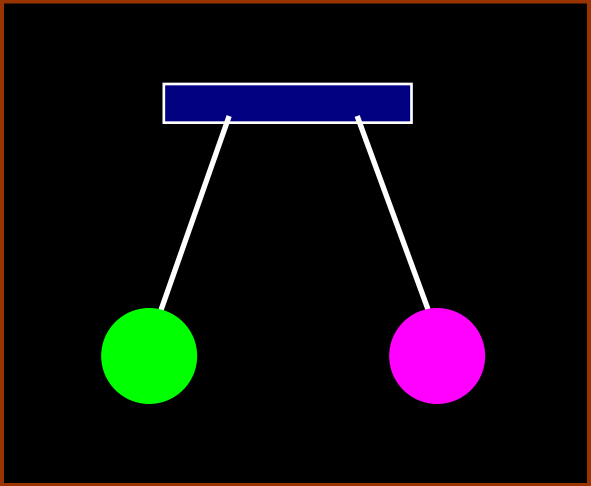
1) Electric Charge I

Two charged balls are repelling each other as they hang from the ceiling. What can you say about their charges?

1) one is positive, the other is negative
2) both are positive
3) both are negative
4) both are positive or both are negative



1) Electric Charge I

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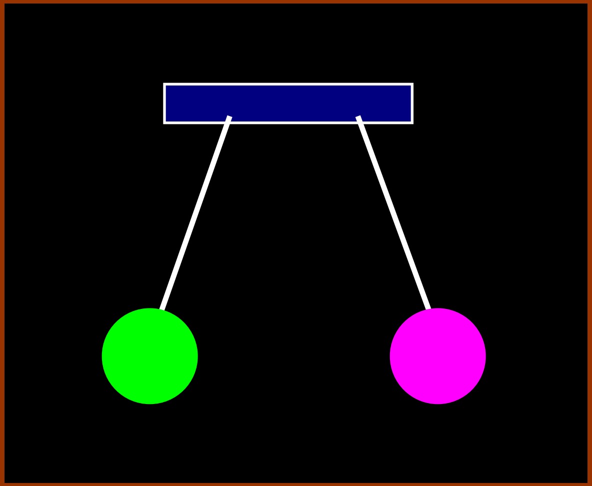
1) one is positive, the other is negative
2) both are positive
3) both are negative
4) both are positive or both are negative

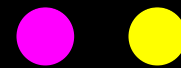
The fact that the balls repel each other only can tell you that they have the same charge, but you do not know the sign. So they can be either both positive or both negative.

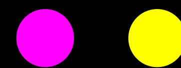


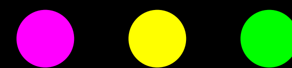
Follow-up: What does the picture look like if the two balls are oppositely charged? What about if both balls are neutral?

2) Electric Charge II

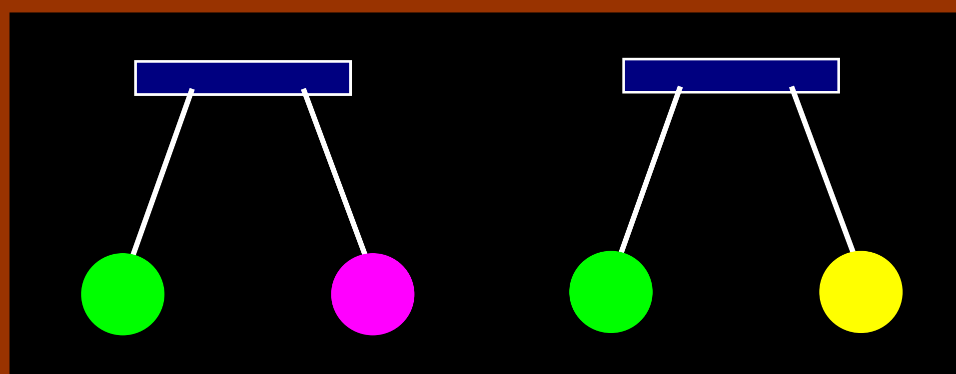
From the picture, what can you conclude about the charges?

1)  have opposite charges

2)  have the same charge

3)  all have the same charge

4) one ball must be neutral (no charge)

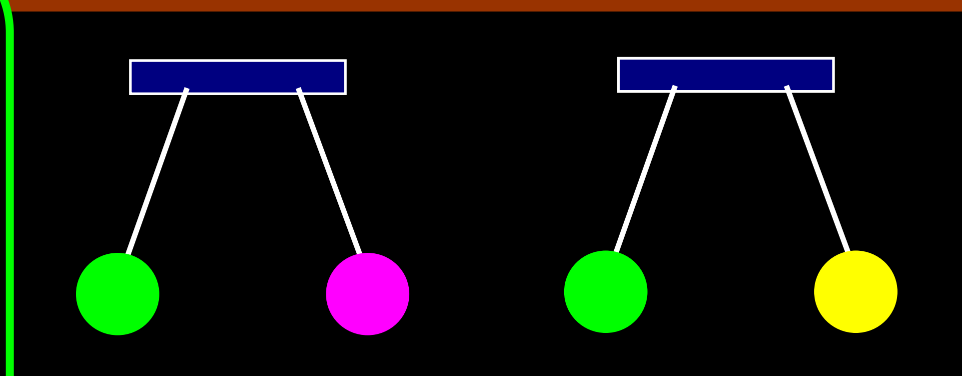


2) Electric Charge II

From the picture, what can you conclude about the charges?

1) have opposite charges
2) have the same charge
3) all have the same charge
4) one ball must be neutral (no charge)

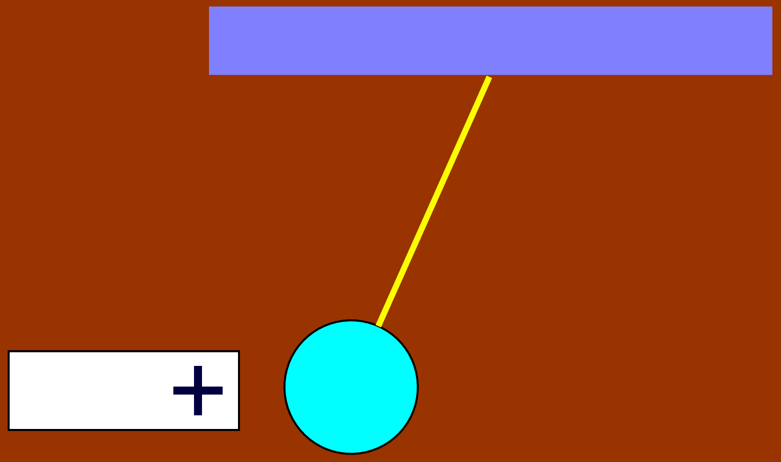
The GREEN and PINK balls must have the same charge, since they repel each other. The YELLOW ball also repels the GREEN, so it must also have the same charge as the GREEN (and the PINK).



3) Conductors I

A metal ball hangs from the ceiling by an insulating thread. The ball is attracted to a positive-charged rod held near the ball. The charge of the ball must be:

1) positive
2) negative
3) neutral
4) positive or neutral
5) negative or neutral



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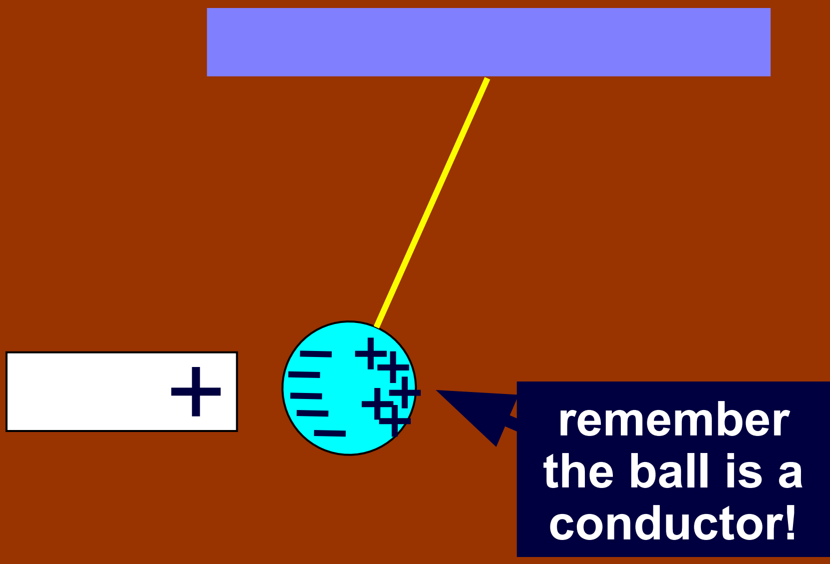
A metal ball hangs from the ceiling by an insulating thread. The ball is attracted to a positive-charged rod held near the ball. The charge of the ball must be:

1) positive
2) negative
3) neutral
4) positive or neutral
5) negative or neutral

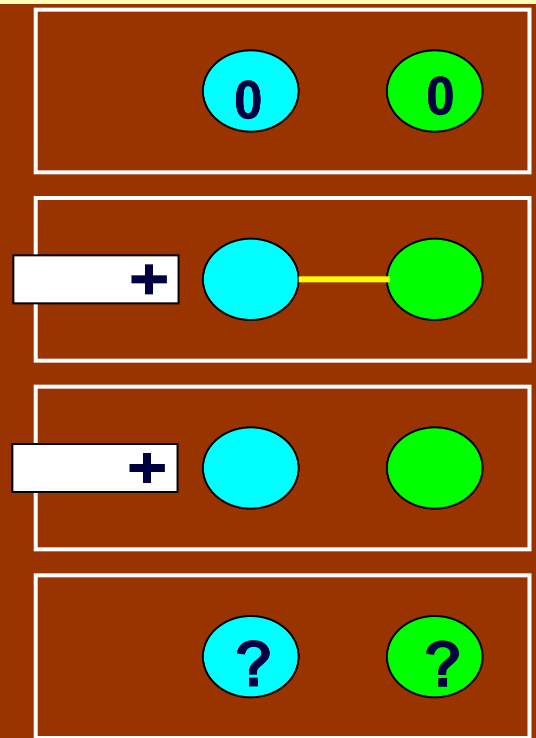
Clearly, the ball will be attracted if its charge is negative. However, even if the ball is neutral, the charges in the ball can be separated by induction (polarization), leading to a net attraction.



4) Conductors II

Two neutral conductors are connected by a wire and a charged rod is brought near, **but *does not touch***. The wire is taken away, and **then the charged rod is removed**. What are the charges on the conductors?

1) 0 0
2) + –
3) – +
4) + +
5) – –

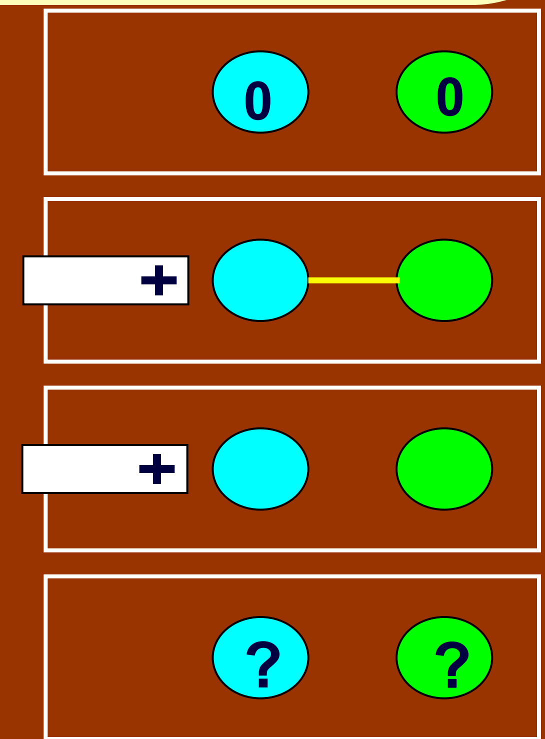


4) Conductors II

Two neutral conductors are connected by a wire and a charged rod is brought near, **but *does not touch***. The wire is taken away, and **then the charged rod is removed**. What are the charges on the conductors?

