Physics 212
Lecture 5

Today's Concept:

Electric Potential Energy

Your Comments

I know this was said by someone last week but...oh god.

I felt pretty good about this prelecture and checkpoint. However, I have one question that has been haunting my dreams. Are we supposed to memorize all these formulas?

That was the hardest homework assignment I've ever done. I gave up

After the horror that was Gaussian surfaces, it's nice to move back to simpler and more familiar territory!

4:00am - *phone rings* "CONDUCTOR!" How do you respond?

Why do the homeworks and lectures seem really out of pace with eachother (i.e. Why does it feel like the homework is leaps and bounds ahead of the class? does the lecture catch up eventually?)

Could you do more examples with systems of multiple point charges, as well as with how to calculate the electric potential energy itself (just for practice) in these systems.

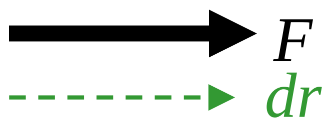
I'm seeing that the prelectures are giving us MANY equations that aren't on our equation sheet. Will we have to try to memorize them?!

Thanks for telling the 8 am lab students that there was no lab this week. Website

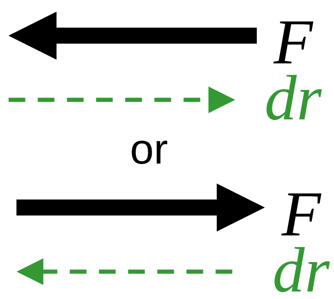
Work (Mechanics Review)

Recall from physics 211:

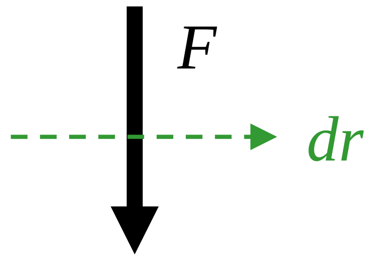
$$W = \int_{\vec{r}_1}^{\vec{r}_2} \vec{F} \cdot d\vec{r} \qquad W_{TOT} = \Delta K$$



$W > 0$ (e.g. $W_{gravity}$ on object dropped)



$W < 0$ (e.g. $W_{gravity}$ on ball going up)



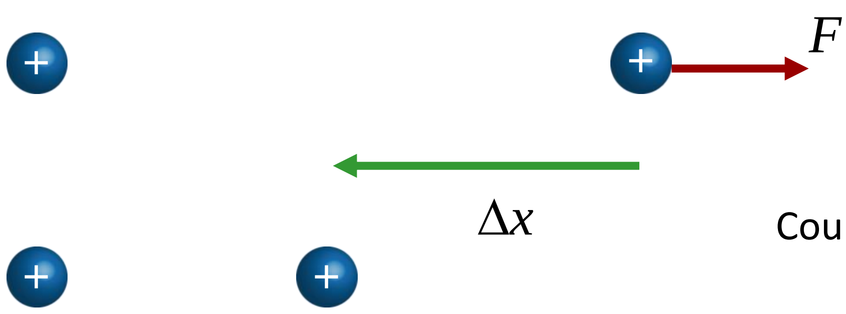
$W = 0$ (e.g. $W_{gravity}$ on moving horizontally)

Potential Energy

$$\Delta U \equiv -W_{conservative}$$

If gravity does negative work, potential energy increases!

Same idea for Coulomb force… if Coulomb force does negative work, potential energy increases.

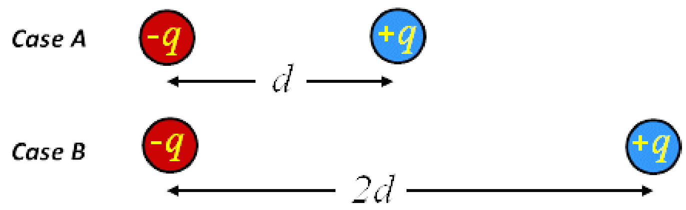


Coulomb force does negative work
Potential energy increases

Prelecture Question 2

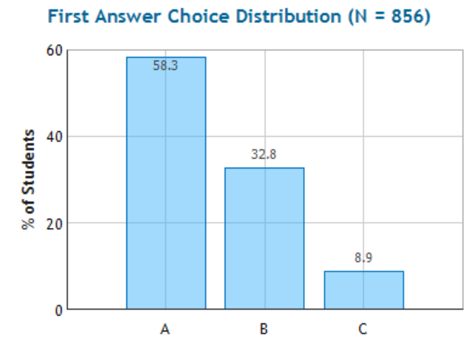
Which configuration has the largest potential energy?

