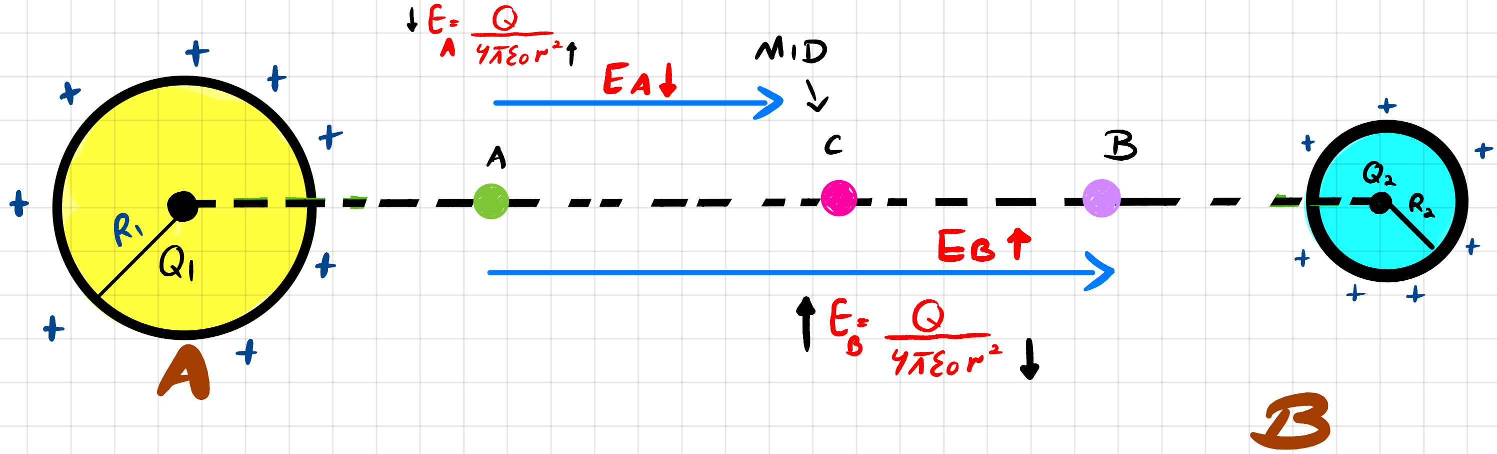
$E = -\frac{\Delta V}{\Delta r}$

Electric potential is a scaler quantity hence at any point resultant can be found by their algebraic sum of all potentials



→ on the line joining their centres, E are oppositely directed

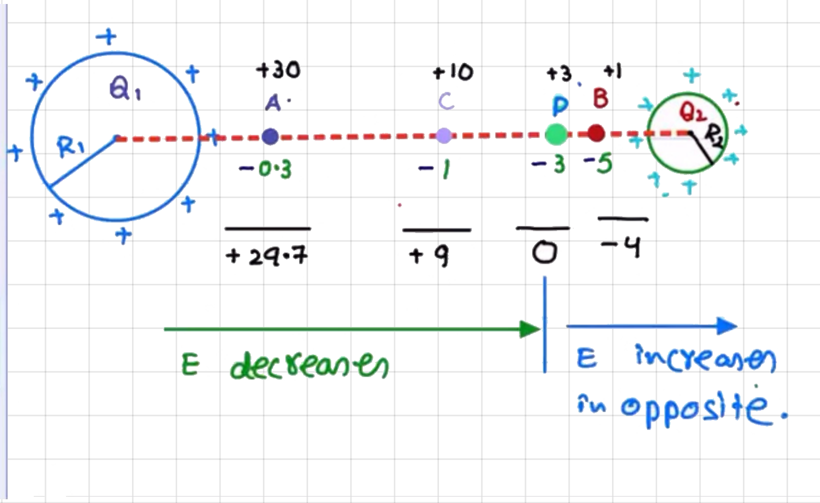
ii If "E" due to Q_2 is assumed to be "+" then due to Q_2 will be "—"