1) 0 0
2) + –
3) – +
4) + +
5) – –

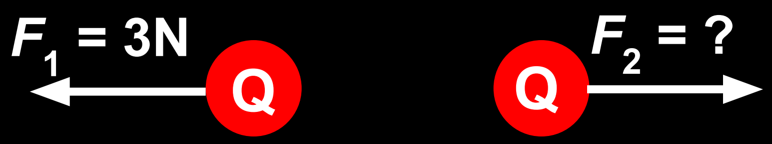
While the conductors are connected, **positive charge will flow from the blue to the green ball due to polarization**. Once disconnected, the **charges will remain on the separate conductors** even when the rod is removed.



Follow-up: What will happen when the conductors are reconnected with a wire?

6) Coulomb's Law I

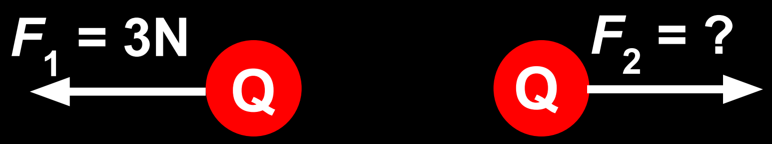
What is the magnitude of the force F_2?



1) 1.0 N
2) 1.5 N
3) 2.0 N
4) 3.0 N
5) 6.0 N

6) Coulomb's Law I

What is the magnitude of the force F_2?

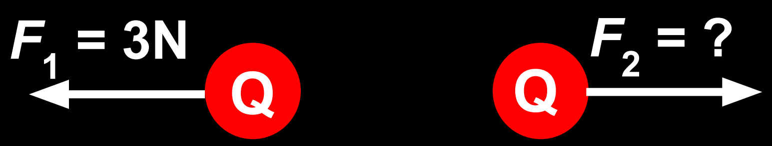


1) 1.0 N
2) 1.5 N
3) 2.0 N
4) 3.0 N
5) 6.0 N

The force F_2 must have the *same magnitude* as F_1. This is due to the fact that the form of Coulomb's Law is totally symmetric with respect to the two charges involved. The force of one on the other of a pair is the same as the reverse.

Note that this sounds suspiciously like Newton's 3rd Law!!

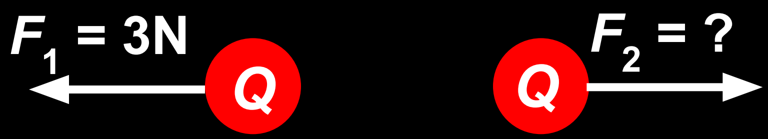
7) Coulomb's Law II



If we increase one charge to **4Q**, what is the magnitude of F_1?

1) 3/4 N
2) 3.0 N
3) 12 N
4) 16 N
5) 48 N

7) Coulomb's Law II



If we increase one charge to **4Q**, what is the magnitude of F_1?

1) 3/4 N
2) 3.0 N
3) 12 N
4) 16 N
5) 48 N

Originally we had:

$$F_1 = k(Q)(Q)/r^2 = 3\ \text{N}$$

Now we have:

$$F_1 = k(4Q)(Q)/r^2$$

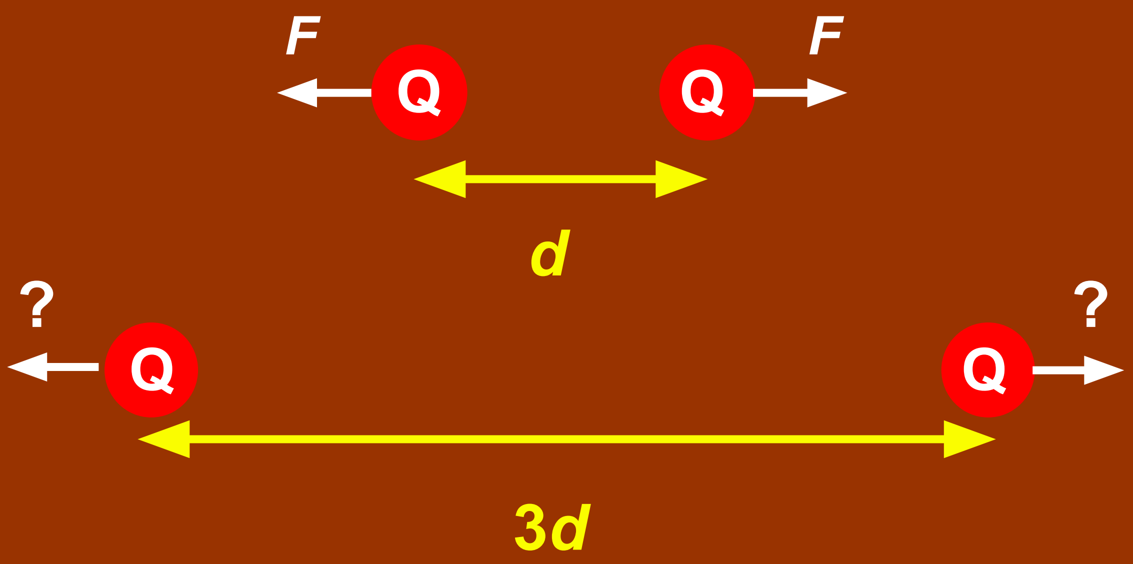
which is 4 times bigger than before.

Follow-up: Now what is the magnitude of F_2?

8) Coulomb's Law III

The force between two charges separated by a distance *d* is *F*. If the charges are pulled apart to a distance 3*d*, what is the force on each charge?

1) 9 *F*
2) 3 *F*
3) *F*
4) 1/3 *F*
5) 1/9 *F*



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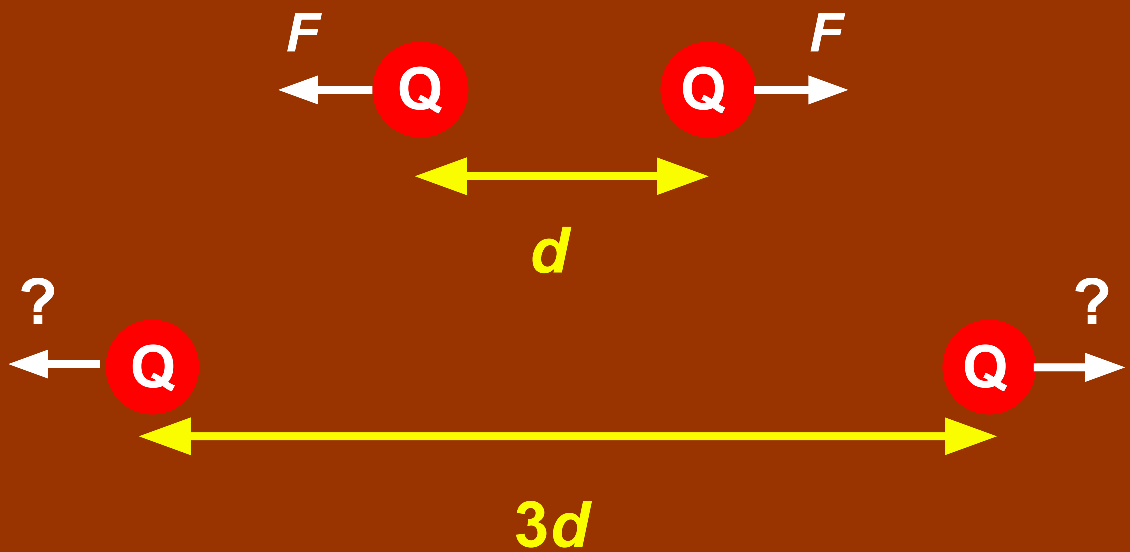
2) 3 *F*
3) *F*
4) 1/3 *F*
5) 1/9 *F*

Originally we had:

$F_{before} = k(Q)(Q)/d^2 = F$

Now we have:

$F_{after} = k(Q)(Q)/(3d)^2 = 1/9\ F$

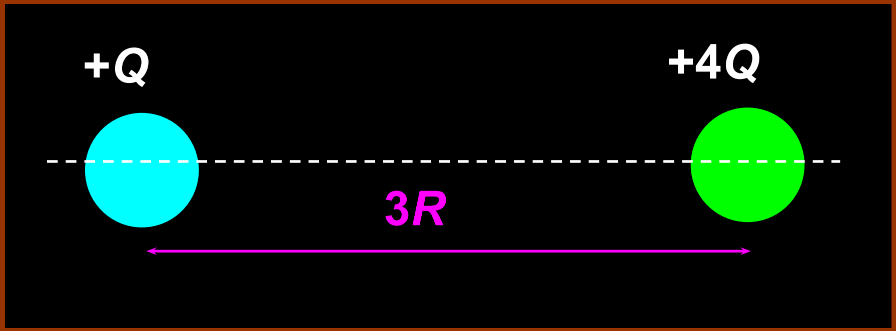


Follow-up: What is the force if the original distance is halved?

9) Electric Force I

Two balls with charges $+Q$ and $+4Q$ are fixed at a separation distance of $3R$. Is it possible to place another charged ball Q_0 on the line between the two charges such that the net force on Q_0 will be zero?

1) yes, but only if Q_0 is positive
2) yes, but only if Q_0 is negative
3) yes, independent of the sign (or value) of Q_0
4) no, the net force can never be zero



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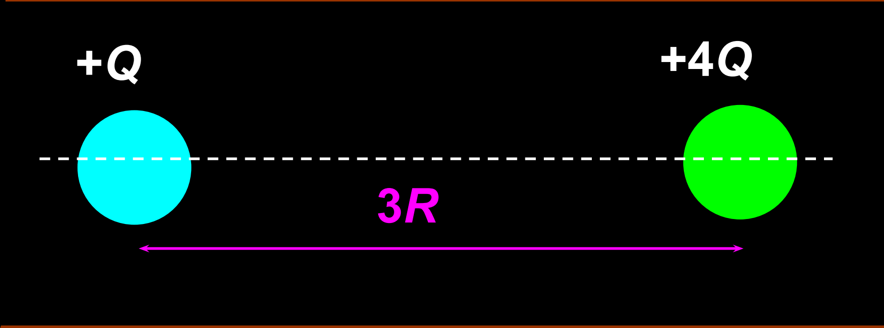
1) yes, but only if Q_0 is positive
2) yes, but only if Q_0 is negative
3) yes, independent of the sign (or value) of Q_0
4) no, the net force can never be zero

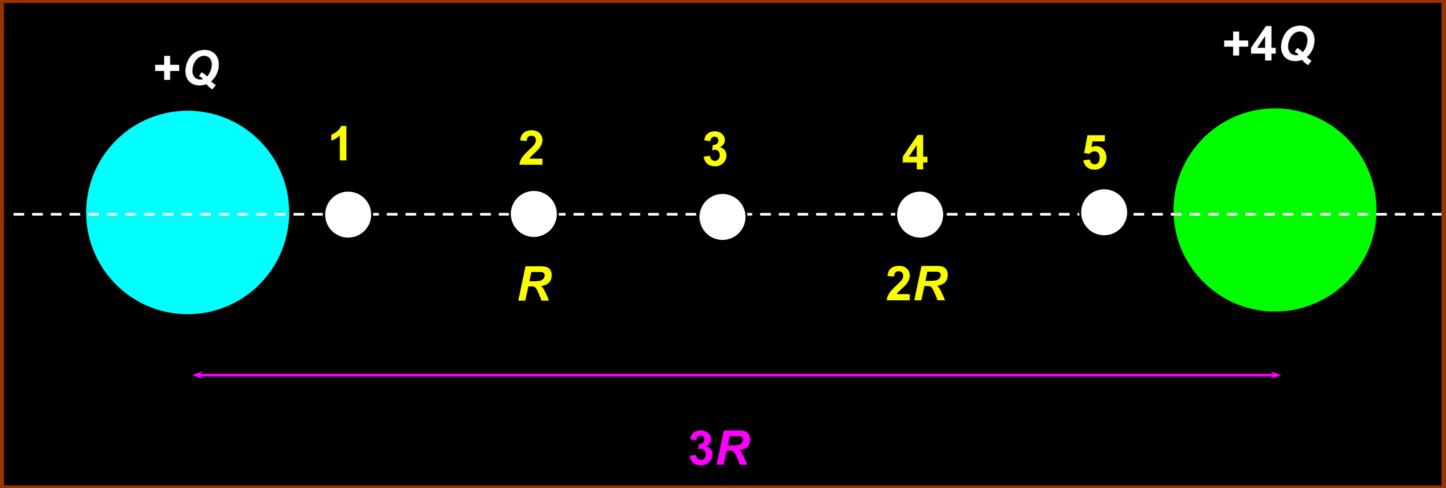
A positive charge would be repelled by both charges, so a point where these two repulsive forces cancel can be found. A negative charge would be attracted by both, and the same argument holds.



