

Your Comments

Pretty confusing! Please go over potential energy directions especially with multiple charge systems. Thankie sai!

The signs in calculations work and potential energy make me confused.

I'm a little confused with the last checkpoint. If 2 charges of opposite sign are moving toward each other, wouldn't the U increase because d is decreasing? but if they are the same charge, they would repel, and so the d would increase, therefore decreasing the U . So wouldn't the fourth checkpoint depend on what sign the charges are?

Can you please give a 5 min recap of the potential energy and potentials from Mechanics ? It will be extremely helpful in understanding this.

Could you go over the calculations of electric field due to two charged objects (like concentric cylinders or one point charge and one sphere) at a point using Gauss law? I haven't been able to finish the homework because my answers don't match. Also please tell us your office hours; I can barely talk to you since I have back to back classes...

When do we get to the Wumbology unit? (The study of Wumbo)

Physics 212

Lecture 5

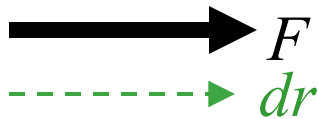
Today's Concept:

Electric Potential Energy

Work (Mechanics Review)

Recall from physics 211:

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

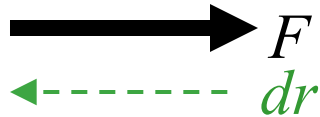


$$W > 0$$

(e.g. W_{gravity} on object dropped)

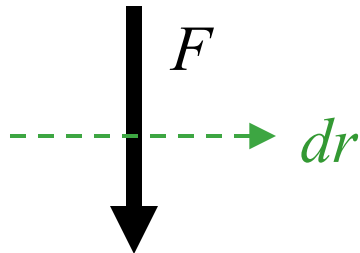


or



$$W < 0$$

(e.g. W_{gravity} on ball going up)



$$W = 0$$

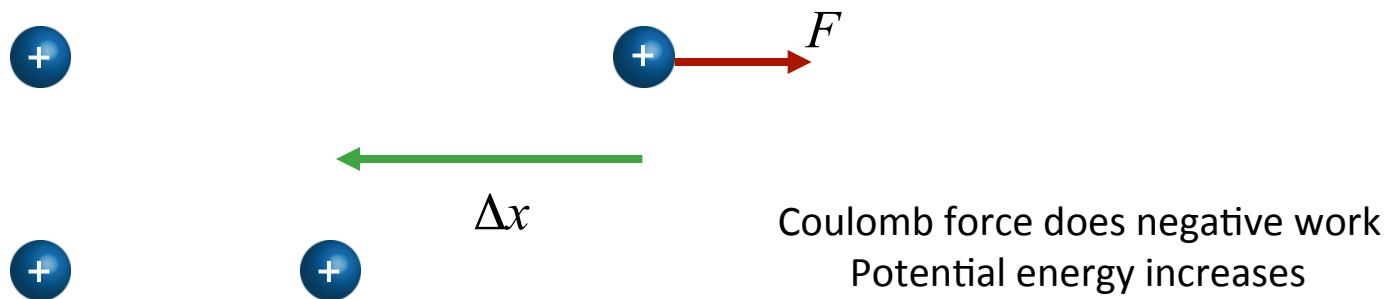
(e.g. W_{gravity} on moving horizontally)

Potential Energy

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

If gravity does negative work, potential energy increases!

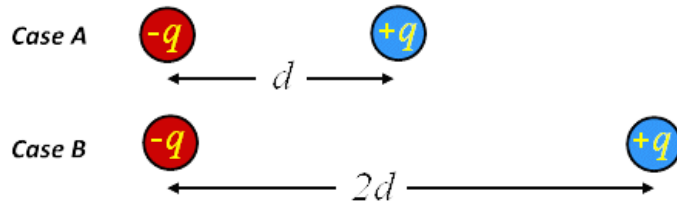
Same idea for Coulomb force... if Coulomb force does negative work, potential energy increases.