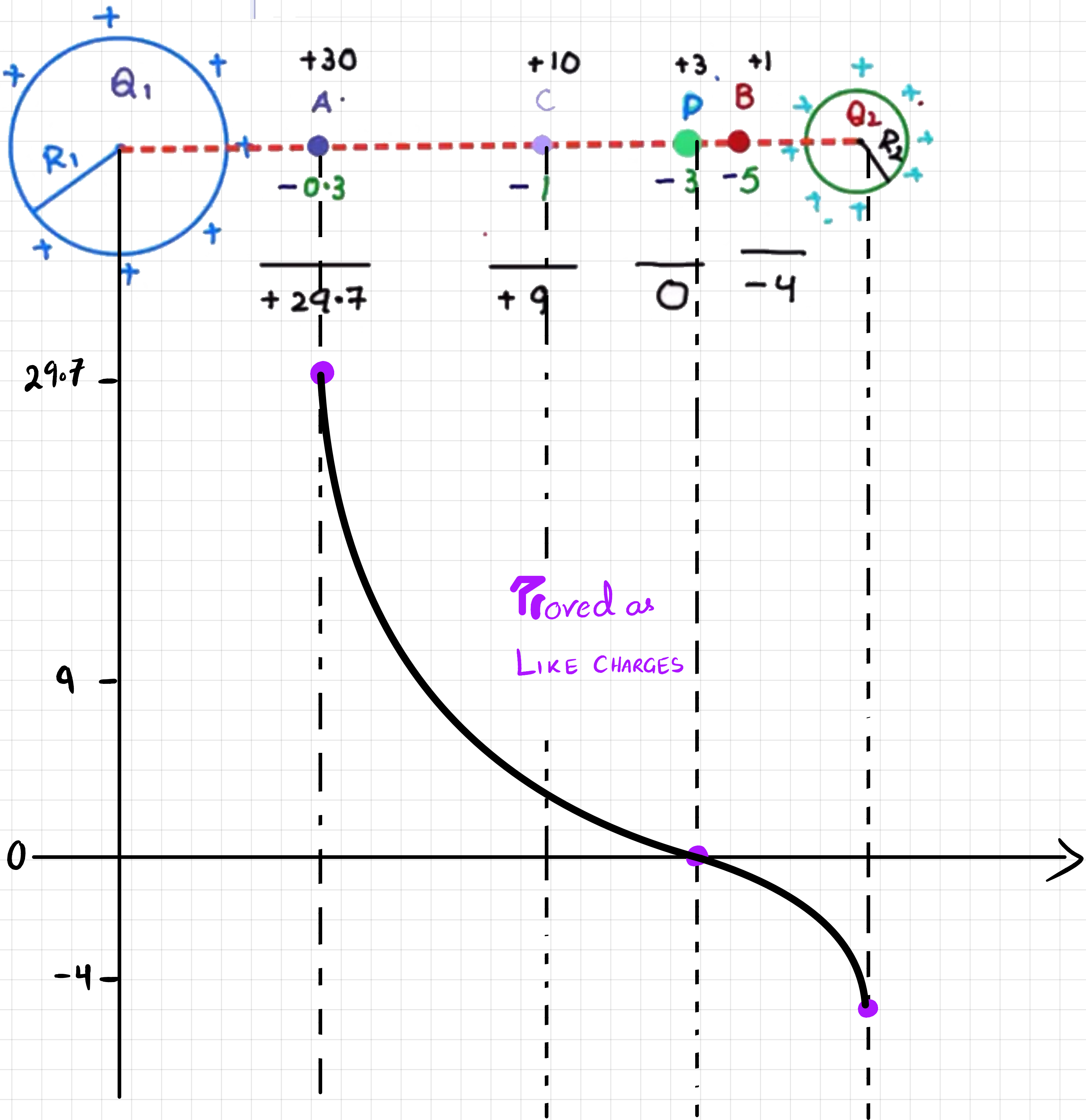


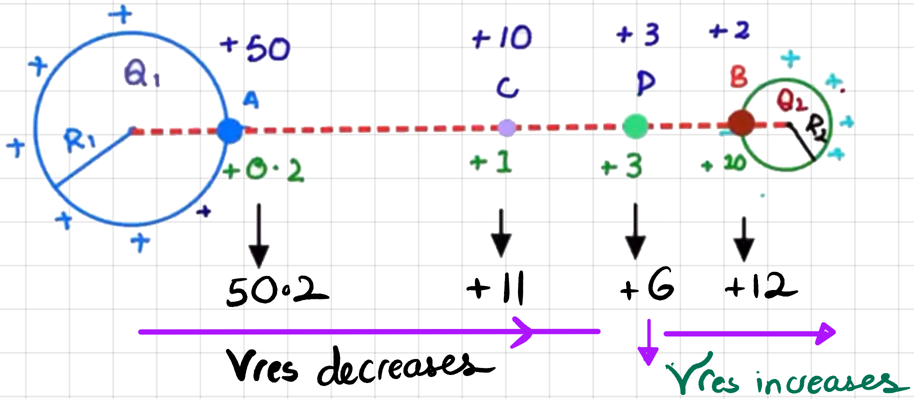
Similarly, as we move close to