Follow-up: What happens if both charges are $+Q$? Where would the $F = 0$ point be in this case?

10) Electric Force II

Two balls with charges $+Q$ and $+4Q$ are separated by $3R$. Where should you place another charged ball Q_0 on the line between the two charges such that the net force on Q_0 will be zero?



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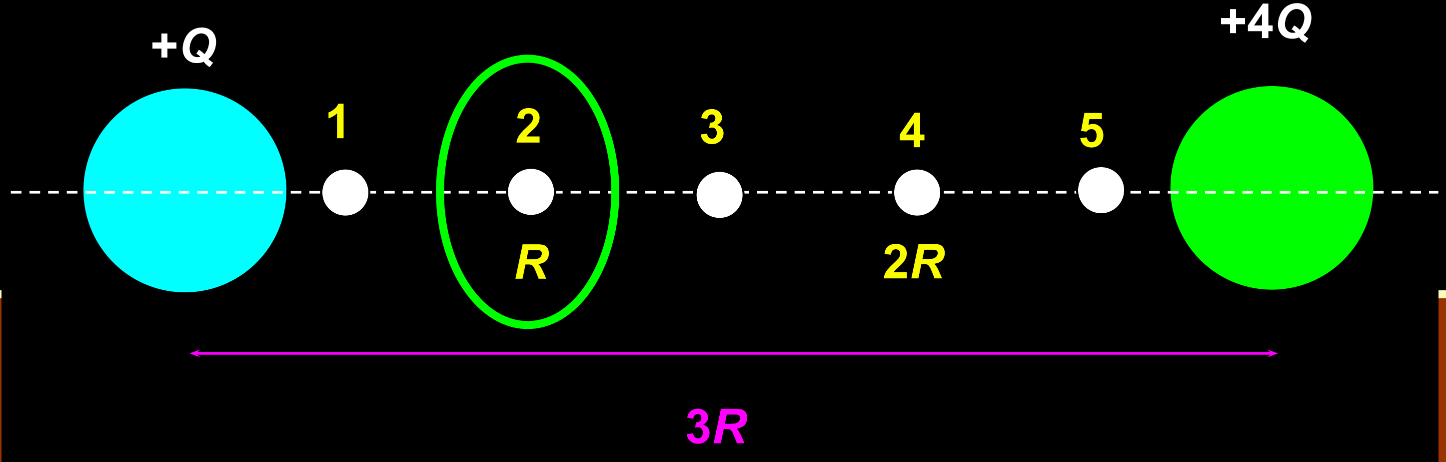
Two balls with charges $+Q$ and $+4Q$ are separated by $3R$. Where should you place another charged ball Q_0 on the line between the two charges such that the net force on Q_0 will be zero?



The force on Q_0 due to $+Q$ is: $F = k(Q_0)(Q)/R^2$

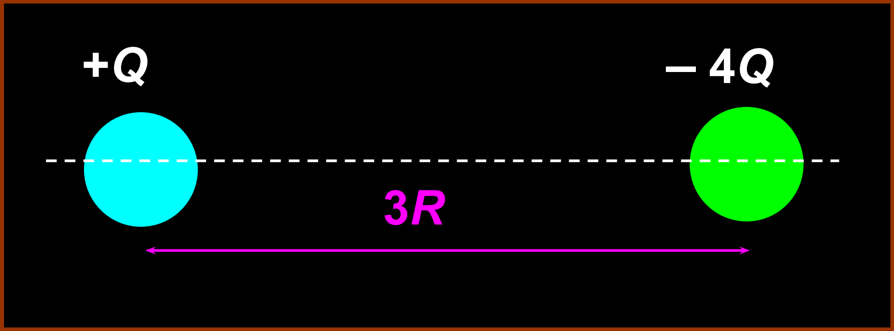
The force on Q_0 due to $+4Q$ is: $F = k(Q_0)(4Q)/(2R)^2$

Since $+4Q$ is 4 times bigger than $+Q$, then Q_0 needs to be farther from $+4Q$. In fact, Q_0 must be twice as far from $+4Q$, since the distance is squared in Coulomb's Law.

11) Electric Force III

Two balls with charges $+Q$ and $-4Q$ are fixed at a separation distance of $3R$. Is it possible to place another charged ball Q_0 *anywhere* on the line such that the net force on Q_0 will be zero?

1) yes, but only if Q_0 is positive
2) yes, but only if Q_0 is negative
3) yes, independent of the sign (or value) of Q_0
4) no, the net force can never be zero



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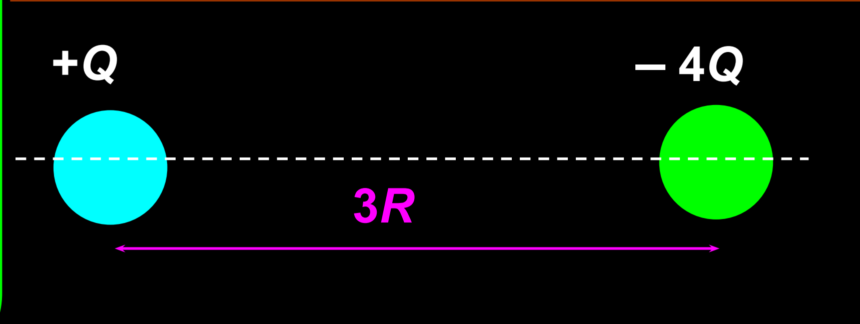
1) yes, but only if Q_0 is positive
2) yes, but only if Q_0 is negative
3) yes, independent of the sign (or value) of Q_0
4) no, the net force can never be zero

A charge (positive or negative) can be placed *to the left* of the $+Q$ charge, such that the repulsive force from the $+Q$ charge cancels the attractive force from $-4Q$.

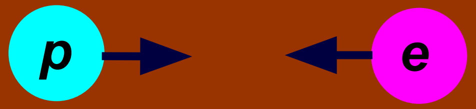


Follow-up: What happens if one charge is $+Q$ and the other is $-Q$?

12) Proton and Electron I

A proton and an electron are held apart a distance of 1 m and then released. As they approach each other, what happens to the force between them?

1) it gets bigger
2) it gets smaller
3) it stays the same

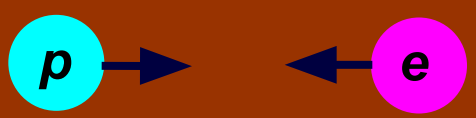


12) Proton and Electron I

A proton and an electron are held apart a distance of 1 m and then released. As they approach each other, what happens to the force between them?

1) it gets bigger
2) it gets smaller
3) it stays the same

By Coulomb's Law, the **force between the two charges is inversely proportional to the distance squared**. So, the closer they get to each other, the bigger the electric force between them gets!



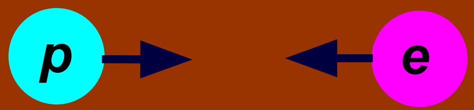
$$F = k\frac{Q_1 Q_2}{r^2}$$

Follow-up: Which particle feels the larger force at any one moment?

13) Proton and Electron II

A proton and an electron are held apart a distance of 1 m and then released. Which particle has the larger acceleration at any one moment?

1) proton
2) electron
3) both the same



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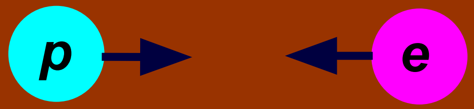
1) proton
2) electron
3) both the same



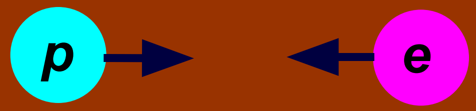
The two particles feel the same force. Since $F = ma$, the particle with the smaller mass will have the larger acceleration. This would be the electron.

$$F = k\frac{Q_1 Q_2}{r^2}$$

14) Proton and Electron III

A proton and an electron are held apart a distance of 1 m and then let go. Where would they meet?

1) in the middle
2) closer to the electron's side
3) closer to the proton's side



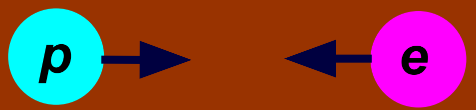
14) Proton and Electron III

A proton and an electron are held apart a distance of 1 m and then let go. Where would they meet?

1) in the middle
2) closer to the electron's side
3) closer to the proton's side

By Newton's 3rd Law, the electron and proton feel the same force. But, since *F* = *ma*, and since the proton's mass is much greater, the proton's acceleration will be much smaller!

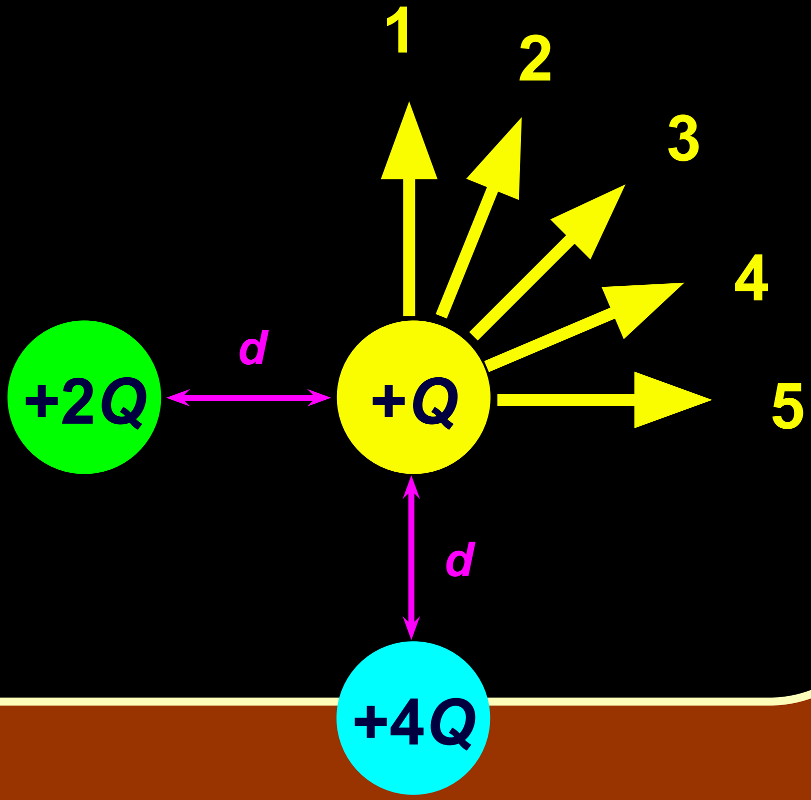
Thus, they will meet closer to the proton's original position.