Prelecture Question 2

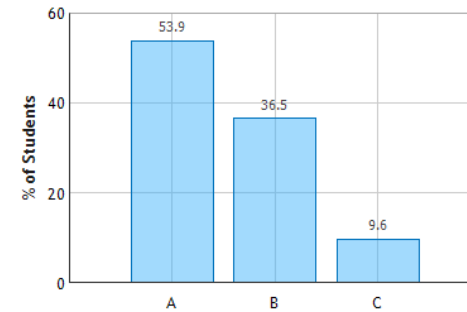
In Case A two charges which are equal in magnitude but opposite in charge are separated by a distance d . In Case B the same charges are separated by a distance $2d$.

Which configuration has the highest potential energy U ?



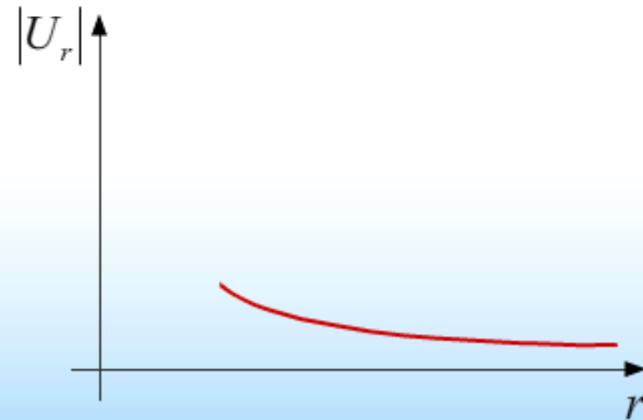
- ☐ Case A has the highest potential energy
- ☒ Case B has the highest potential energy
- ☐ Both cases have the same potential energy

First Answer Choice Distribution (N = 1128)



Electric Potential Energy

$$U_r \equiv \Delta U_{\infty r} = \frac{q_1 q_2}{4\pi\epsilon_0 r}$$



CheckPoint 4

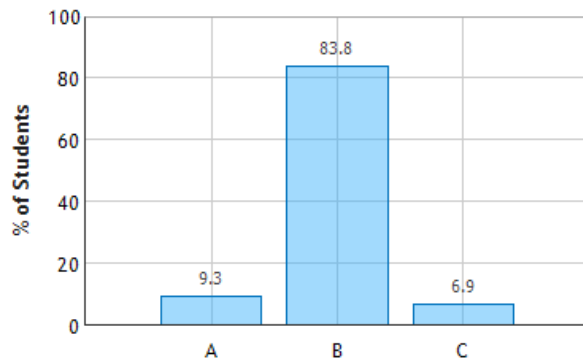
A charge is released from rest in a region of electric field. The charge will start to move

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

B) In a direction that makes its potential energy decrease.

C) Along a path of constant potential energy.

Motion of Point Charge in Electric Field:
Question 1 (N = 1112)

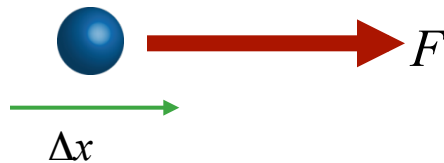


"Potential energy is always minimized in systems. Balls roll downhill, not uphill."

