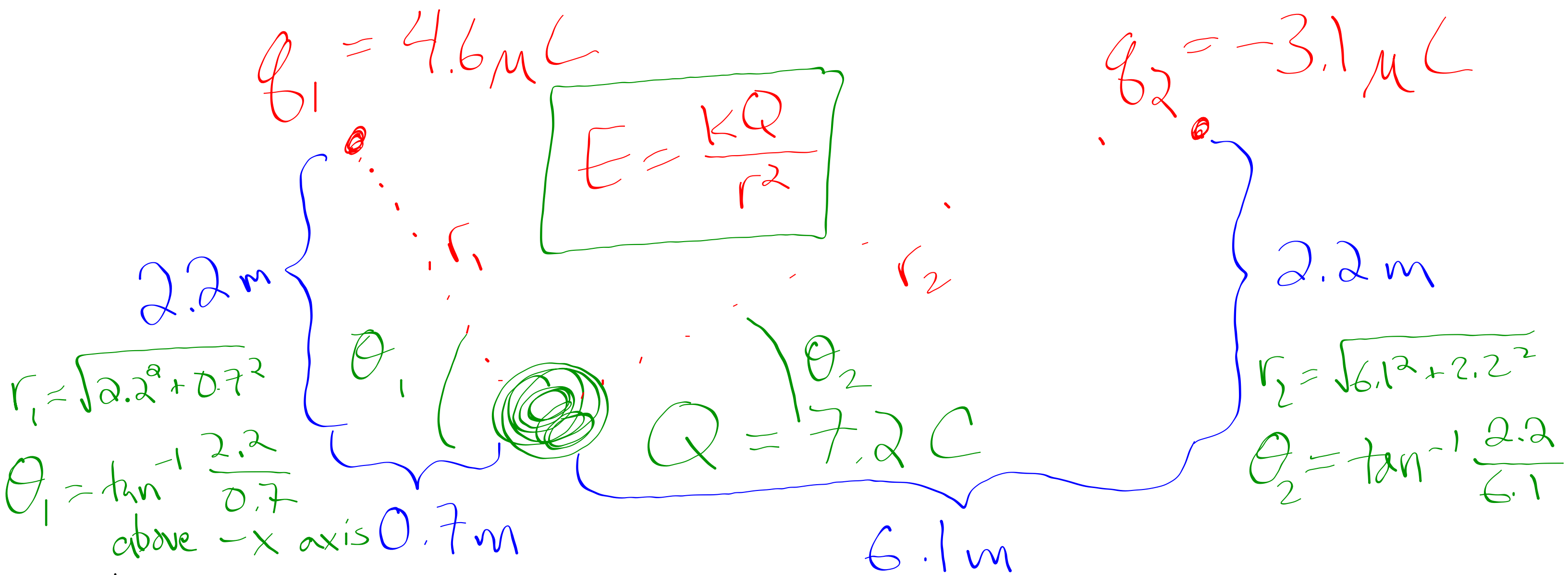


1. What is the magnitude & direction of the electric field at q_1 & q_2 (due to Q)?
2. What is the magnitude & direction of the electric field at Q due to q_1 & q_2?