Q2, r for Q2 decreases and its E increases (- sign)

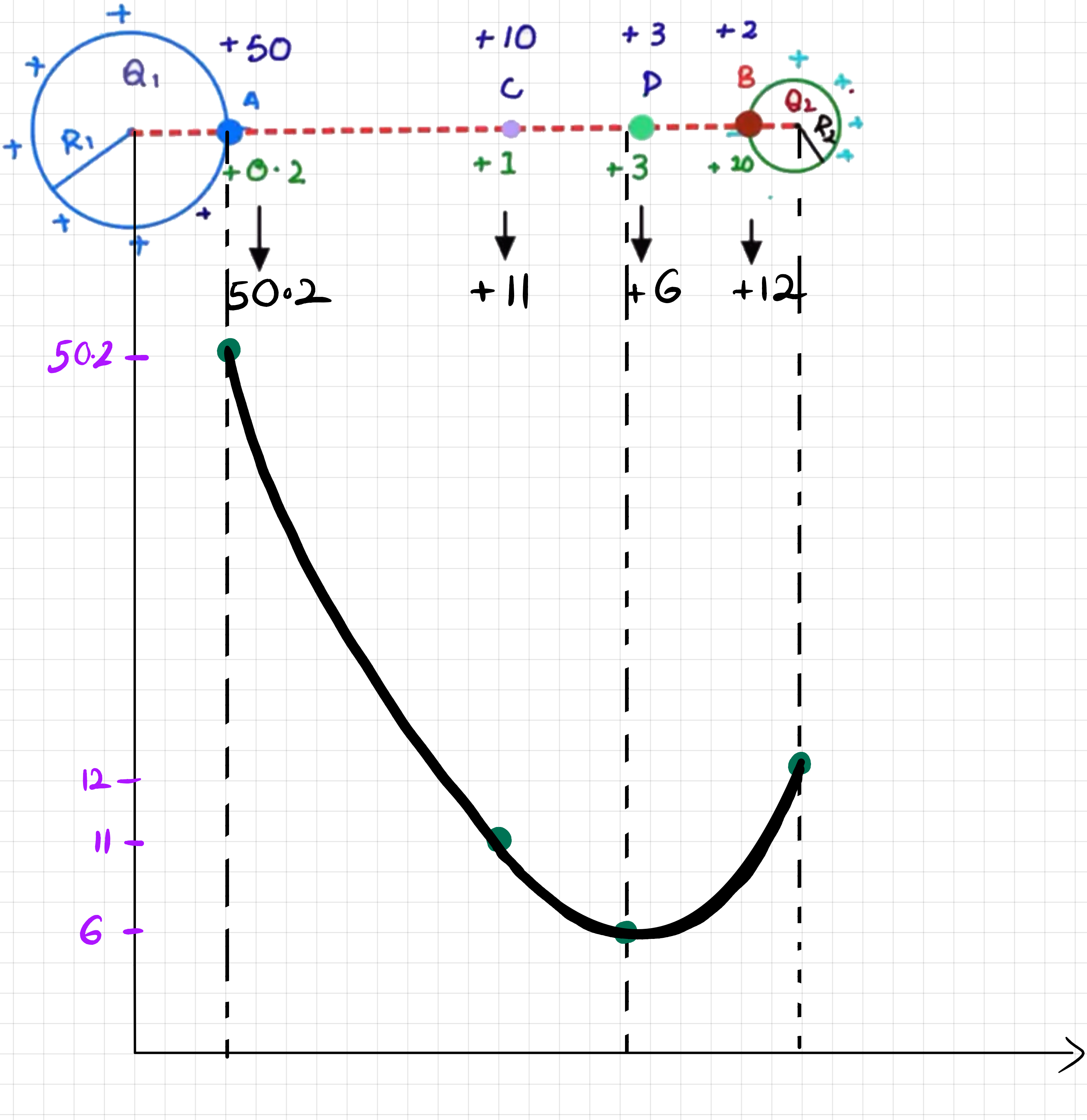
★ $E_{mid} \propto Q$!