It will move in the same direction as F

Work done by force is positive

$\Delta U = -\text{Work}$, so is negative

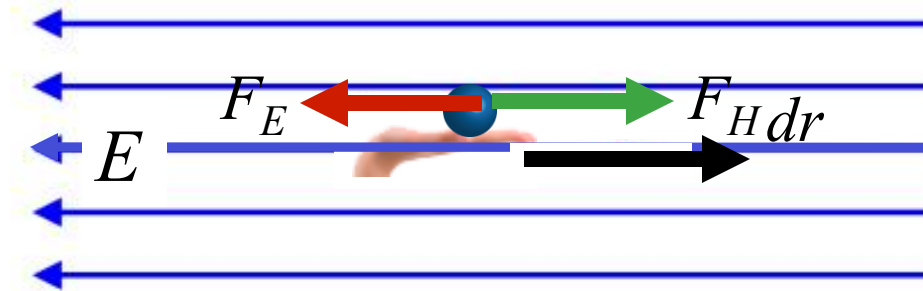


Nature wants things to move in such a way that PE decreases

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

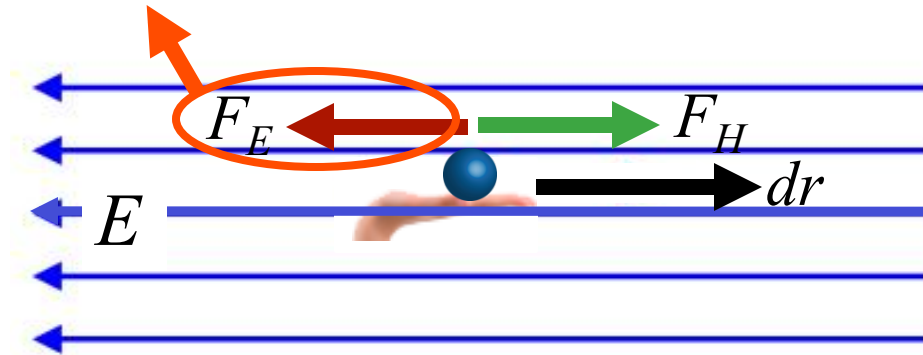
C) $W_H < 0$ and $W_E < 0$

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

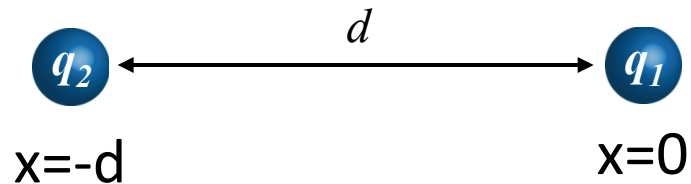
B) Negative

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 ”

$$\begin{aligned}\Delta U &\equiv -\int_{-\infty}^d \mathbf{F} \cdot d\mathbf{r} \\ &= \int_{-\infty}^d F \cdot dx \\ &= \int_{-\infty}^d k \frac{q_1 q_2}{x_{12}^2} dx\end{aligned}$$

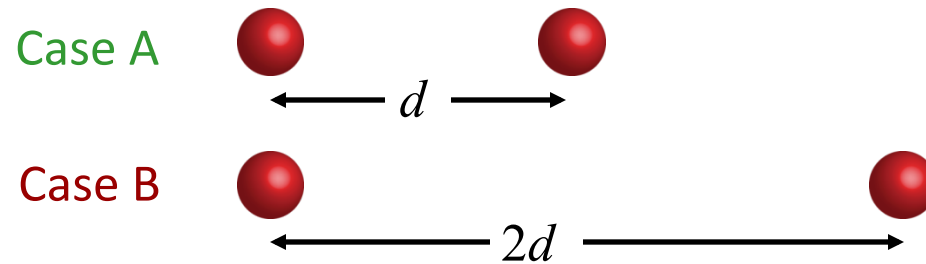


$$= -kq_1 q_2 \left[-\frac{1}{d} - \left(-\frac{1}{\infty} \right) \right] = k \frac{q_1 q_2}{d} = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{d}$$

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

For point charges often choose $r = \text{infinity}$ 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