2. What is the magnitude & direction of the electric field at Q due to q_1 & q_2?

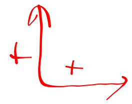
r_1 & r_2 are still the same

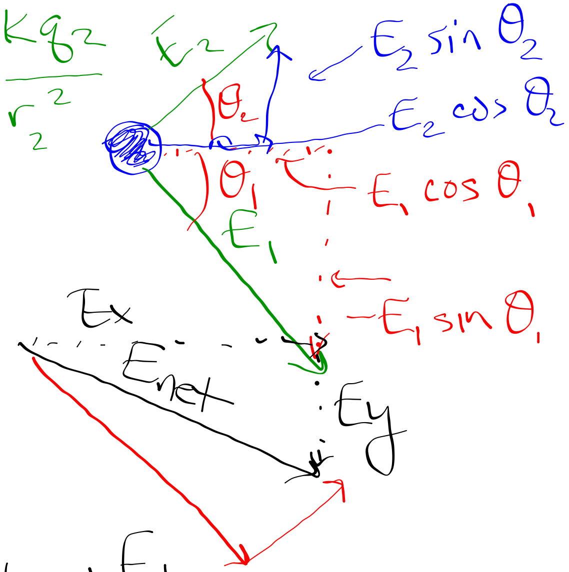
θ_1 & θ_2 are still the same

$$\vec{E}_{net} = \vec{E}_1 + \vec{E}_2$$

$$E_1 = \frac{kq_1}{r_1^2}$$

$$E_2 = \frac{kq_2}{r_2^2}$$



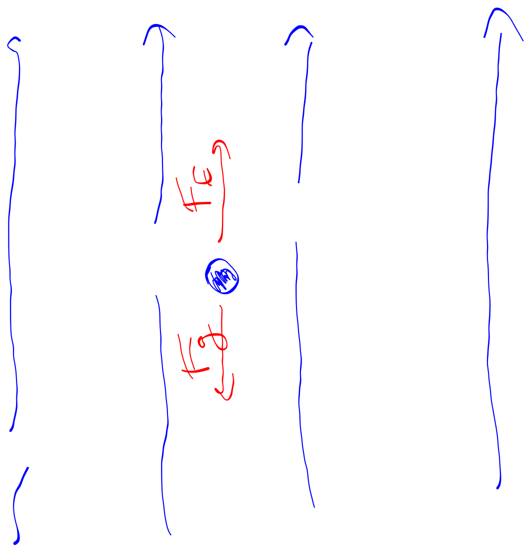


$$E_x = E_1 \cos\theta_1 + E_2 \cos\theta_2$$

$$E_y = -E_1 \sin\theta_1 + E_2 \sin\theta_2$$

$$E_{net} = \sqrt{E_x^2 + E_y^2} \qquad \theta = -\tan^{-1}\frac{E_y}{E_x}$$

23. A proton ($m_o = 1.67 \times 10^{-27}$ kg) is suspended at rest in a uniform electric field **E**. Take into account gravity and determine **E**. Remember, electric fields are vectors!



$$E = \frac{F}{q}$$

$$F_E = E \cdot q$$

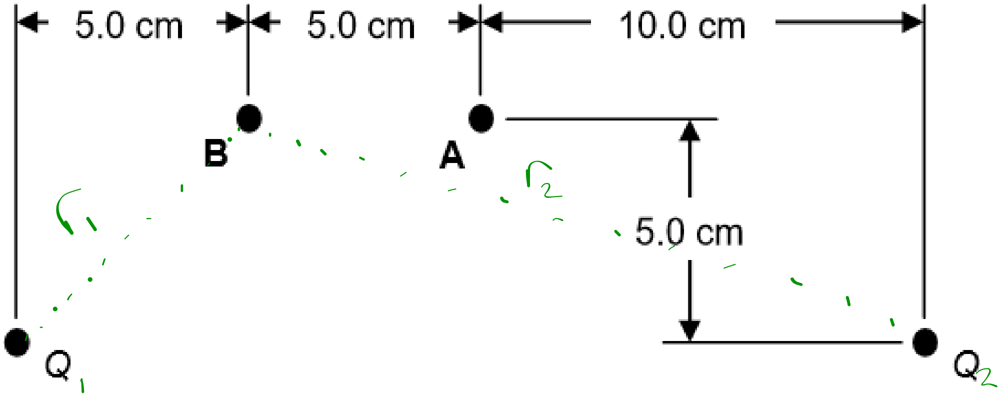
$$F_g = F_E$$

$$mg = E \cdot q$$

$$E = \frac{mg}{q} = \frac{(1.67E{-}27)(9.8)}{1.6E{-}19}$$

$$E = 1.02E{-}7 \ \text{N/C} \ (\text{up})$$

25. Determine the net electric field at A and B in the diagram to the right due to the two positive charges ($Q = 4.0\ \mu C$ shown.