Follow-up: Which particle will be moving faster when they meet?

15) Forces in 2D

Which of the arrows best represents the direction of the net force on charge +*Q* due to the other two charges?



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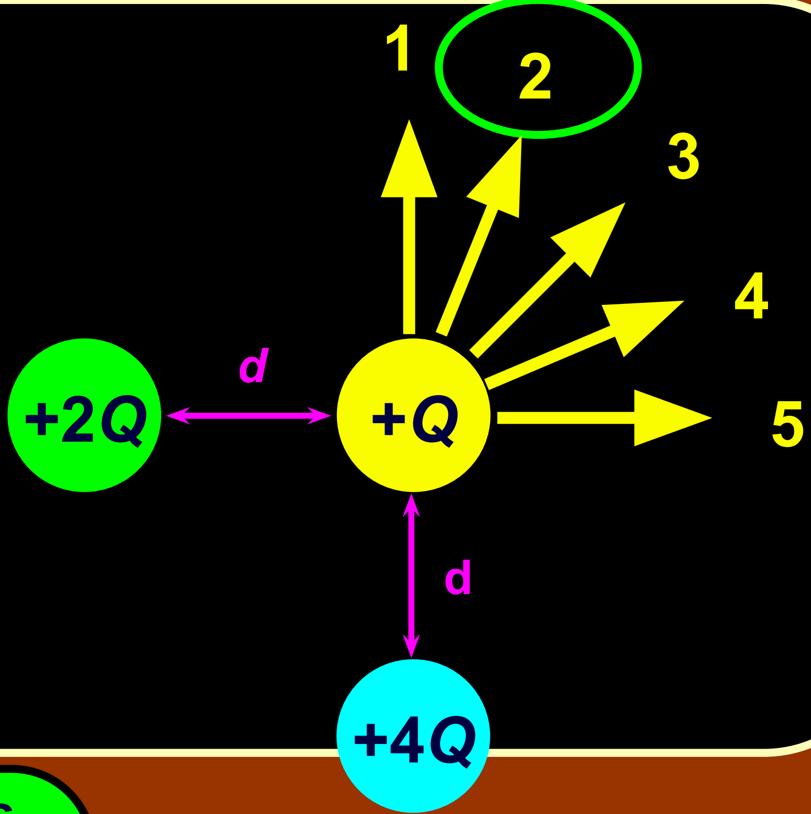
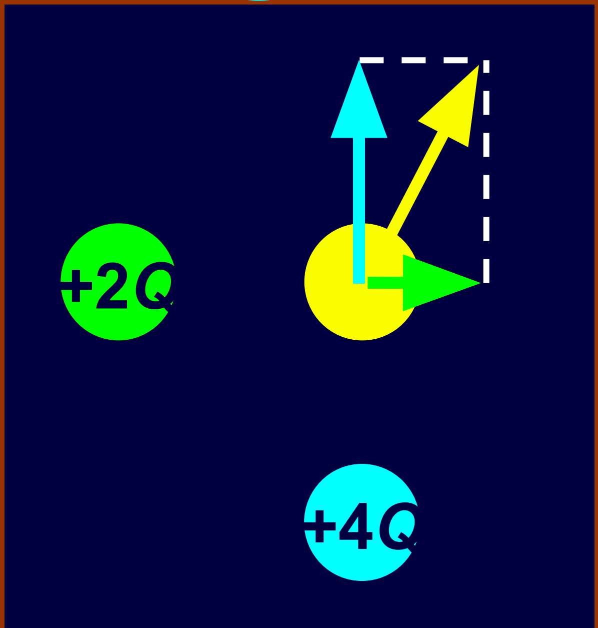


The charge +2*Q* repels +*Q* towards the right. The charge +4*Q* repels +*Q* upwards, but with a stronger force. Therefore, the **net force is up and to the right, but mostly up**.



Follow-up: What happens if the yellow charge would be +3*Q*?

16) Electric Field

You are sitting a certain distance from a point charge, and you measure an electric field of E_0. If the charge is **doubled** and your distance from the charge is also **doubled**, what is the electric field strength now?

(1) $4\ E_0$

(2) $2\ E_0$

(3) E_0

(4) $1/2\ E_0$

(5) $1/4\ E_0$

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(1) $4\ E_0$

(2) $2\ E_0$

(3) E_0

(4) $1/2\ E_0$

(5) $1/4\ E_0$

Remember that the electric field is: $E = kQ/r^2$. Doubling the charge puts a factor of 2 in the numerator, but doubling the distance puts a factor of 4 in the denominator, because it is distance squared!! Overall, that gives us a factor of 1/2.

Follow-up: If your distance is doubled, what must you do to the charge to maintain the same E field at your new position?

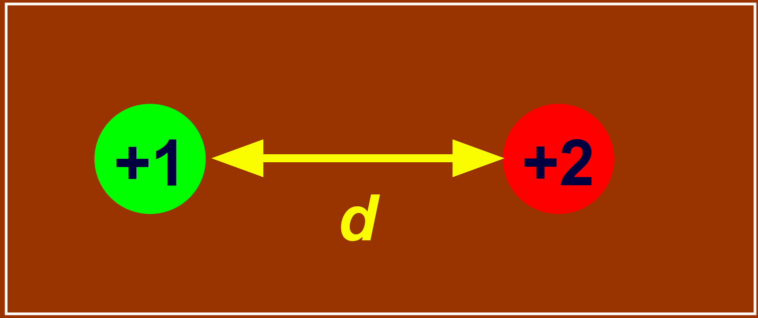
17) Field and Force I

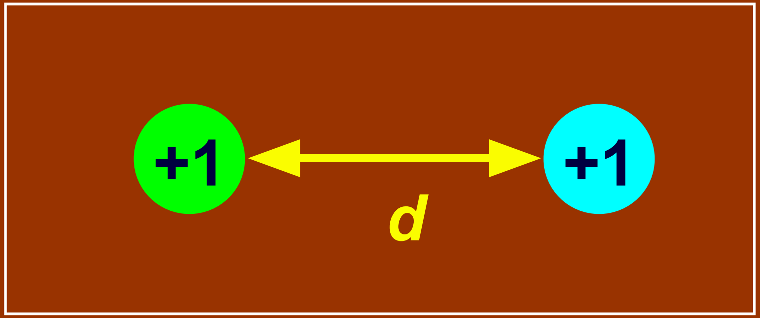
Between the red and the blue charge, which of them experiences the greater *electric field* due to the green charge?

1) +1

2) +2

3) the same for both





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Between the red and the blue charge, which of them experiences the greater *electric field* due to the green charge?

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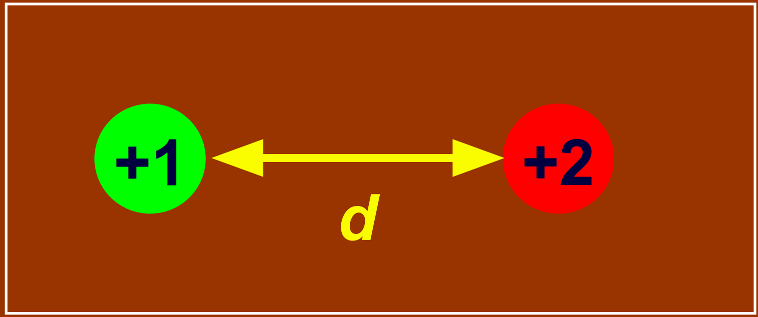
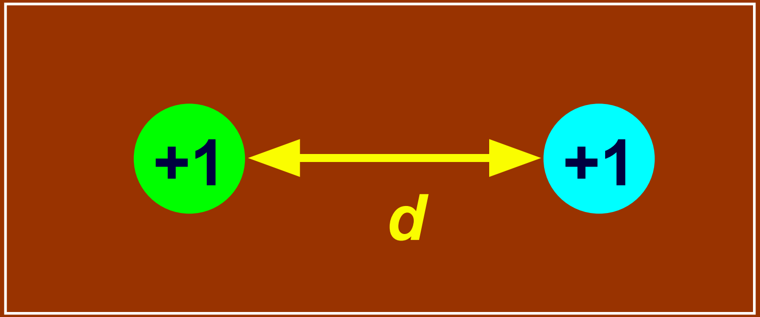




Both charges feel the same electric field due to the green charge because they are at the same point in space!

$$E = k\frac{Q}{r^2}$$

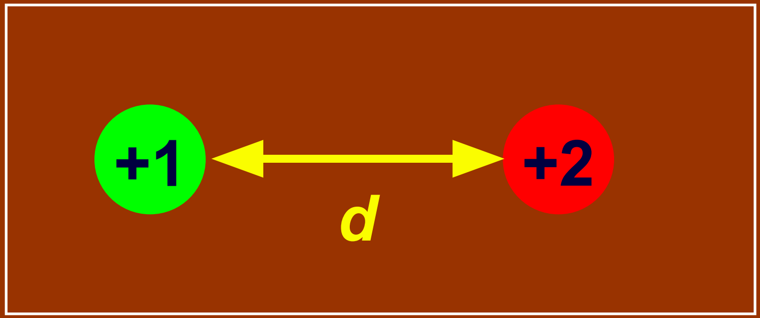
18) Field and Force II

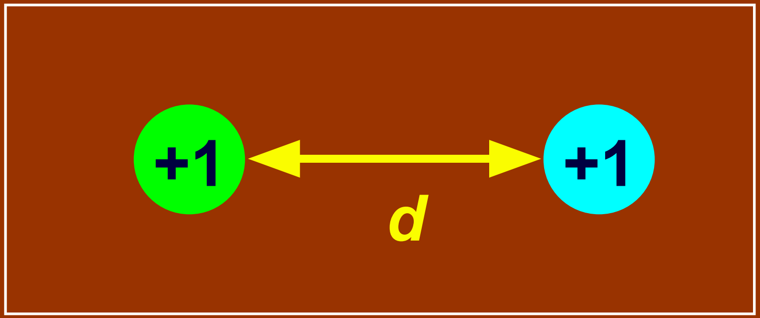
Between the red and the blue charge, which of them experiences the greater ***electric force*** due to the green charge?

1) +1

2) +2

3) the same for both





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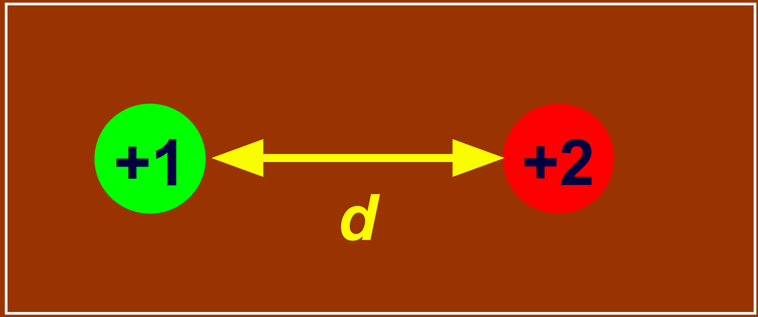
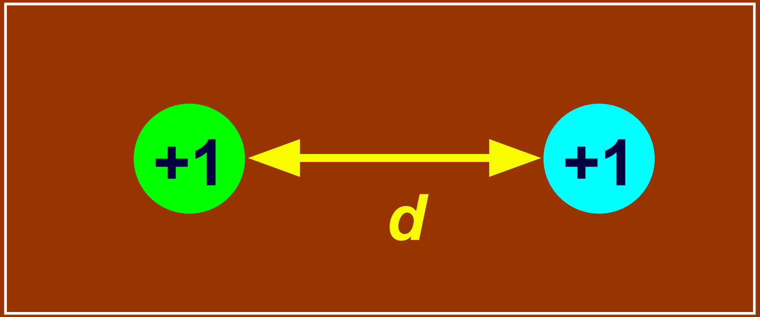
2) +2

3) the same for both



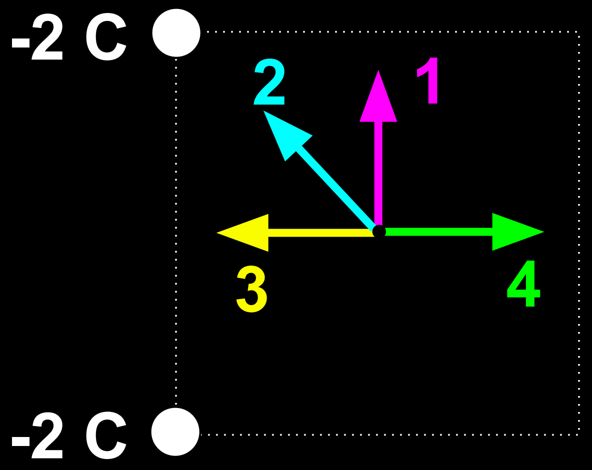


The electric field is the same for both charges, but the force on a given charge also depends on the magnitude of that specific charge.

$$F = qE$$

19) Superposition I

What is the electric field at the center of the square?