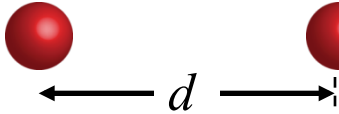
B) Case B

Clicker Question Discussion

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

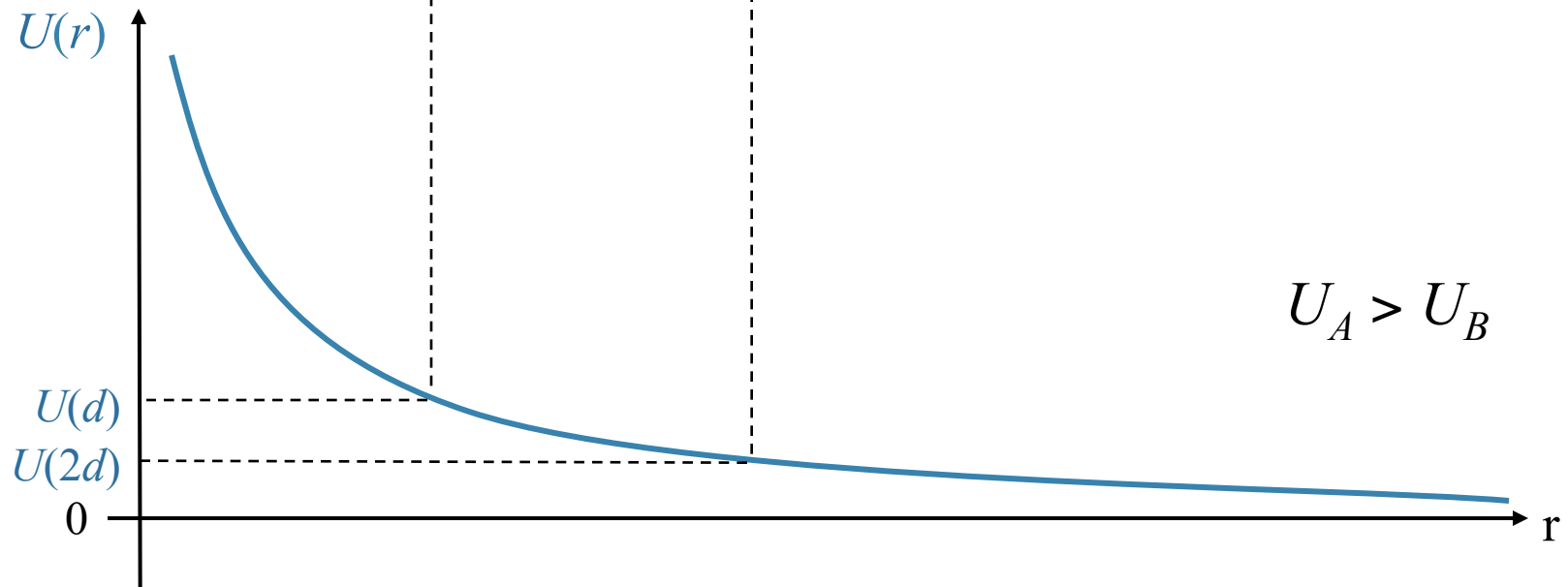
$$U(r) = \frac{q_1 q_2}{4\pi\epsilon_0 r}$$