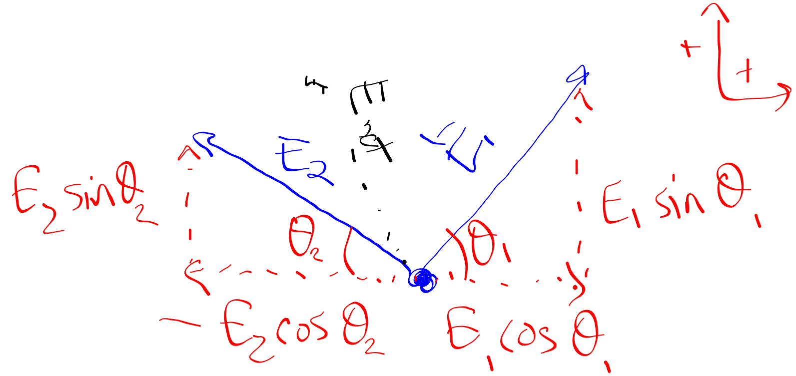
$$r_1 = \sqrt{0.05^2 + 0.05^2}$$

$$r_2 = \sqrt{0.15^2 + 0.05^2}$$

$$E_1 = \frac{kQ_1}{r_1^2} \qquad E_2 = \frac{kQ_2}{r_2^2}$$

$$\theta_1 = \tan^{-1}\frac{0.05}{0.05}$$

$$\theta_2 = \tan^{-1}\frac{0.05}{0.15}$$

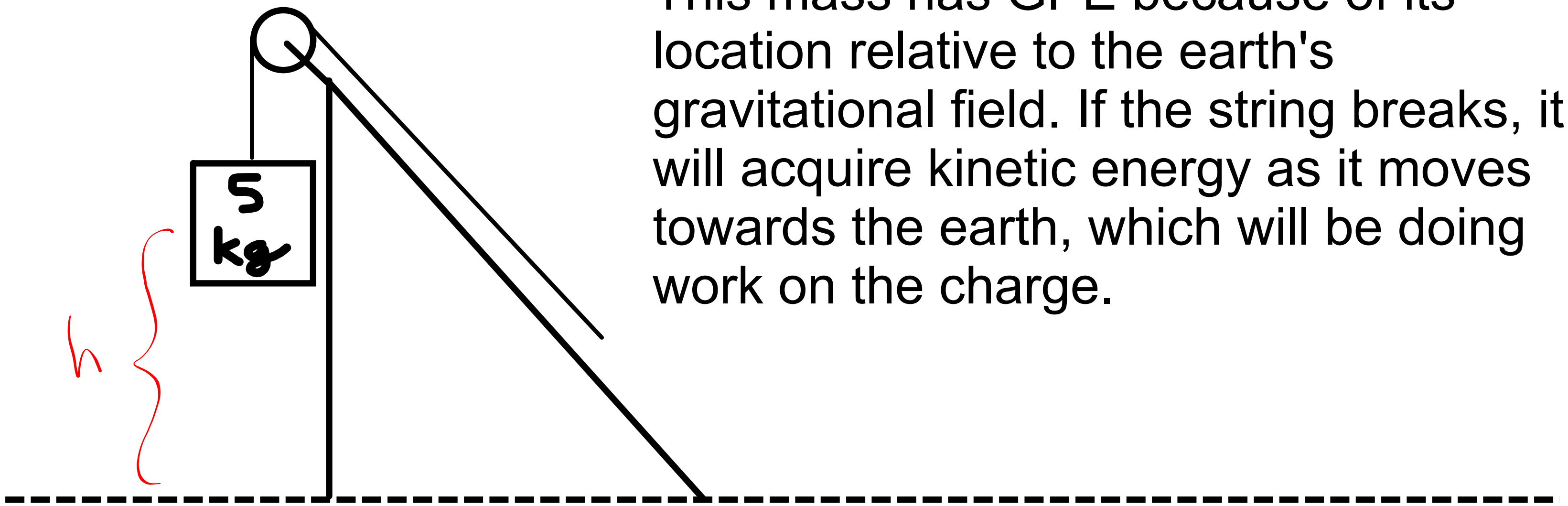


$$E_x = -E_2\cos\theta_2 + E_1\cos\theta_1 \qquad E_{NET} = \sqrt{E_x^2 + E_y^2}$$