Which configuration has the highest potential energy U?



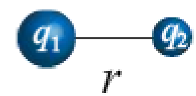
- Case A has the highest potential energy
- Case B has the highest potential energy
- Both cases have the same potential energy

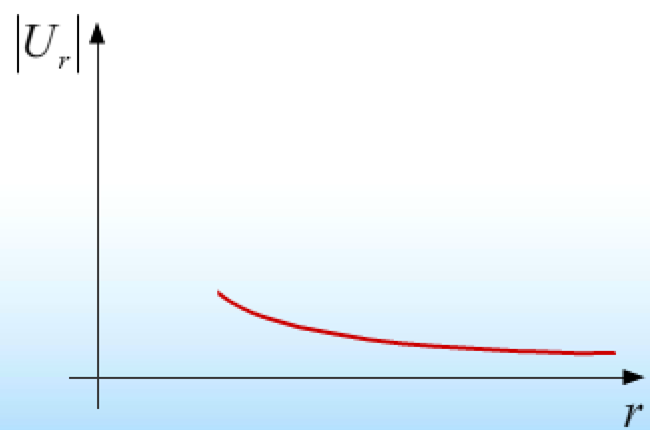
A) A B)B C) Same



Electric Potential Energy

$$U_r \equiv \Delta U_{\infty r} = \frac{q_1 q_2}{4\pi\varepsilon_o r}$$





CheckPoint 4

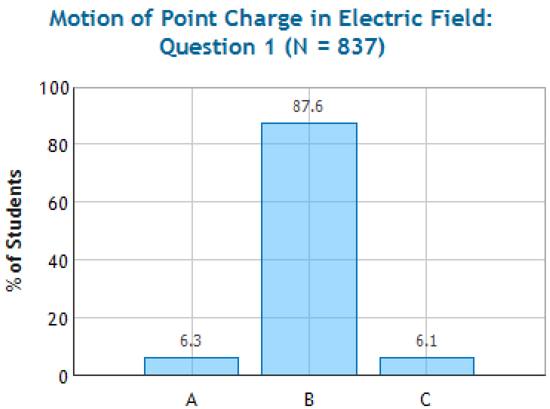
"Could you please explain why the particle always moves in the direction to decrease its potential energy? Thank you!"

A charge is released from rest in a region of electric field. The charge will start to move

A) In a direction that makes its potential energy increase.

$\boxed{\text{B) In a direction that makes its potential energy decrease}}$

C) Along a path of constant potential energy.

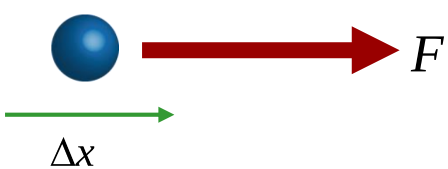


"Just like in 211, objects will want to move to where there is the lowest potential energy.

It will move in the same direction as F

Work done by force is positive

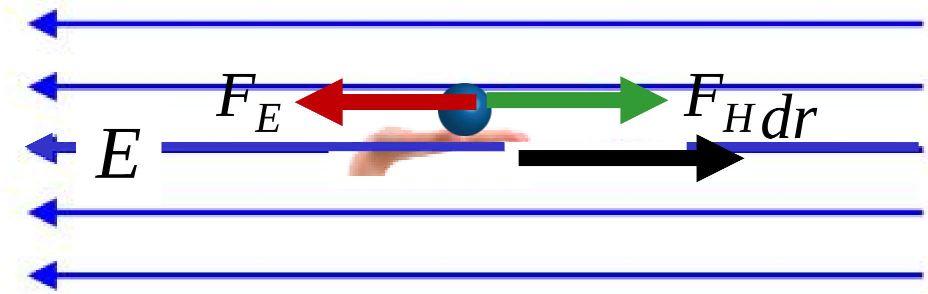
$\Delta U = -$Work, so is is negative



Nature wants things to move in such a way that PE decreases

Clicker Question

You hold a positively charged ball and walk due east in a region that contains an electric field directed due west.