5) $E = 0$

19) Superposition I

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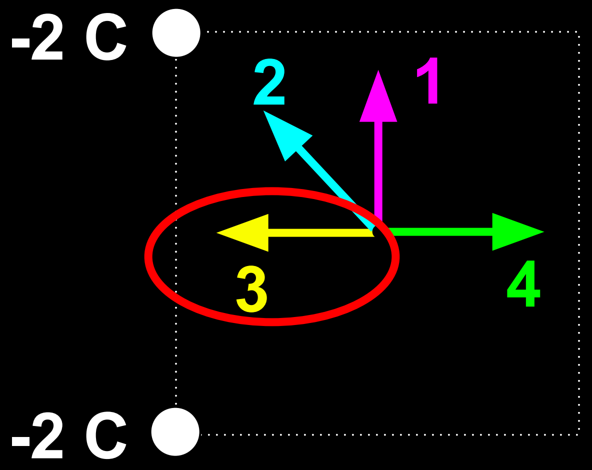


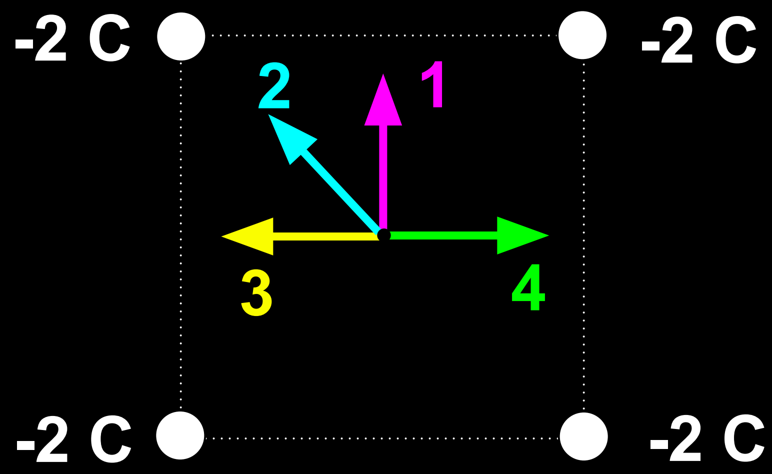
5) $E = 0$

For the upper charge, the *E* field vector at the center of the square points towards that charge. For the lower charge, the same thing is true. Then the vector sum of these two *E* field vectors points to the left.

Follow-up: What if the lower charge was +2 C? What if both charges were +2 C?

20) Superposition II

What is the electric field at the center of the square?



5) $E = 0$

20) Superposition II

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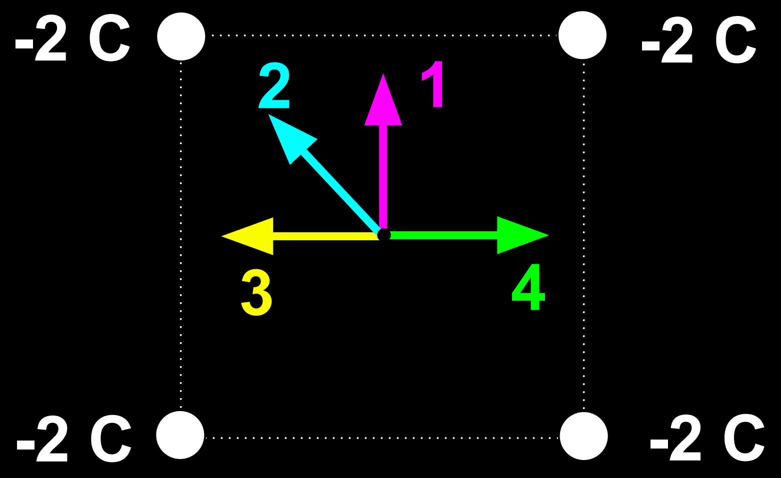


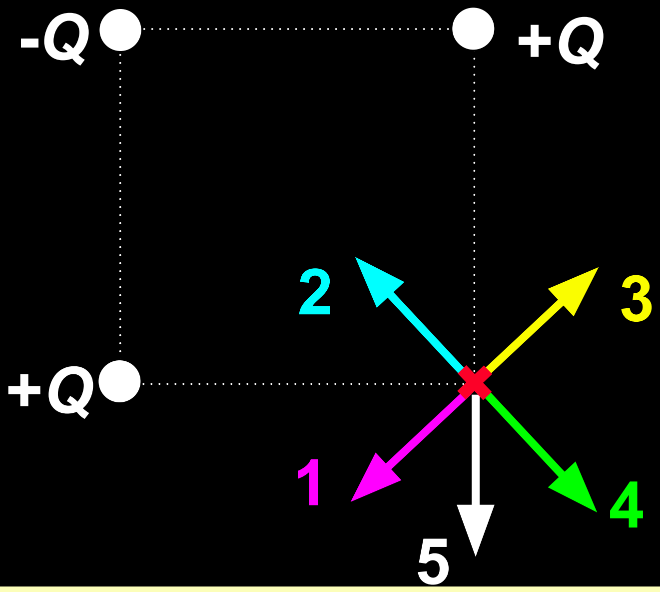
5) $E = 0$

The four *E* field vectors all point outwards from the center of the square toward their respective charges. Because they are all equal, the net *E* field is zero at the center!!

Follow-up: What if the upper two charges were +2 C? What if the right-hand charges were +2 C?

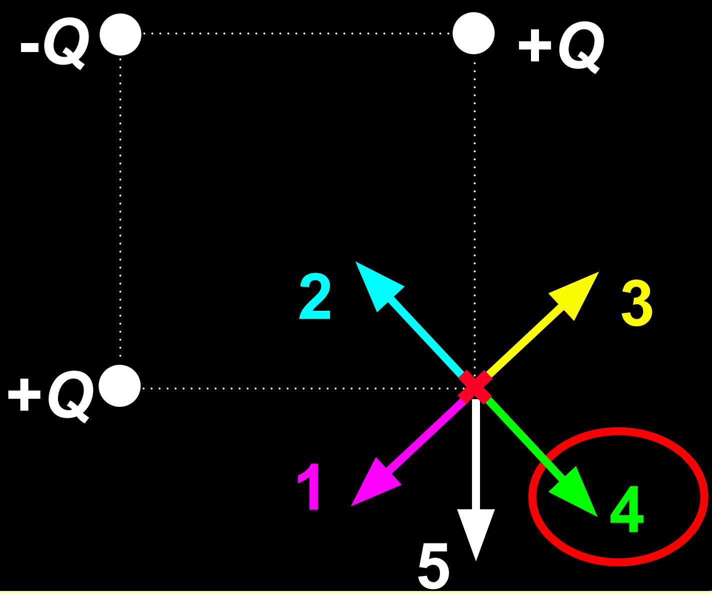
21) Superposition III

What is the direction of the electric field at the position of the *X* ?



21) Superposition III

What is the **direction** of the electric field at the position of the ***X*** ?



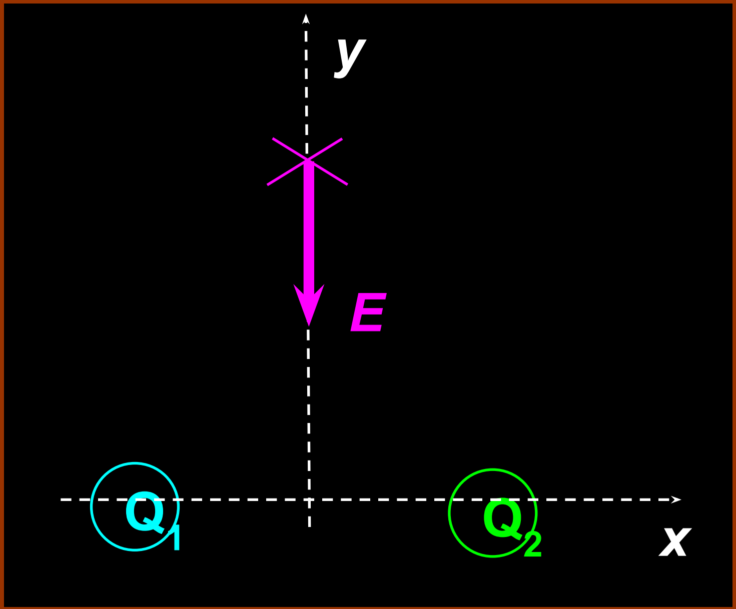
The two +*Q* charges give a resultant *E* field that is **down and to the right**. The –*Q* charge has an *E* field **up and to the left**, but **smaller** in magnitude. Therefore, the **total electric field is down and to the right**.

Follow-up: What if all three charges reversed their signs?

22) Find the Charges

Two charges are fixed along the *x*-axis. They produce an electric field ***E*** directed along the negative *y*-axis at the indicated point. Which of the following is true?

1) charges are equal and positive
2) charges are equal and negative
3) charges are equal and opposite
4) charges are equal, but sign is undetermined
5) charges cannot be equal



22) Find the Charges

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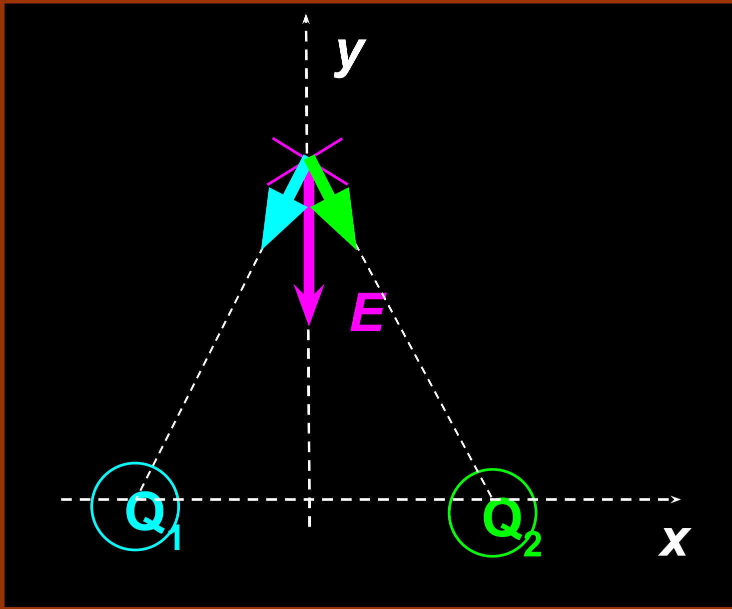
1) charges are equal and positive
2) charges are equal and negative
3) charges are equal and opposite
4) charges are equal, but sign is undetermined
5) charges cannot be equal

The way to get the resultant PINK vector is to use the GREEN and BLUE vectors. These *E* vectors correspond to equal charges (because the lengths are equal) that are both negative (because their directions are toward the charges).