$$E_y = E_2\sin\theta_2 + E_1\sin\theta_1 \qquad \theta = \left(\tan^{-1}\frac{E_y}{E_x}\right) + 180$$

Objectives:

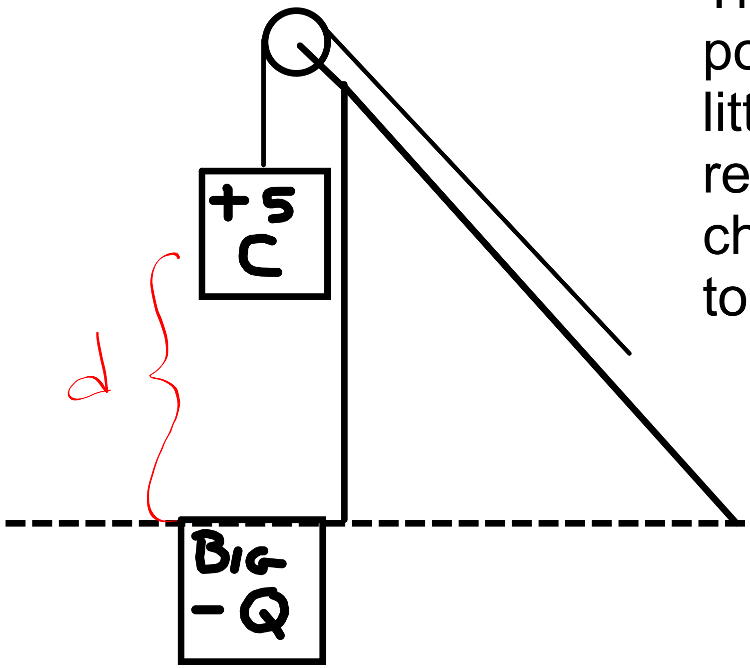
- Students will understand and be able to explain the concept of electric potential
- Students will be able to describe the work done to a charged particle as it moves through an electric field
- Students will understand the similarities (and differences) between electric potential and gravitational potential energy
- Students will be able to solve problems involving electric potential (including electric field and Coulomb's Law)



This mass has GPE because of its location relative to the earth's gravitational field. If the string breaks, it will acquire kinetic energy as it moves towards the earth, which will be doing work on the charge.

$$\Delta GPE = mgh - mgh_0 = \Delta KE$$

This situation is similar - there is potential energy associated with the little charge because of its location relative to the big charge (its KE could change...as the big charge does work to it)