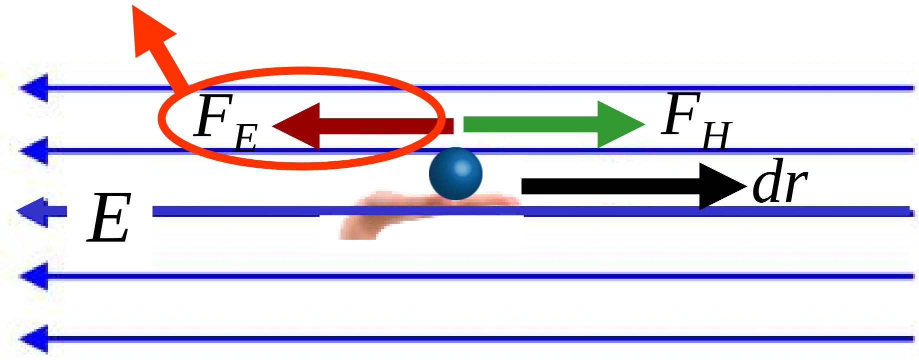
W_H is the work done by the hand on the ball
W_E is the work done by the electric field on the ball

Which of the following statements is true:

A) $W_H > 0$ and $W_E > 0$
B) $\boxed{W_H > 0 \text{ and } W_E < 0}$
C) $W_H < 0$ and $W_E < 0$
D) $W_H < 0$ and $W_E > 0$

Clicker Question

Conservative force: $\Delta U = -W_E$



B) $W_H > 0$ and $W_E < 0$

Is ΔU positive, negative or zero?

A) Positive

B) Negative

C) Zero

Example: Two Point Charges

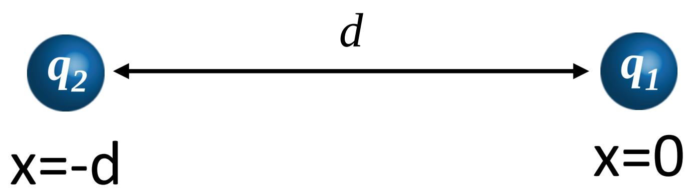
Calculate the change in potential energy for two point charges originally very far apart moved to a separation of "d"

$$\Delta U \equiv -\int_i^f \vec{F}\cdot d\vec{r}$$

$$= \int_{-\infty}^{-d} F dx$$

$$= \int_{-\infty}^{-d} k\frac{q_1 q_2}{x_{12}^2} dx$$

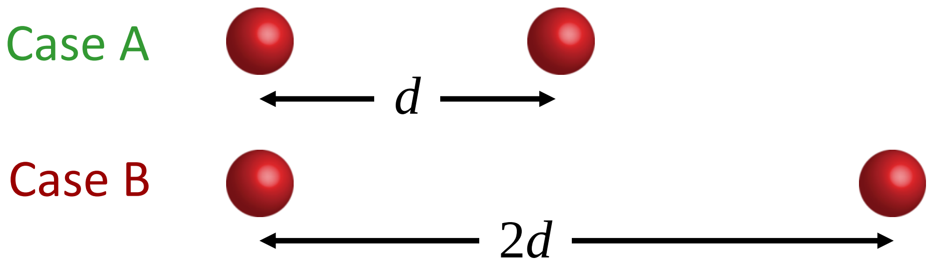
$$= -kq_1 q_2\left[-\frac{1}{d} - \left(-\frac{1}{\infty}\right)\right] = k\frac{q_1 q_2}{d} = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{d}$$



Charged particles with the same sign have an increase in potential energy when brought closer together.

For point charges often choose $r =$ infinity as "zero" potential energy.

Clicker Question



In case A two negative charges which are equal in magnitude are separated by a distance d. In case B the same charges are separated by a distance $2d$. Which configuration has the highest potential energy?

A) Case A
B) Case B

Clicker Question Discussion

As usual, choose $U = 0$ to be at infinity:

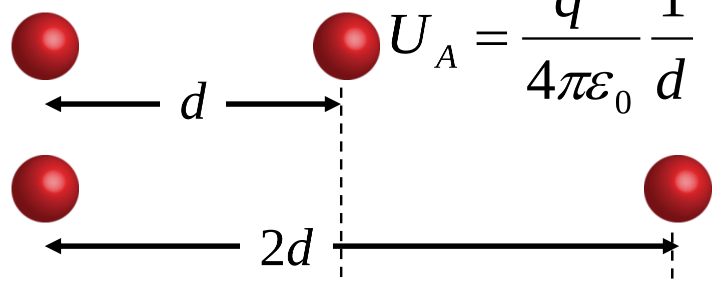
$$U(r) = \frac{q_1 q_2}{4\pi\varepsilon_0}\frac{1}{r}$$