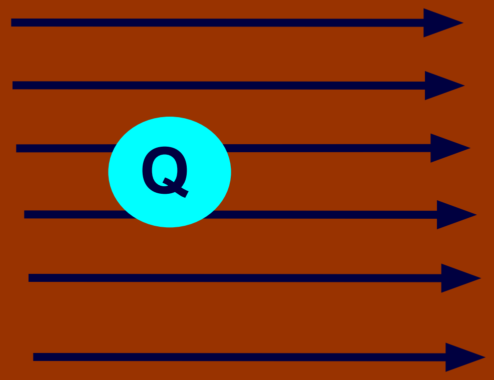


Follow-up: How would you get the *E* field to point toward the right?

23) Uniform Electric Field

In a uniform electric field in empty space, a 4 C charge is placed and it feels an electrical force of 12 N. If this charge is removed and a 6 C charge is placed at that point instead, what force will it feel?

1) 12 N
2) 8 N
3) 24 N
4) no force
5) 18 N



23) Uniform Electric Field

In a uniform electric field in empty space, a 4 C charge is placed and it feels an electrical force of 12 N. If this charge is removed and a 6 C charge is placed at that point instead, what force will it feel?

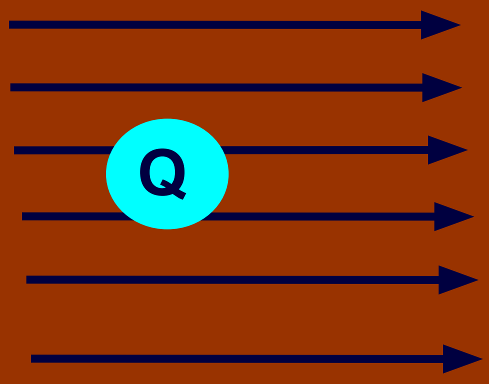
1) 12 N
2) 8 N
3) 24 N
4) no force
5) 18 N

Since the 4 C charge feels a force, there must be an electric field present, with magnitude:

$$E = F / q = 12\ N / 4\ C = 3\ N/C$$

Once the 4 C charge is replaced with a 6 C charge, this new charge will feel a force of:

$$F = q E = (6\ C)(3\ N/C) = 18\ N$$



Follow-up: What if the charge is placed at a *different position* in the field?

24) Electric Field Lines I

What are the signs of the charges whose electric fields are shown at right?

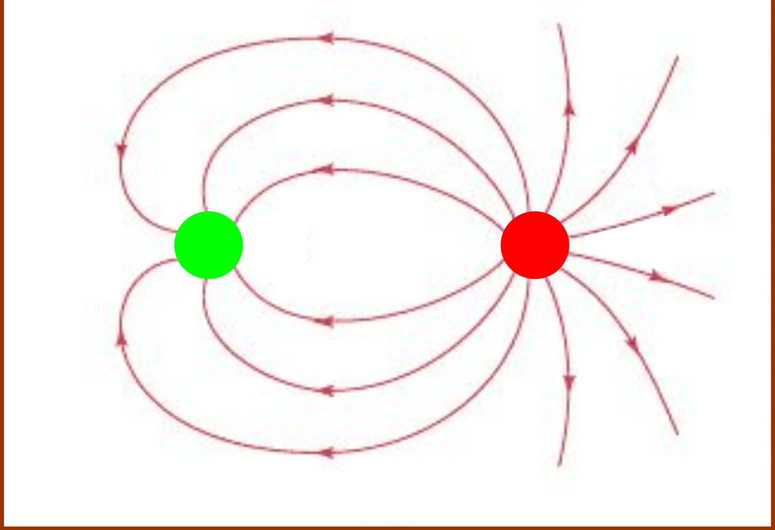
1) + −

2) − +

3) − −

4) + +

5) no way to tell



24) Electric Field Lines I

What are the signs of the charges whose electric fields are shown at right?

1) + −

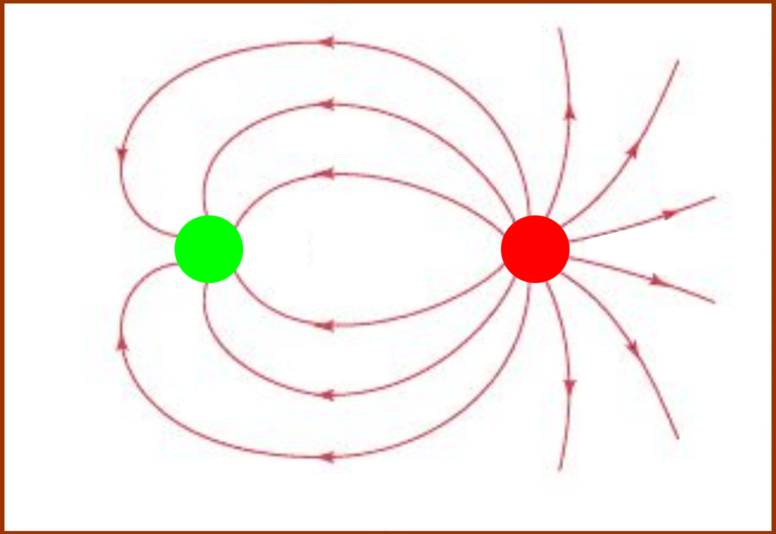
2) − +

3) − −

4) + +

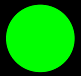
5) no way to tell

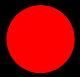
Electric field lines originate on positive charges and terminate on negative charges.



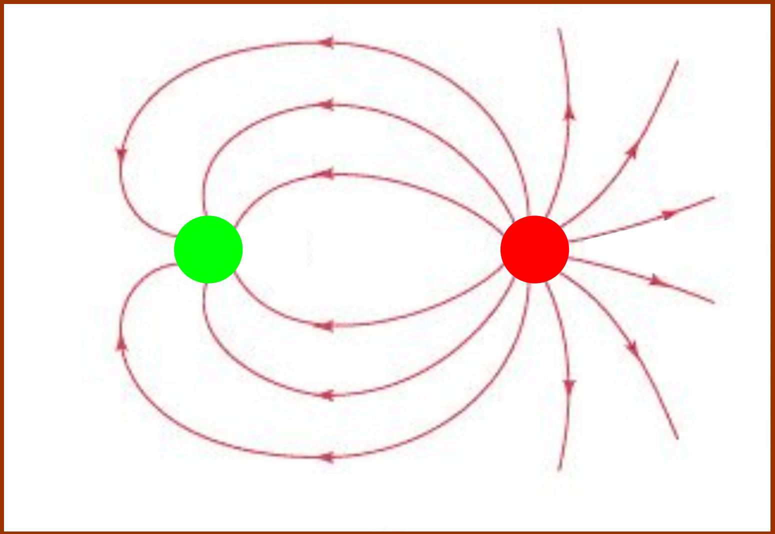
25) Electric Field Lines II

Which of the charges has the greater magnitude?

1) 

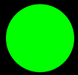
2) 

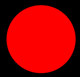
3) Both the same



25) Electric Field Lines II

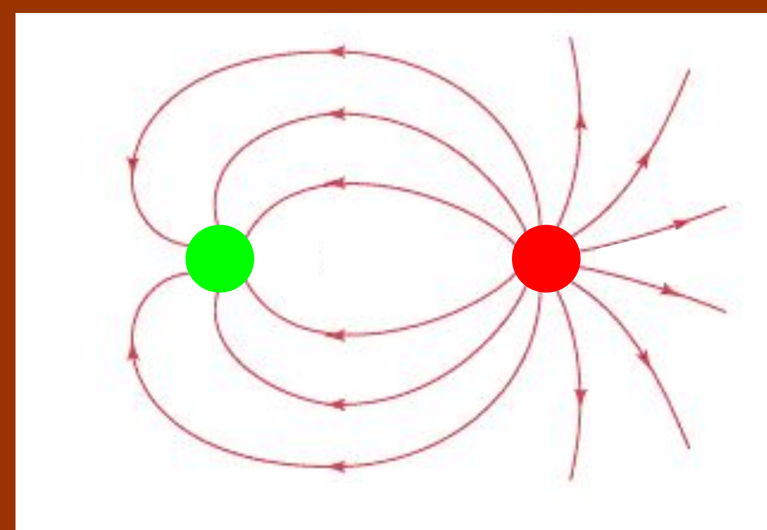
Which of the charges has the greater magnitude?

1) 

2) 

3) Both the same

The field lines are denser around the red charge, so the red one has the greater magnitude.

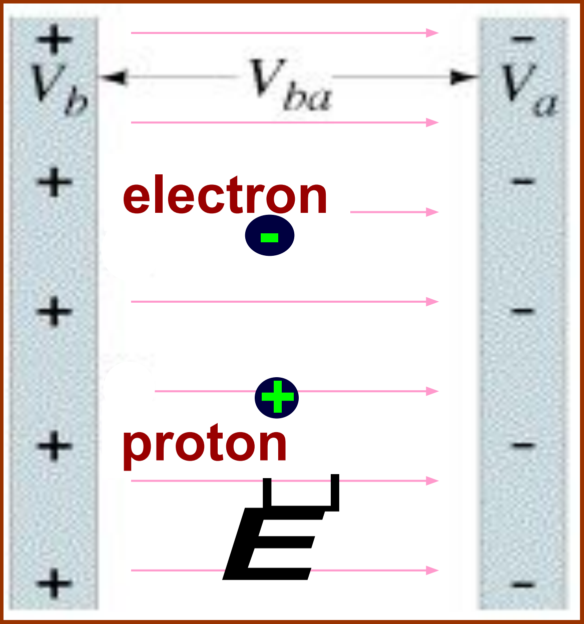


Follow-up: What is the red/green ratio of magnitudes for the two charges?

26) Electric Potential Energy I

A proton and an electron are in a constant electric field created by oppositely charged plates. You release the proton from the positive side and the electron from the negative side. Which feels the larger electric force?

1) proton
2) electron
3) both feel the same force
4) neither – there is no force
5) they feel the same magnitude force but opposite direction

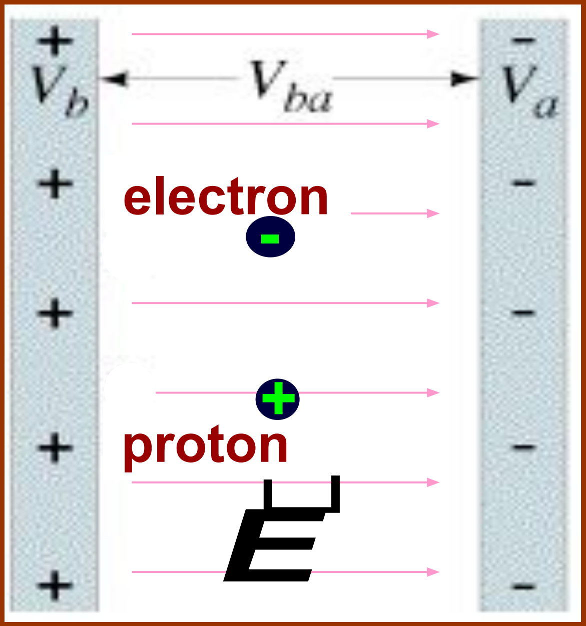


26) Electric Potential Energy I

A proton and an electron are in a constant electric field created by oppositely charged plates. You release the proton from the positive side and the electron from the negative side. Which feels the larger electric force?