B/W LIKE CHARGES



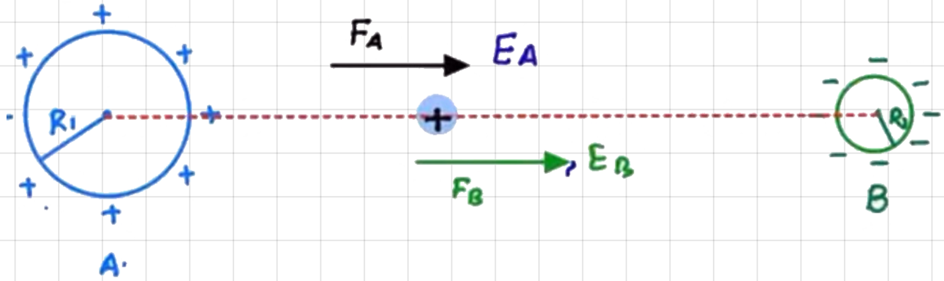



Q1
R1
+50
A
+0·2
50·2
+10
C
+1
+11
+3
D
+3
+6
+2
B
+20
+12
Q2
R2
Vres decreases
Vres increases


Q1
R1
+50
A
+0·2
50·2
+10
C
+1
+11
+3
D
+3
+6
+2
B
+20
+12
Q2
R2