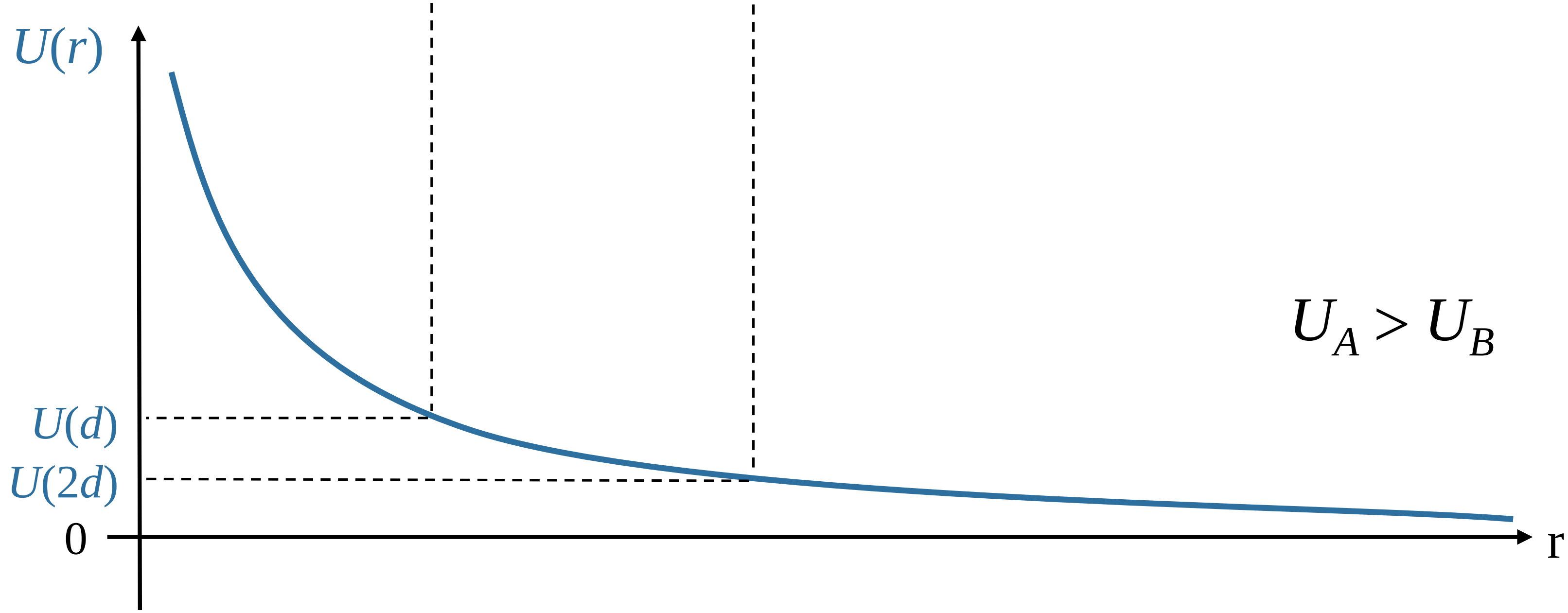
Case A

$$U_A = \frac{q^2}{4\pi\varepsilon_0}\frac{1}{d}$$

Case B

$$U_B = \frac{q^2}{4\pi\varepsilon_0}\frac{1}{2d}$$



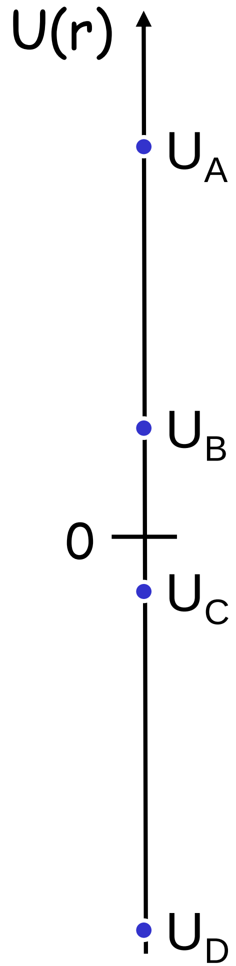


$$U_A > U_B$$

And Remember

U is just a number (not a vector)