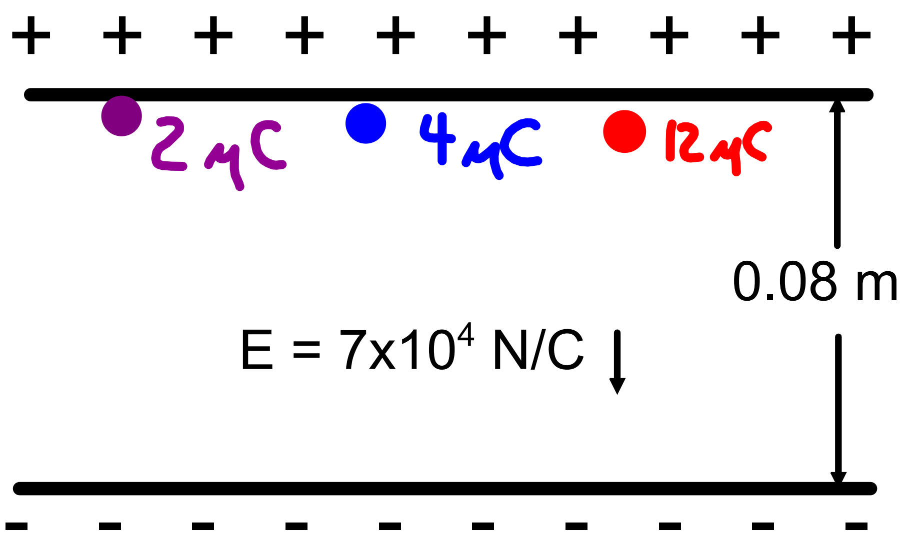
$\Delta ElPE = \Delta KE$

It's easiest to look at electrical potential within a **uniform** electric field (E has the same magnitude and direction in every location). Here's how we can make one:

Take two metal plates - one with a negative charge, and one with a positive charge. The resulting electric field is very nearly uniform when the plates are relatively large and close.

http://www.falstad.com/vector3de/

WARM-UP: Assume three charges (as shown) are moved from the positive to the negative plate through the **uniform** electric field between the plates. How much work is done on each charge?



$W = F \cdot d$

$E = \frac{F}{q}$; $F = \boxed{E \cdot q}$

$W_2 = E \cdot q_2 \cdot d$
$= 0.0112\ J$

$W_4 = E \cdot q_4 \cdot d$
$= 0.0224\ J$

$W_{12} = E \cdot q_{12} \cdot d$
$= 0.0672\ J$

What happens if we determine the work on a per-charge (coulomb) basis? For each case, determine the work done / charge being moved:

$$\frac{W_2}{q} = \frac{.0112\,J}{2\times10^{-6}\,C} = 5600\ J/C$$

$$\frac{W_4}{q} = \frac{.0224\,J}{4\times10^{-6}\,C} = 5600\ J/C$$

$$\frac{W_{12}}{q} = \frac{.0672\,J}{12\times10^{-6}\,C} = 5600\ J/C$$

The quantity W/q is called **Electric Potential Difference (or electric potential)**

$$V_{ba} = \frac{W_{ba}}{q}$$

$J/C = \text{Volt}\ (V)$

W_{ba} = the work **required** to move charge q from Point A to Point B (Joules)

- when work is (+), the E-field is resisting the motion and something else must do work on q to get it from A to B
- when work is (-), the E-field does the work and q acquires KE or energy in some other form

q = the charge that is being moved from Point A to Point B (coulombs)

- include the negative sign if q is negative

V_{ba} = the electric potential difference between Point A and Point B (**Volts**) (**1 V = 1J/C**)

When V is positive, a motionless negative charge would move from Point A to Point B by virtue of the electric field alone. (Negative charges will tend to move towards more positive voltages.) When V is negative, a motionless positive charge would move from Point A to Point B by virtue of the electric field alone. (Positive charges will tend to move towards more negative voltages.)

Electric Potential Difference (A to B)	Charge moving in the field (A to B)	Who does the work? E-field on its own? Applied force?	Direction of E-field?	Direction of force on particle?
Positive	+			
Negative	+			
Positive	−			
Negative	−			

E-field

A B

$V_{ba} = \frac{W_{ba}}{q}$

+

Work = − (negative)

Electric potential difference = − (negative)

force from E-field in direction of motion

−

Work = + (positive)

Electric potential difference = − (negative)

force from E-field in opposite dir. of motion

B A

$V_{ba} = \frac{W_{ba}}{q}$

+

Work = + (positive)

Electric potential difference = + (positive)

force from E-field in opposite dir. of motion

B A

−

Work = − (negative)

Electric potential difference = + (positive)

force from E-field in direction of motion

Some important points about Electric Potential:

- Electrical potential energy is like gravitational potential energy: it is RELATIVE (it's the difference between two points that matters, not the absolute amount of potential energy a charge has at a given location).
  > A potential difference of 10 V implies that Point B has a potential that is 10 V higher than Point A.
- A "reference potential" (like h = 0) is a point infinitely far away -- this point's potential is 0 V by definition.
- When we refer to the electric potential of a single point, we always mean RELATIVE TO 0 V (just like height!) - since the only thing that matters with electric potential is the DIFFERENCE in potential energy between two locations ...
- Some other charge (Q), or a uniform electric field (E), must be present for there to be a potential difference.
- Electric potential difference is directly related to the kinetic energy a charge loses or gains when it moves through this difference if unaffected by any other forces except the electric field.
- Our notation assumes that charges start at Point A and end at Point B. The subscripts (V_{ba}) reminds us that to find the difference, we subtract the potential at A from the potential at B (V_b-V_a)
- Because this is associated with energy, a scalar, the sign of V doesn't tell us anything about direction. Because electrostatic forces can be attractive or repulsive, the sign we choose to use for work is arbitrary. Therefore, when working with electric potential, you should always make a drawing and check all of the relevant signs within the context of your drawing according to the conventions discussed earlier

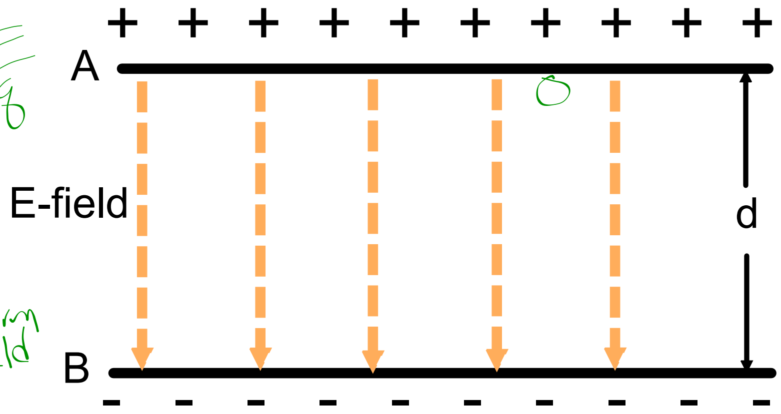
CASE 1: UNIFORM ELECTRIC FIELDS
(between charged plates)

$V_{ba} = ?$ $E = \frac{F}{q}$

$V_{ba} = \frac{W_{ba}}{q}$

$W = F \cdot d$ uniform e-field

$E \cdot q$



$V_{ba} = \frac{E \cdot \cancel{q} \cdot d}{\cancel{q}}$

$V_{ba} = E \cdot d$ (in a uniform e-field)

- In words: the electric potential difference between two charged plates is the product of the electric field between the plates and the distance separating the plates.
- This assumes the E-field between the plates is uniform.

EXAMPLE 1: A positive charge acquires 18 J of kinetic energy as it moves between two charged plates. If the electric potential difference between the two plates is 35 V,

a) How much charge moved?

$V_{ba} = \frac{W_{ba}}{q}$ $q = \frac{W_{ba}}{V_{ba}} = \frac{-18J}{-35 J/C} = 0.51 C$

b) If the plates are 12 cm apart, what is the E-field between the plates?

$V_{ba} = E \cdot d$; $E = \frac{V_{ba}}{d} = \frac{35V}{0.12m} = 291.7\ N/C$

c) Which plate has the higher electrical potential, the + or the - plate?