1) proton
2) electron
3) both feel the same force
4) neither – there is no force
5) they feel the same magnitude force but opposite direction

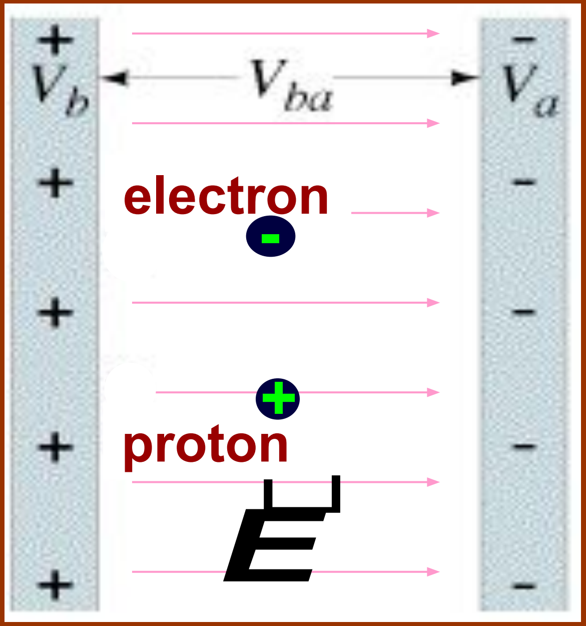
Since $F = qE$ and the proton and electron have the same charge in magnitude, they both experience the same force. However, the forces point in opposite directions because the proton and electron are oppositely charged.



27) Electric Potential Energy II

A proton and an electron are in a constant electric field created by oppositely charged plates. You release the proton from the positive side and the electron from the negative side. Which has the larger acceleration?

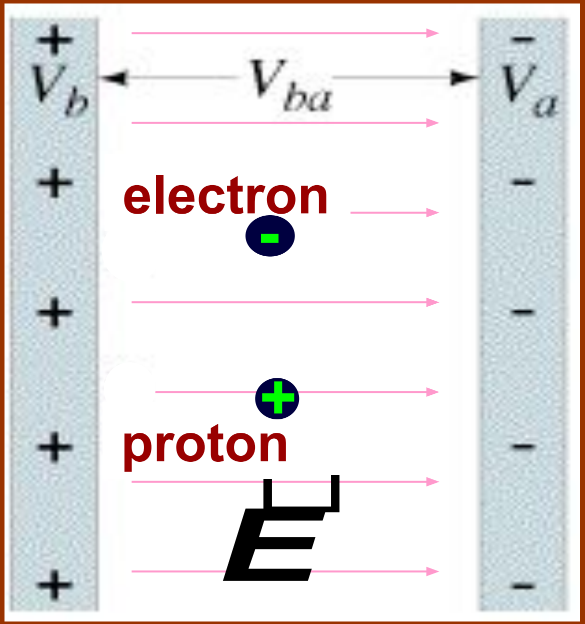
1) proton
2) electron
3) both feel the same acceleration
4) neither – there is no acceleration
5) they feel the same magnitude acceleration but opposite direction



27) Electric Potential Energy II

A proton and an electron are in a constant electric field created by oppositely charged plates. You release the proton from the positive side and the electron from the negative side. Which has the larger acceleration?

1) proton
2) electron
3) both feel the same acceleration
4) neither – there is no acceleration
5) they feel the same magnitude acceleration but opposite direction

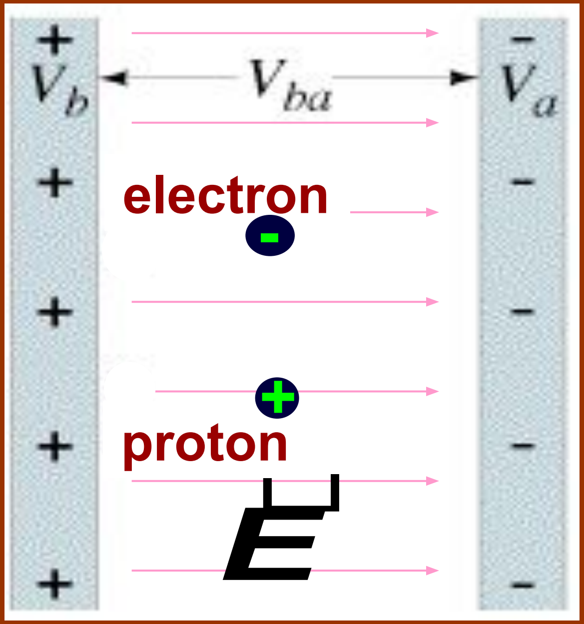


Since $F = ma$ and the electron is much less massive than the proton, then the electron experiences the larger acceleration.

28) Electric Potential Energy III

A proton and an electron are in a constant electric field created by oppositely charged plates. You release the proton from the positive side and the electron from the negative side. When it strikes the opposite plate, which one has more KE?

1) proton
2) electron
3) both acquire the same KE
4) neither – there is no change of KE
5) they both acquire the same KE but with opposite signs

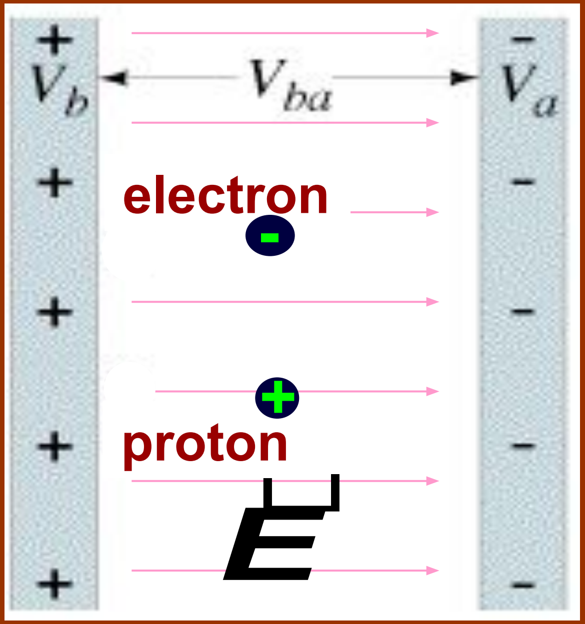


28) Electric Potential Energy III

A proton and an electron are in a constant electric field created by oppositely charged plates. You release the proton from the positive side and the electron from the negative side. When it strikes the opposite plate, which one has more KE?

1) proton
2) electron
3) both acquire the same KE
4) neither – there is no change of KE
5) they both acquire the same KE but with opposite signs

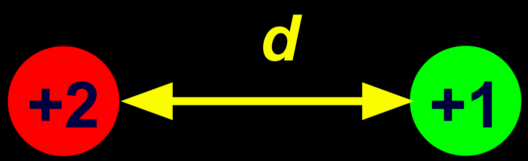
Since PE = qV and the proton and electron have the same charge in magnitude, they both have the same electric potential energy initially. Because energy is conserved, they both must have the same kinetic energy after they reach the opposite plate.



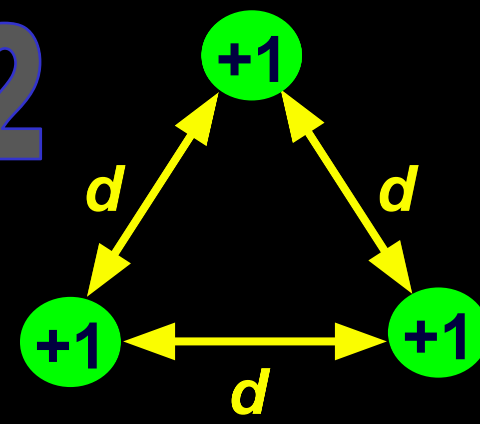
29) Work and Potential Energy

Which group of charges took *more work* to bring together from a very large initial distance apart?

1



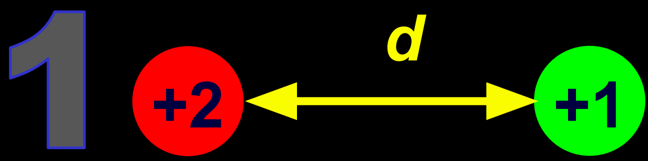
2

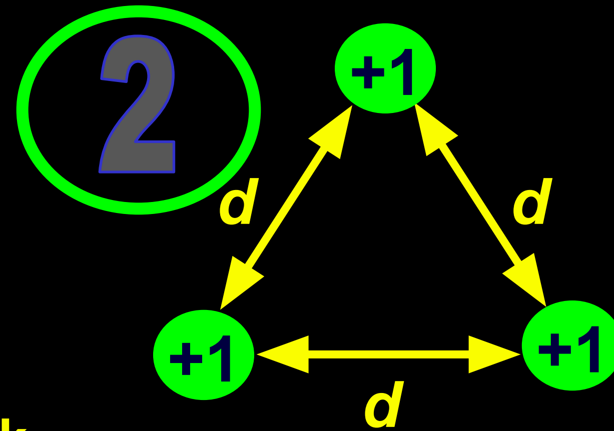


3 Both took the same amount of work

29) Work and Potential Energy

Which group of charges took ***more work*** to bring together from a very large initial distance apart?





3 Both took the same amount of work

The work needed to assemble a collection of charges is the same as the **total PE** of those charges:

$$PE = k\frac{Q_1 Q_2}{r}$$

added over all pairs

For case 1: only 1 pair

$$PE = k\frac{(+2)(+1)}{d} = k\frac{2}{d}$$

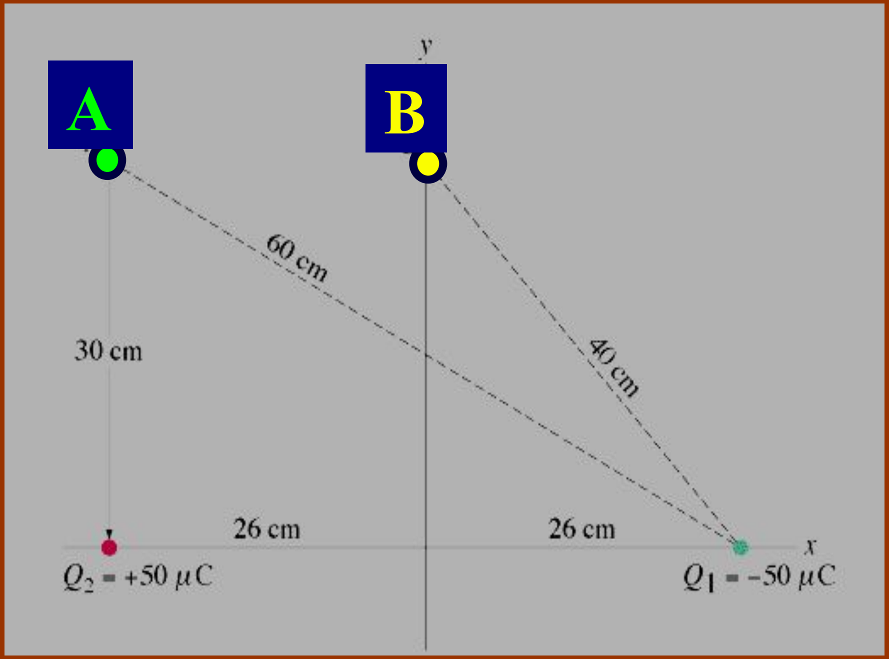
For case 2: there are 3 pairs

$$PE = 3k\frac{(+1)(+1)}{d} = 3k\frac{1}{d}$$

30) Electric Potential I

What is the electric potential at point A?