- U DOES have a sign



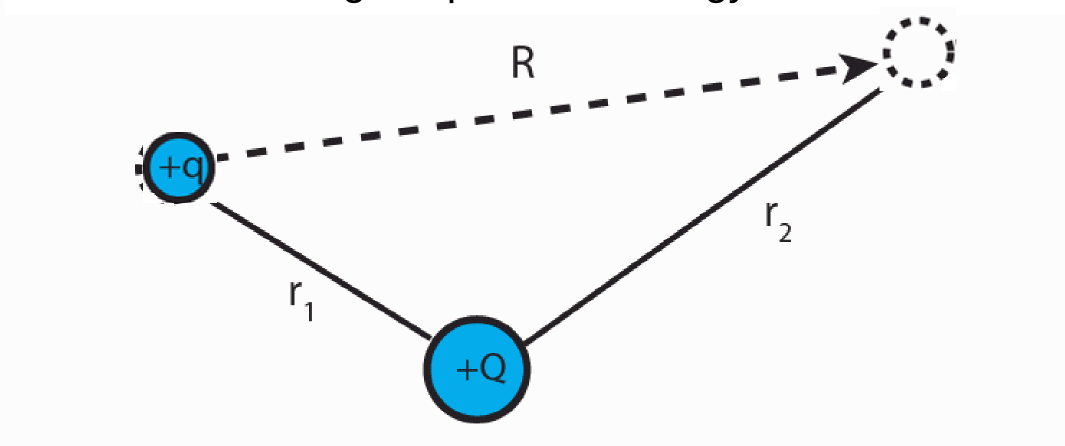
$U_A > U_B$

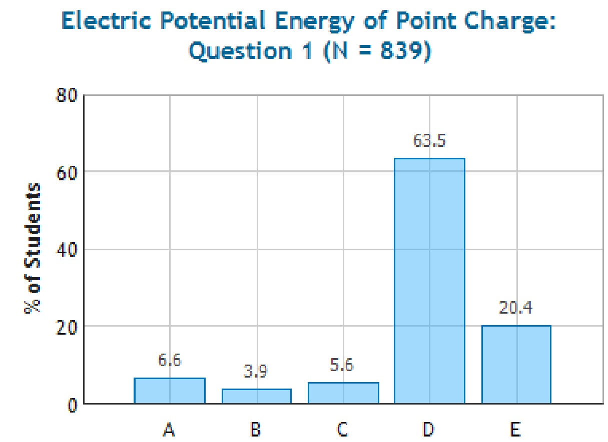
$U_B > U_C$

$U_C > U_D$

CheckPoint 1

A charge +q is moved from position 1 to position 2,
What is the change in potential energy?





A $\dfrac{kQq}{R}$ B $\dfrac{kQqR}{r_1^2}$ C $\dfrac{kQqR}{r_2^2}$

D $kQq\left(\dfrac{1}{r_2}-\dfrac{1}{r_1}\right)$ E $kQq\left(\dfrac{1}{r_1}-\dfrac{1}{r_2}\right)$

The initial potential energy is represented by kQq/r1, and the final is represented by kQq/r2. The difference is then kQq(1/r2-1/r1).

$$U_1 = \frac{kQq}{r_1} \qquad U_2 = \frac{kQq}{r_2}$$

$$\Delta U \equiv U_2 - U_1 = kQq\left(\frac{1}{r_2}-\frac{1}{r_1}\right)$$

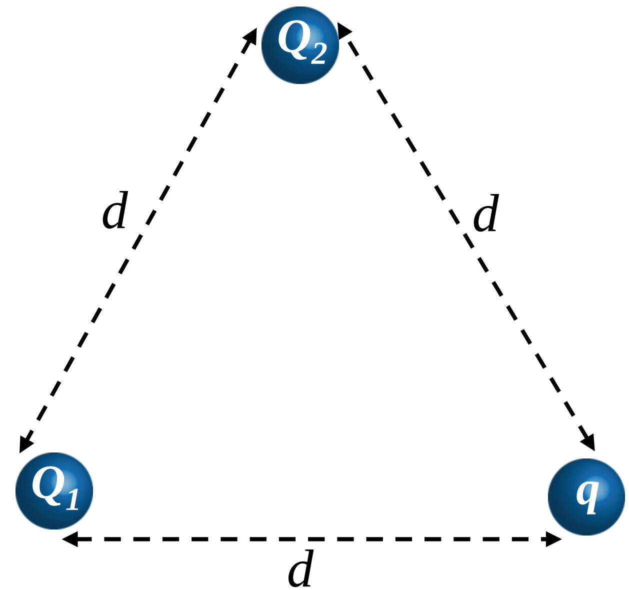
Note: $+q$ moves AWAY from $+Q$.
Its Potential energy MUST DECREASE
$\Delta U < 0$

Potential Energy of Many Charges

Two charges are separated by a distance d. What is the change in potential energy when a third charge q is brought from far away to a distance d from the original two charges?

$$\Delta U = \frac{qQ_1}{4\pi\varepsilon_0}\frac{1}{d} + \frac{qQ_2}{4\pi\varepsilon_0}\frac{1}{d}$$

(superposition)



"Can you go over in further depth, what electric potential energy actually means for a system of charges?"