Case A


$$U_A = \frac{q^2}{4\pi\epsilon_0 d}$$

Case B

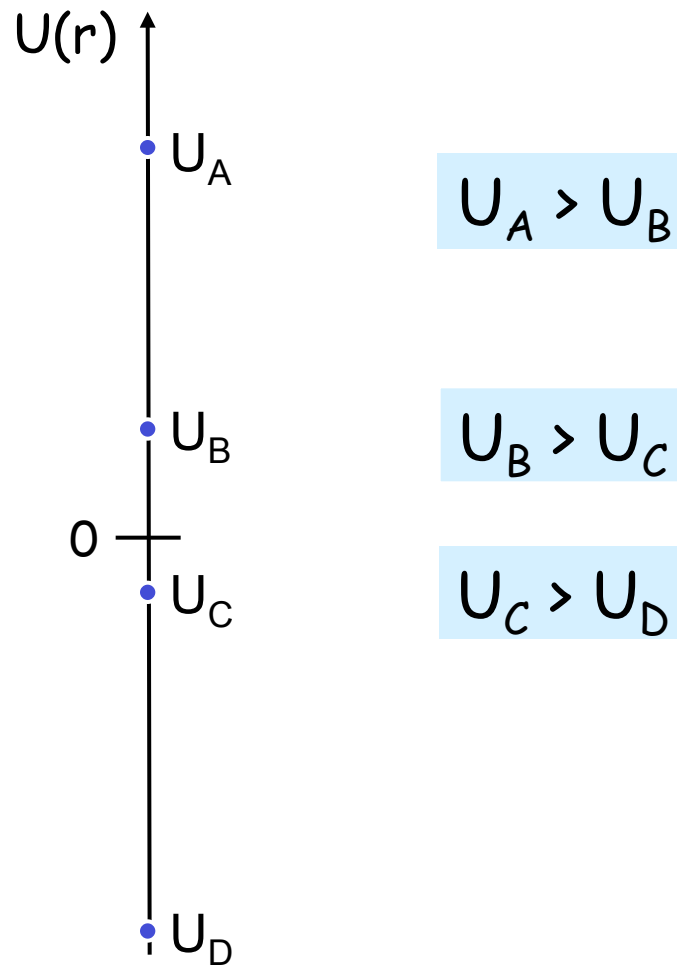

$$U_B = \frac{q^2}{4\pi\epsilon_0 2d}$$



And Remember

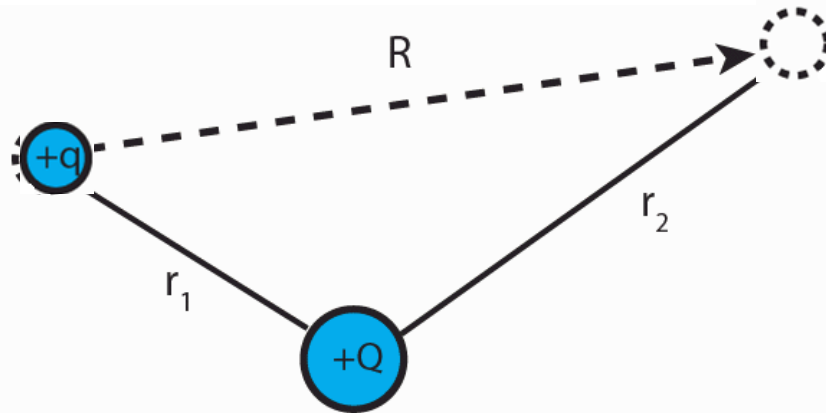
U is just a number (not a vector)

- U DOES have a sign



CheckPoint 1

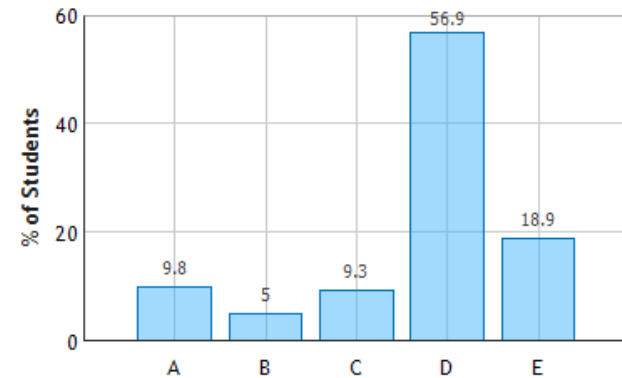
A charge $+q$ is moved from position 1 to position 2, What is the change in potential energy?



- A $\frac{kQq}{R}$ B $\frac{kQqR}{r_1^2}$ C $\frac{kQqR}{r_2^2}$
 D $kQq\left(\frac{1}{r_2} - \frac{1}{r_1}\right)$ E $kQq\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$

The initial potential energy is represented by kQq/r_1 , and the final is represented by kQq/r_2 . The difference is then $kQq(1/r_2 - 1/r_1)$.

Electric Potential Energy of Point Charge:
Question 1 (N = 1117)



$$U_1 = \frac{kQq}{r_1}$$

$$U_2 = \frac{kQq}{r_2}$$



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

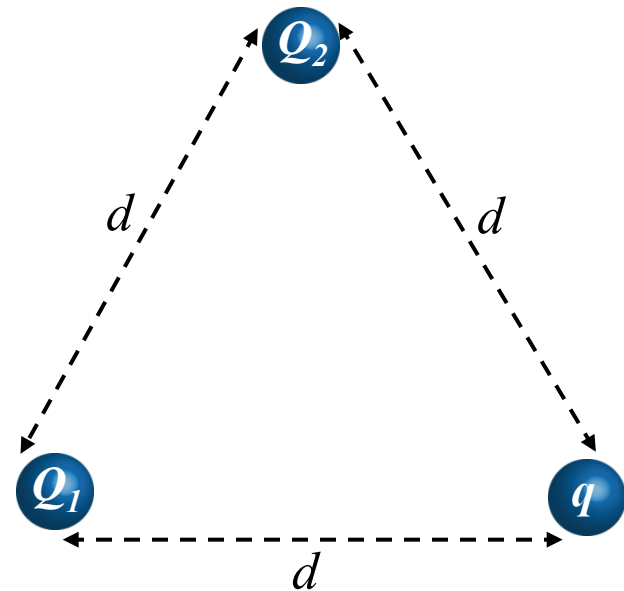
Note: $+q$ moves **AWAY** from $+Q$.
Its Potential energy **MUST DECREASE**
 $\Delta U < 0$

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?

$$\Delta U = \frac{qQ_1}{4\pi\epsilon_0} \frac{1}{d} + \frac{qQ_2}{4\pi\epsilon_0} \frac{1}{d}$$

(superposition)



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.