50.2
12
11
6

Between Two Unlike Charges

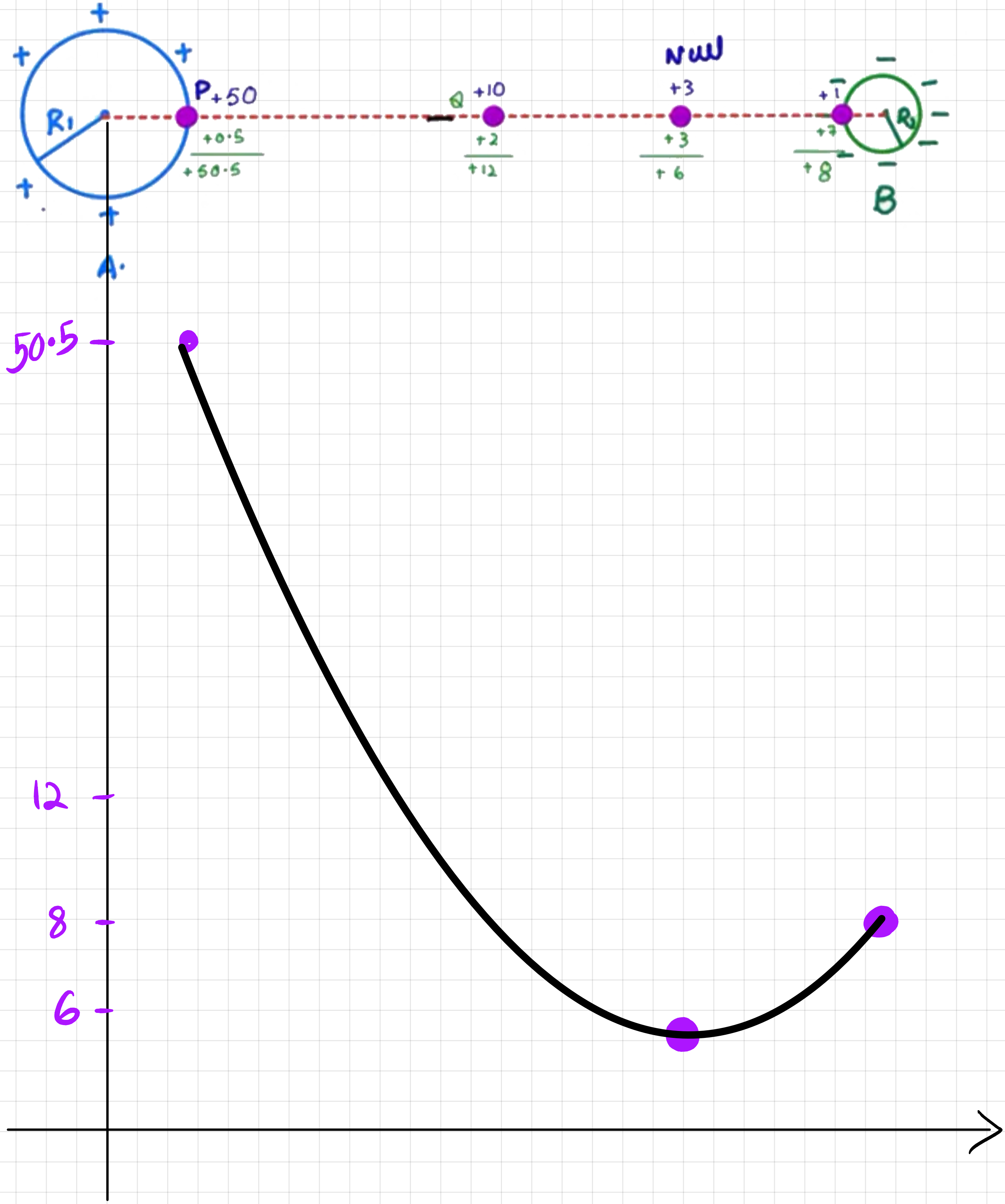
→ For Electric Potential ! + & − V is scalar !



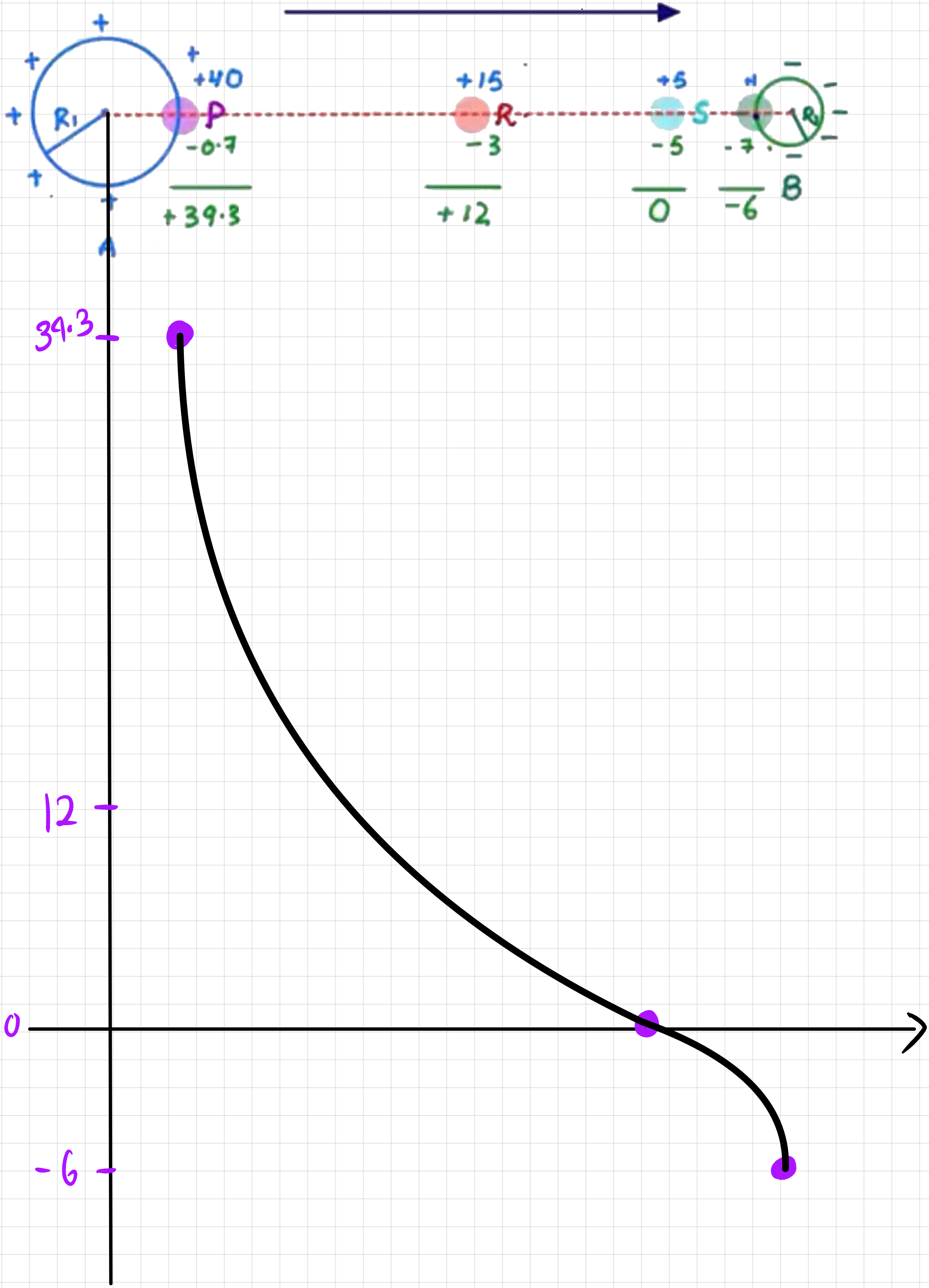
At any position on the line joining their centres