Potential Energy of Many Charges

What is the total energy required to bring in three identical charges, from infinitely far away to the points on an equilateral triangle shown.

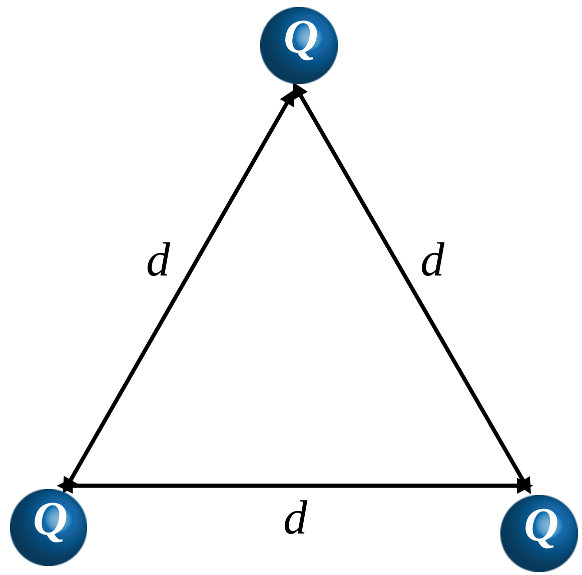
A) 0

B) $\Delta U = \frac{Q^2}{4\pi\varepsilon_0}\frac{1}{d}$

C) $\Delta U = 2\frac{Q^2}{4\pi\varepsilon_0}\frac{1}{d}$

D) $\Delta U = 3\frac{Q^2}{4\pi\varepsilon_0}\frac{1}{d}$

E) $\Delta U = 6\frac{Q^2}{4\pi\varepsilon_0}\frac{1}{d}$



$$W = \sum W_i = -\frac{3}{4\pi\varepsilon_0}\frac{Q^2}{d}$$

$$\boxed{\Delta U = +\frac{3}{4\pi\varepsilon_0}\frac{Q^2}{d}}$$

Work by E to bring in first charge: $W_1 = 0$

Work by E to bring in second charge : $W_2 = -\frac{1}{4\pi\varepsilon_0}\frac{Q^2}{d}$

Work by E to bring in third charge : $W_3 = -\frac{1}{4\pi\varepsilon_0}\frac{Q^2}{d} - \frac{1}{4\pi\varepsilon_0}\frac{Q^2}{d} = -\frac{2}{4\pi\varepsilon_0}\frac{Q^2}{d}$

Potential Energy of Many Charges

Suppose one of the charges is negative. Now what is the total energy required to bring the three charges in from infinitely far away?