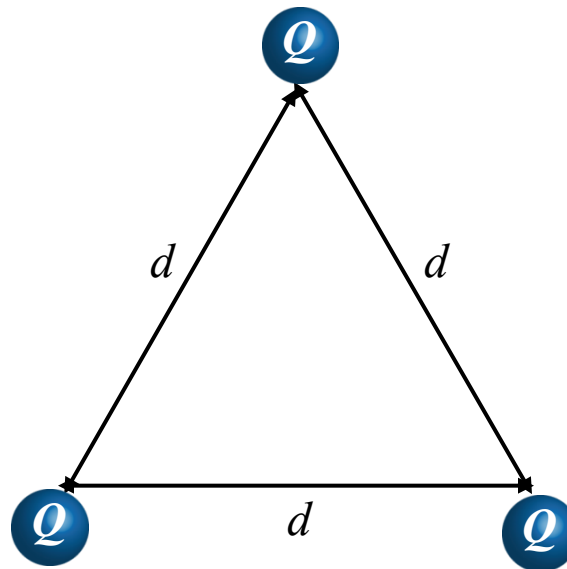
A) 0

B) $\Delta U = \frac{Q^2}{4\pi\epsilon_0} \frac{1}{d}$

C) $\Delta U = 2 \frac{Q^2}{4\pi\epsilon_0} \frac{1}{d}$

D) $\Delta U = 3 \frac{Q^2}{4\pi\epsilon_0} \frac{1}{d}$

E) $\Delta U = 6 \frac{Q^2}{4\pi\epsilon_0} \frac{1}{d}$



$$W = \sum W_i = -\frac{3}{4\pi\epsilon_0} \frac{Q^2}{d}$$

$$\Delta U = +\frac{3}{4\pi\epsilon_0} \frac{Q^2}{d}$$

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

Work by E to bring in second charge: $W_2 = -\frac{1}{4\pi\epsilon_0} \frac{Q^2}{d}$

Work by E to bring in third charge: $W_3 = -\frac{1}{4\pi\epsilon_0} \frac{Q^2}{d} - \frac{1}{4\pi\epsilon_0} \frac{Q^2}{d} = -\frac{2}{4\pi\epsilon_0} \frac{Q^2}{d}$

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?