Direction of electric force acting on positive point charge is same

Since $E = F/q$ → E for both Q_1 & Q_2 will have same direction



R1
A
P +50
+0·5
+50·5
Q
+10
+2
+12
Nw
+3
+3
+6
+1
+7
+8
R2
B
50·5
12
8
6



+40
-0.7
+39.3
+15
-3
+12
+5
-5
0
-7
-6
P
R
S
A
B
R_1
R_2
39.3
12
0
-6

Distance of Closest Approach

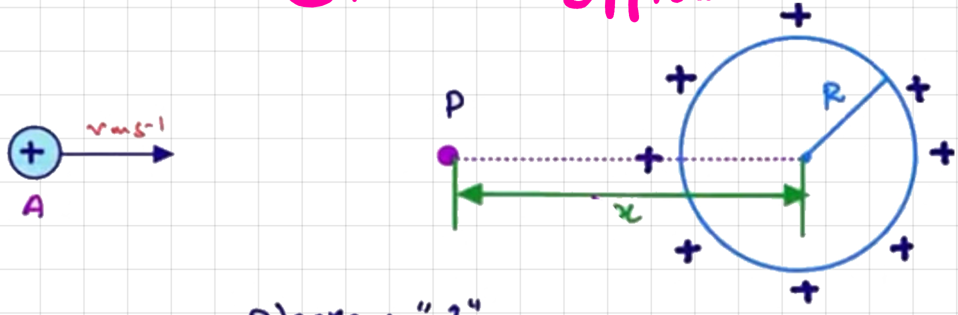


Diagram "1"

As shown about when a test positive charge is drifted towards a charged body. Due to repulsion the particle loses its Kinetic Energy and it gains electric potential energy and eventually it will stop at P and the separation between the source charge and particle will be the closest distance of approach.

Loss in K.E = Gain in E.P.E

$$\frac{1}{2}mv^2 = \{\overset{0}{V_A} - V_B\} \times q$$

$$\frac{1}{2}mv^2 = -\frac{Q}{4\pi\varepsilon_0 x} \times q \rightarrow \frac{1}{\cancel{2}}x = \frac{Qq}{\underset{2}{\cancel{4}}\pi\varepsilon_0 x\, mv^2}$$

$$\hookrightarrow \frac{Qq}{2\pi\varepsilon_0 x\, mv^2}$$