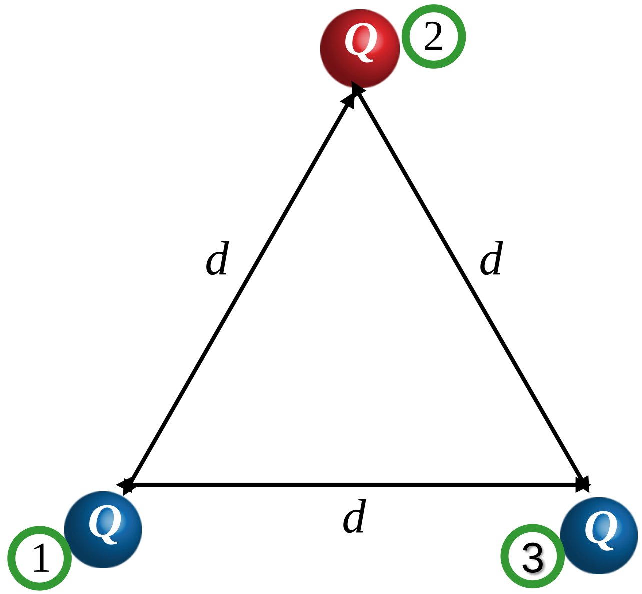
A) 0

B) $\Delta U = +1\frac{Q^2}{4\pi\varepsilon_0}\frac{1}{d}$

C) $\Delta U = -1\frac{Q^2}{4\pi\varepsilon_0}\frac{1}{d}$

D) $\Delta U = +2\frac{Q^2}{4\pi\varepsilon_0}\frac{1}{d}$

E) $\Delta U = -2\frac{Q^2}{4\pi\varepsilon_0}\frac{1}{d}$



$$W = \sum W_i = +\frac{1}{4\pi\varepsilon_0}\frac{Q^2}{d}$$

$$\boxed{\Delta U = -\frac{1}{4\pi\varepsilon_0}\frac{Q^2}{d}}$$

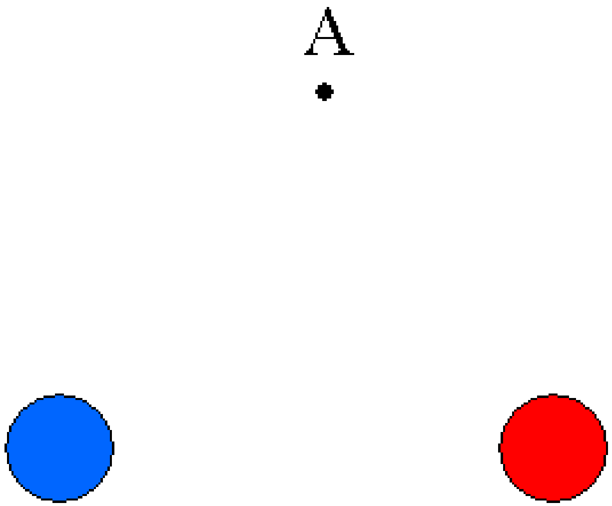
Work by E to bring in first charge: $W_1 = 0$

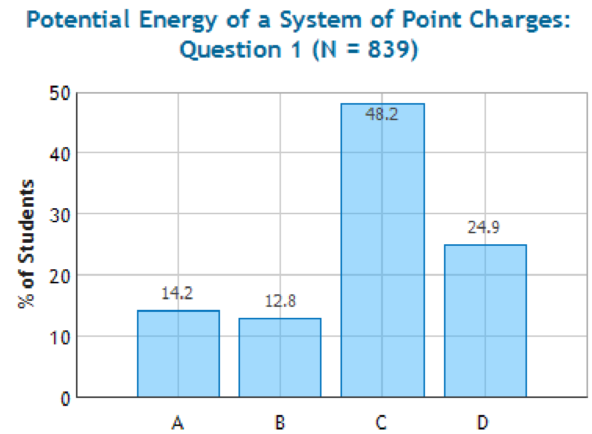
Work by E to bring in second charge : $W_2 = +\frac{1}{4\pi\varepsilon_0}\frac{Q^2}{d}$

Work by E to bring in third charge : $W_3 = +\frac{1}{4\pi\varepsilon_0}\frac{Q^2}{d} - \frac{1}{4\pi\varepsilon_0}\frac{Q^2}{d} = 0$

CheckPoint 2

Two charges with equal magnitude but opposite sign are located at equal distances from the point labeled A





If a third charge is brought in from far away to point A, how does the potential energy of the collection of charges change?

Increases	Decreases	Same	Depends on sign of charge
A	B	C	D

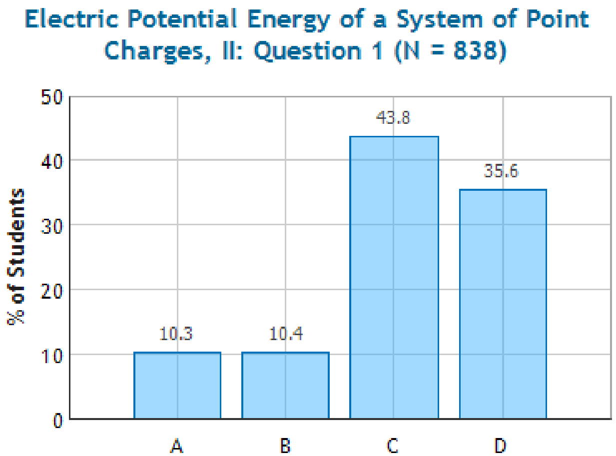
"No matter what the sign of the third charge is, it will have an equal negative and positive change in potential energy because the two other charges have the same magnitude and are equidistant from point A"

CheckPoint 3

A positive charge is placed on the left side of a negative charge. The magnitude of the negative charge is twice that of the positive charge.

Is there any (finite) location that a third charge can be placed such that the total potential energy of the system does not change?

- YES, as long as the third charge is positive
- YES, as long as the third charge is negative
- YES, no matter what the third charge is
- NO



C) "at a distance r away from the negative charge and 2r from the positive charge, the potential energy between the new charge and the existing charges will be 0."

D) "The U between the positive charge and third charge will always have a smaller magnitude than the U between the negative charge and third charge."

LET'S DO THE CALCULATION!