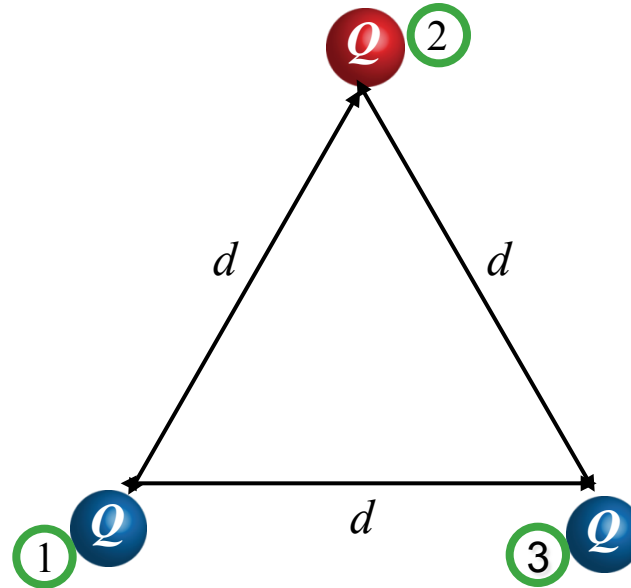
A) 0

B) $\Delta U = +1 \frac{Q^2}{4\pi\epsilon_0 d}$

C) $\Delta U = -1 \frac{Q^2}{4\pi\epsilon_0 d}$

D) $\Delta U = +2 \frac{Q^2}{4\pi\epsilon_0 d}$

E) $\Delta U = -2 \frac{Q^2}{4\pi\epsilon_0 d}$



$$W = \sum W_i = + \frac{1}{4\pi\epsilon_0} \frac{Q^2}{d}$$

$$\Delta U = - \frac{1}{4\pi\epsilon_0} \frac{Q^2}{d}$$

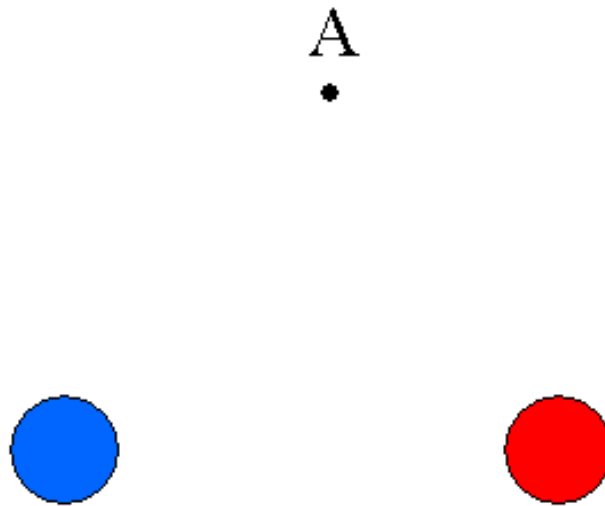
Work by E to bring in first charge: $W_1 = 0$

Work by E to bring in second charge: $W_2 = + \frac{1}{4\pi\epsilon_0} \frac{Q^2}{d}$

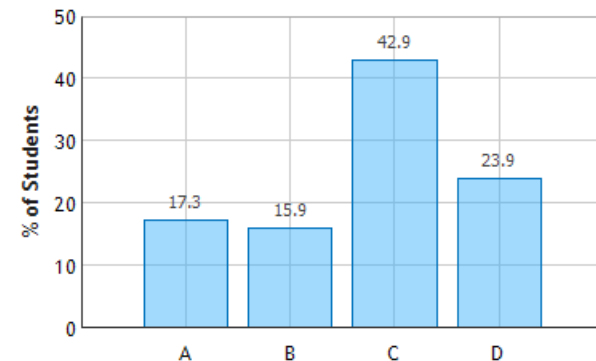
Work by E to bring in third charge: $W_3 = + \frac{1}{4\pi\epsilon_0} \frac{Q^2}{d} - \frac{1}{4\pi\epsilon_0} \frac{Q^2}{d} = 0$

Checkpoint 2

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



Potential Energy of a System of Point Charges:
Question 1 (N = 1114)



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

C) “The potential energy will be positive for the charge of the same sign and negative for the charge of the opposite sign, yielding a potential that is the same relative to the first.”

D) “The sign will determine if the sum of the potential energies will be a positive or a negative number.”

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.



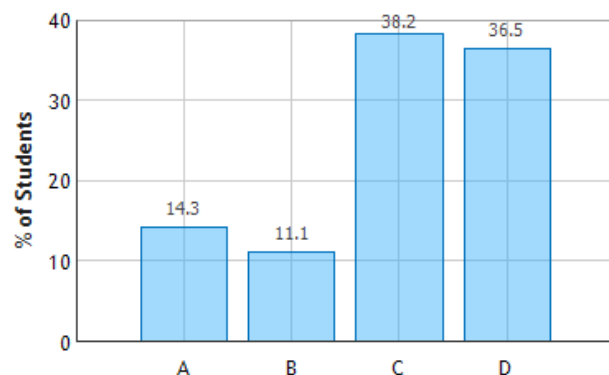
Is there any (finite) location that a third charge can be placed such that the total potential energy of the system does not change?

- ☐ 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) “Placing a charge twice the distance from the plus to the minus will keep the potential energy the same no matter the sign.”

D) “It is impossible because the potential energy between the new charge and each of the original charges will be different from one another and will be unable to completely cancel.”