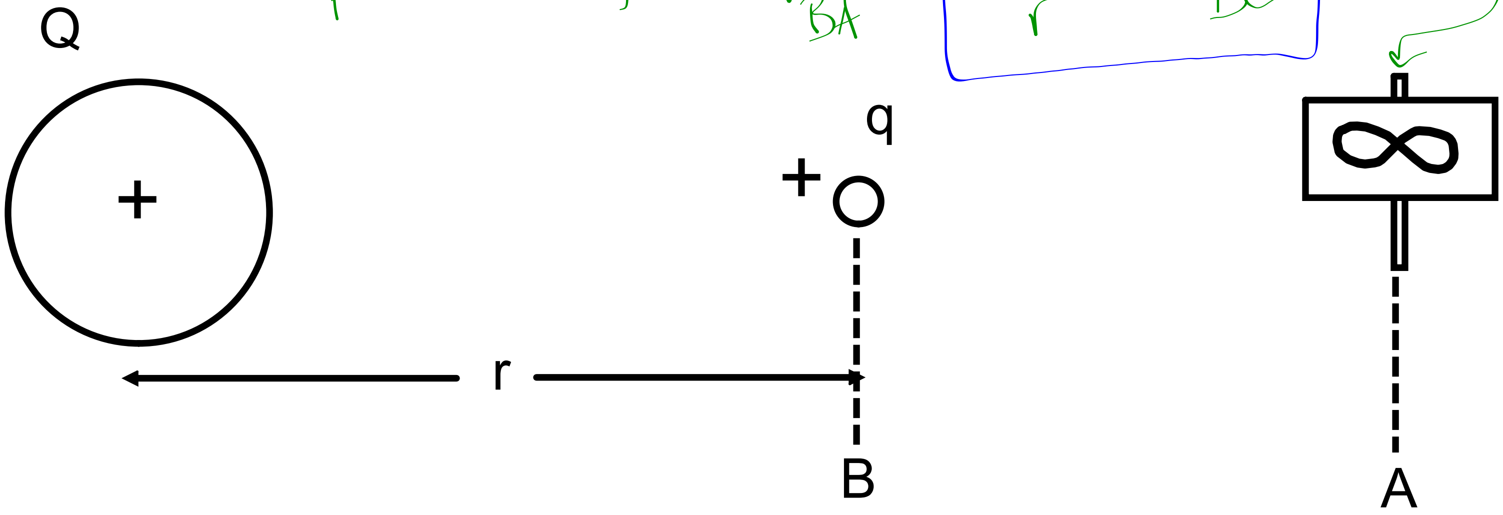
Since q added KE, W is ⊖ ⊖ → $V_{ba} = \frac{W_{ba} \leftarrow ⊖}{q \leftarrow ⊕}$ ⊕ plate has higher V

d) How much electrical potential enegy did the charge lose in moving as it did?

18 J

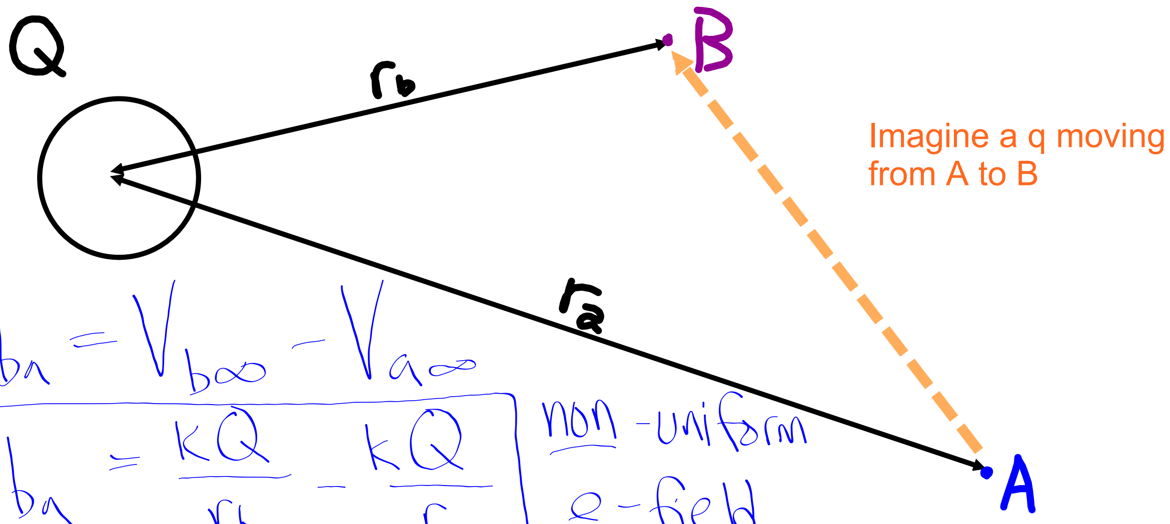
CASE 2: NON-UNIFORM ELECTRIC FIELDS
(point charges)