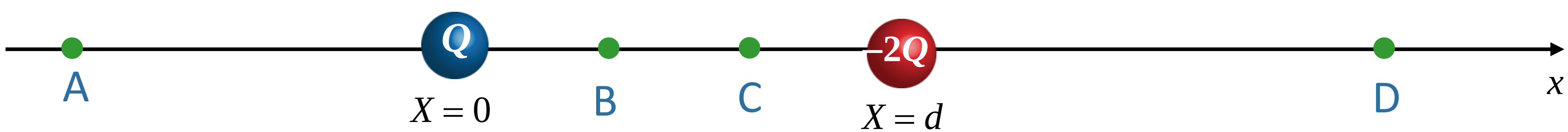
Example

A positive charge q is placed at $x = 0$ and a negative charge $-2q$ is placed at $x = d$. At how many different places along the x axis could another positive charge be placed without changing the total potential energy of the system?

A) 0
B) 1
C) 2
D) 3

Example

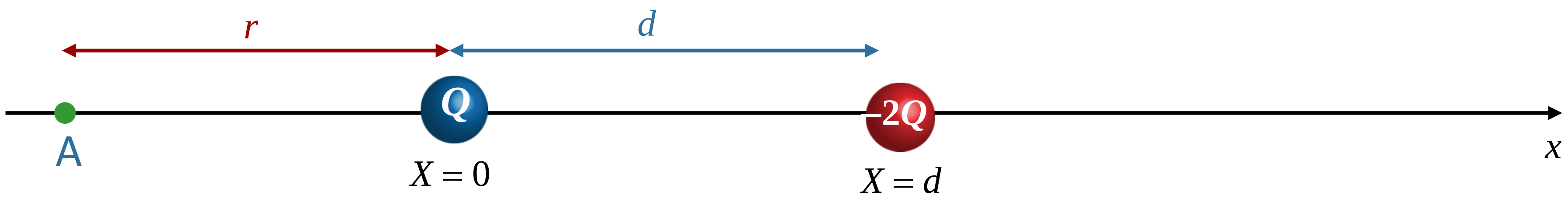
At which two places can a positive charge be placed without changing the total potential energy of the system?



A) A & B
B) A & C
C) B & C
D) B & D
E) A & D

Let's calculate the positions of A and B

Lets work out where A is



$$\Delta U = +\frac{1}{4\pi\varepsilon_0}\frac{Qq}{r} - \frac{1}{4\pi\varepsilon_0}\frac{2Qq}{r+d}$$

Set $\Delta U = 0$

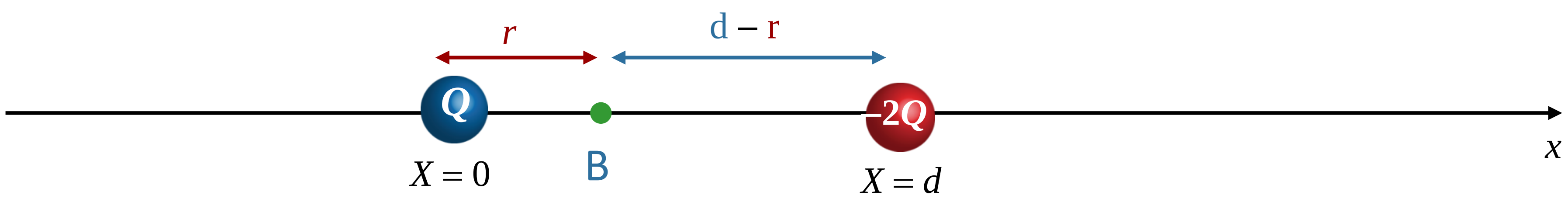
$$\frac{1}{r} = \frac{2}{r+d}$$

$$\boxed{r = d}$$

Makes Sense!

q is twice as far from $-2Q$ as it is from $+Q$

Lets work out where B is



Setting $\Delta U = 0$ → $$\frac{1}{r} = \frac{2}{d-r}$$

$$2r = d - r$$

$$\boxed{r = \frac{d}{3}}$$

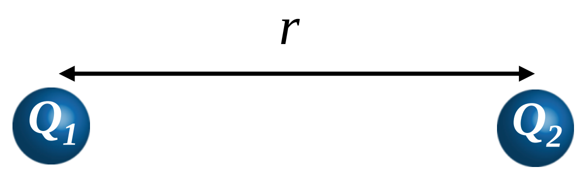
Makes Sense!

q is twice as far from -2*Q* as it is from + *Q*

Summary

For a pair of charges:

Just evaluate $$U = k\frac{q_1 q_2}{r}$$



(We usually choose $U = 0$ to be where the charges are far apart)

For a collection of charges:

Sum up $$U = k\frac{q_1 q_2}{r}$$ for all pairs