Electric Potential Energy of a System of Point Charges, II: Question 1 (N = 1113)

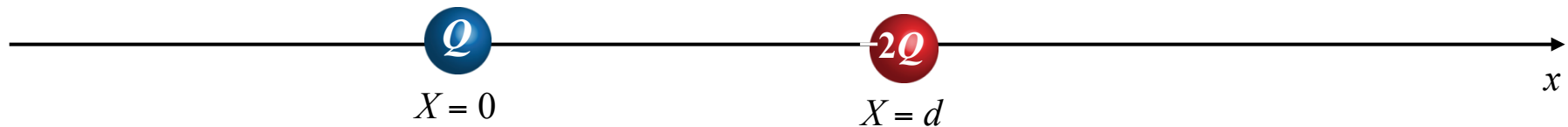


LET'S DO THE CALCULATION!

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

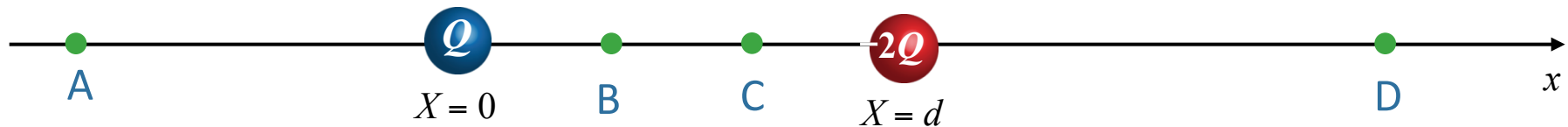
C) 2

D) 3

Example



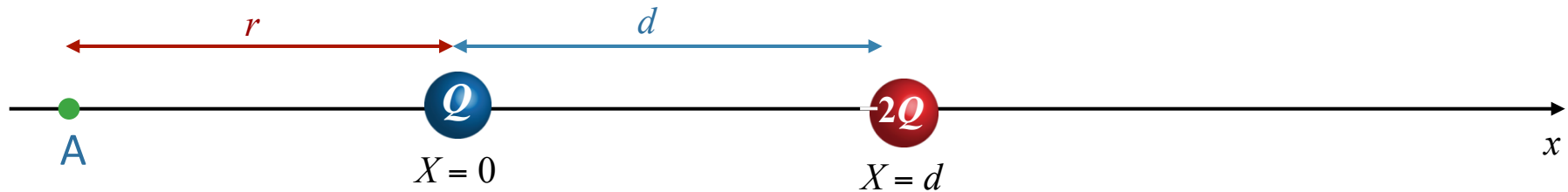
At which two places can a positive charge be placed without changing the total potential energy of the system?



- 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



$$\Delta U = + \frac{1}{4\pi\epsilon_0} \frac{Qq}{r} - \frac{1}{4\pi\epsilon_0} \frac{2Qq}{r+d}$$

Set $\Delta U = 0$

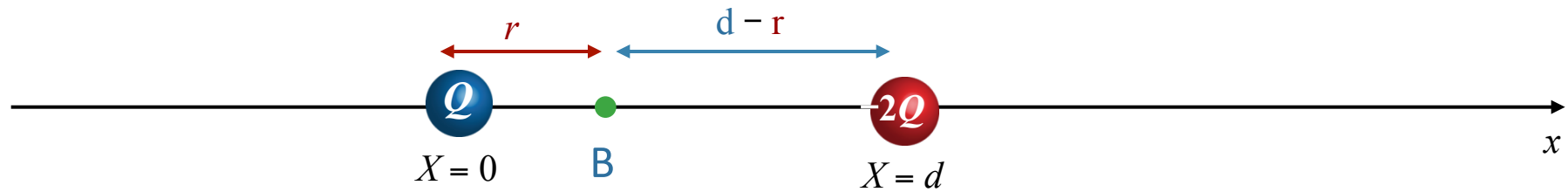
$$\frac{1}{r} = \frac{2}{r+d}$$

$$r = d$$

Makes Sense!

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

Lets work out where B is



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

$2r = d - r$

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

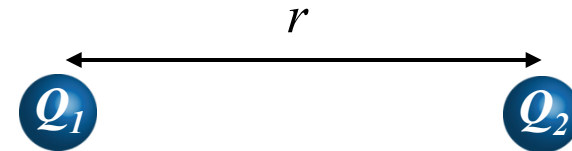
Makes Sense!

q is twice as far from $-2Q$ 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