"point voltage": $V_{BA} = \boxed{\frac{kQ}{r} = V_{B\infty}}$ 0 V



What is the electric potential difference between Point B (a point r meters from Q) and Point A (a point in this case infinitely far away from Q so that if q were there, it would have no electric potential energy as a result of Q)?

So to find the electric potential between TWO points in space near a charge Q:



$$V_{ba} = V_{b\infty} - V_{a\infty}$$

$$\boxed{V_{ba} = \frac{kQ}{r_b} - \frac{kQ}{r_a}}$$

non-uniform e-field

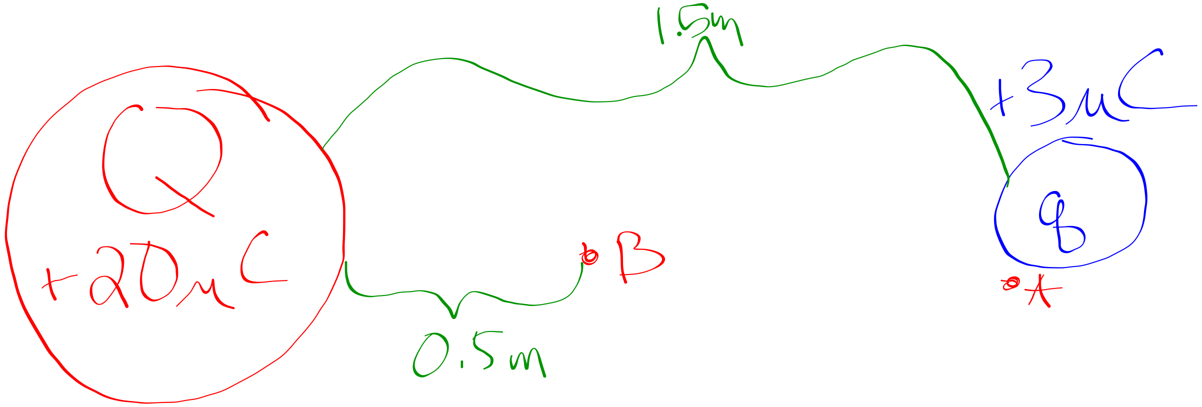
In order to determine the work needed to move q from A to B, or to determine the energy associated with this, we would first need to know the electric potential difference between these two points, V_{ba}.

Using a point infinitely far away as our zero V reference point:

$$V_{ba} = (V_{b\infty} - V_{a\infty}) = \left(\frac{kQ}{r_b} - \frac{kQ}{r_a}\right)$$

We'll use this to help us define the energy associated with moving a q between two different points near a single Q.

EXAMPLE 2: How much work is required to bring a +3 *u*C charge from a point that is 1.5 m away from a +20 *u*C charge to a point that is only 0.5 m away from the same +20 *u*C charge?



$$V_{ba} = \frac{W_{ba}}{q}$$

$$W_{ba} = (V_{ba})\cdot(q)$$
$$= (240{,}000\ J/C)(3E{-}6\ C)$$
$$= 0.72\ J$$

$$V_{ba} = V_{b\infty} - V_{a\infty} = \frac{kQ}{r_b} - \frac{kQ}{r_a} = \frac{(9E9)(20E{-}6)}{0.5} - \frac{(9E9)(20E{-}6)}{1.5}$$

$$= 360{,}000\ V - 120{,}000\ V = 240{,}000\ V$$

- This equals the increase in q's electric potential energy and also equals the work we must do on q to move it from Point A to Point B.
- If Q were not present, it wouldn't take any work to move q.
- The fact that W_{ba} is positive means that it will take work to move q.