1) $V > 0$
2) $V = 0$
3) $V < 0$

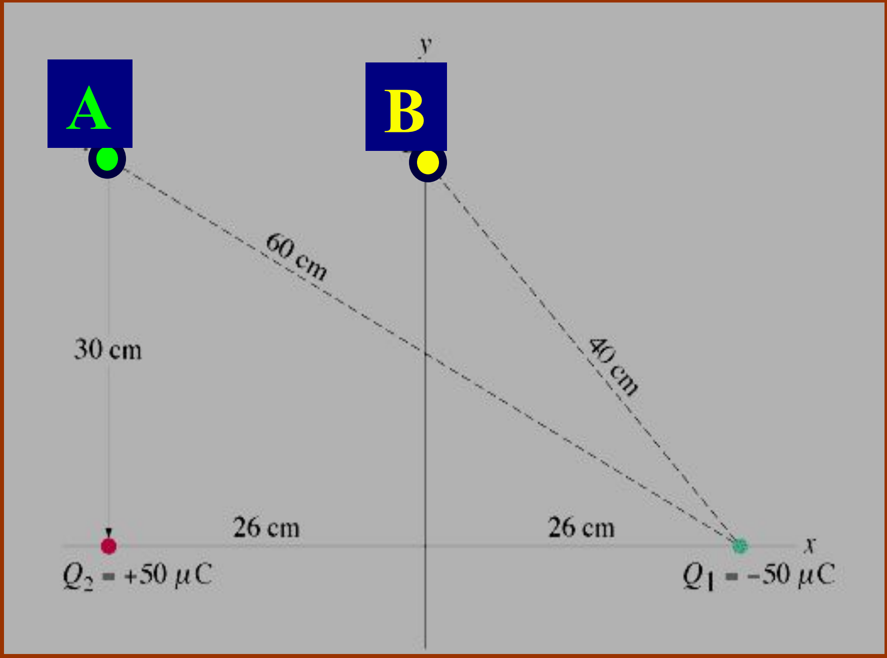


30) Electric Potential I

What is the electric potential at point A?

1) $V > 0$
2) $V = 0$
3) $V < 0$

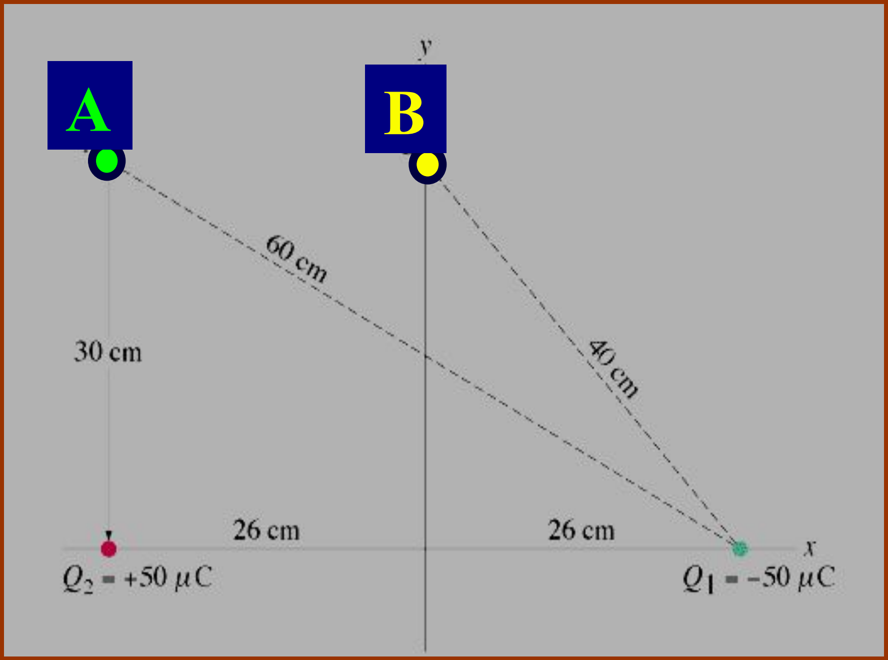
Since Q_2 (which is positive) is closer to point A than Q_1 (which is negative) and since the total potential is equal to $V_1 + V_2$, then the total potential is positive.



31) Electric Potential II

What is the electric potential at point B?

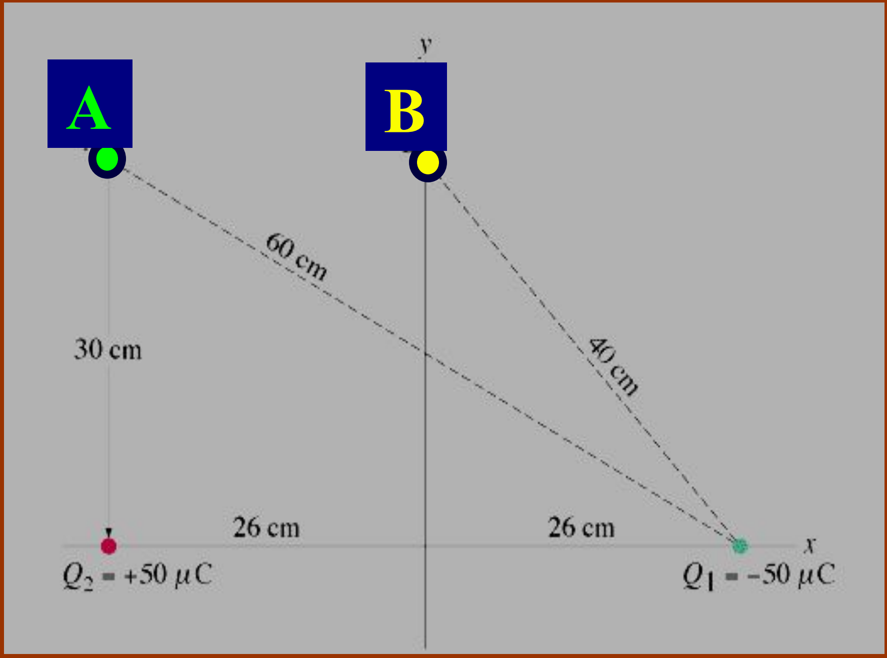
1) $V > 0$
2) $V = 0$
3) $V < 0$



31) Electric Potential II

What is the electric potential at point B?

1) $V > 0$
2) $V = 0$
3) $V < 0$



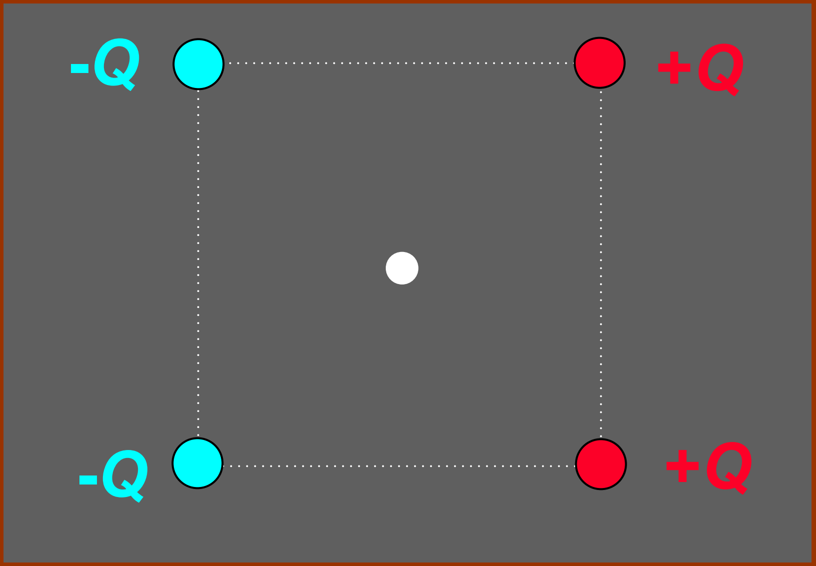
Since Q_2 and Q_1 are equidistant from point B, and since they have equal and opposite charges, then the total potential is zero.

Follow-up: What is the potential at the origin of the *x-y* axes?

32) Hollywood Square

Four point charges are arranged at the corners of a square. Find the **electric field E** and the **potential V** at the **center of the square**.

1) $E = 0$ $V = 0$
2) $E = 0$ $V \neq 0$
3) $E \neq 0$ $V \neq 0$
4) $E \neq 0$ $V = 0$
5) $E = V$ regardless of the value



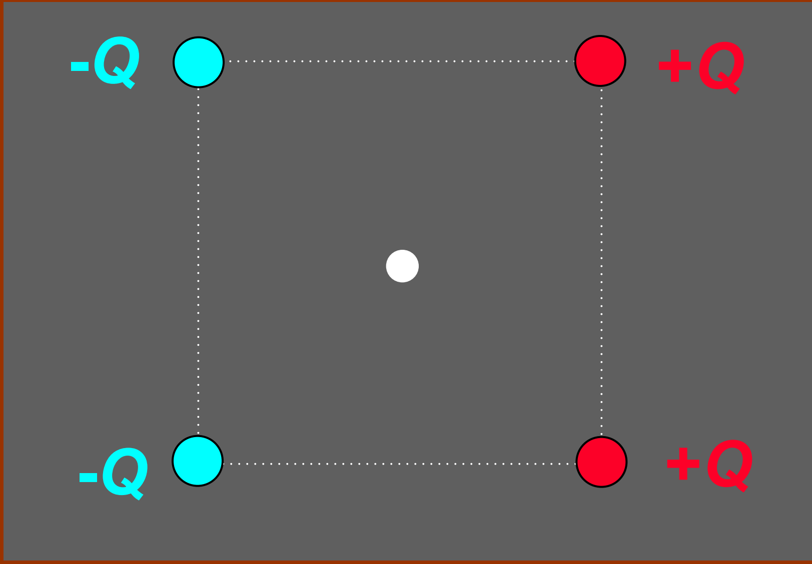
32) Hollywood Square

Four point charges are arranged at the corners of a square. Find the **electric field *E*** and the **potential *V*** at the **center of the square**.

1) $E = 0 \quad V = 0$
2) $E = 0 \quad V \neq 0$
3) $E \neq 0 \quad V \neq 0$
4) $E \neq 0 \quad V = 0$
5) $E = V$ regardless of the value

The **potential is zero**: the scalar contributions from the two positive charges cancel the two minus charges.

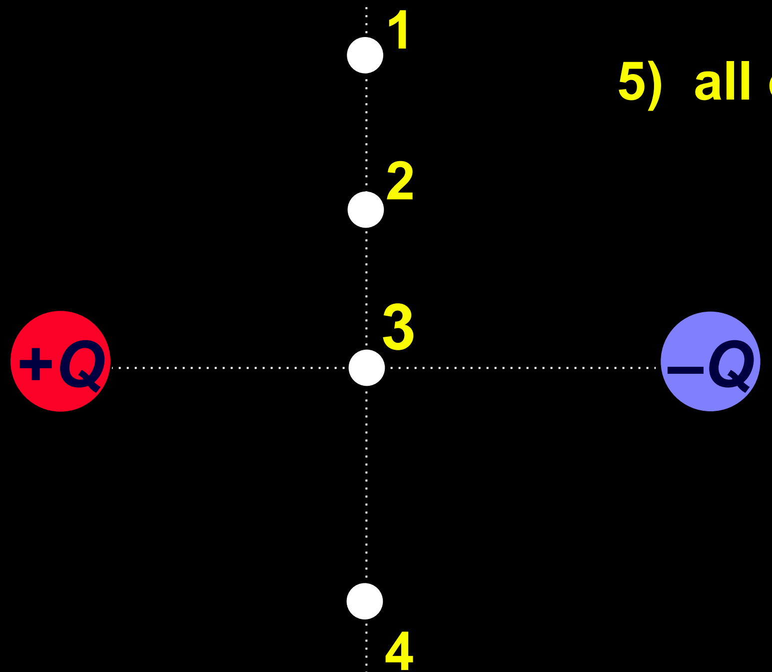
However, the contributions from the electric field add up as vectors, and they do not cancel (so **it is non-zero**).



Follow-up: What is the direction of the electric field at the center?

33) Equipotential Surfaces I

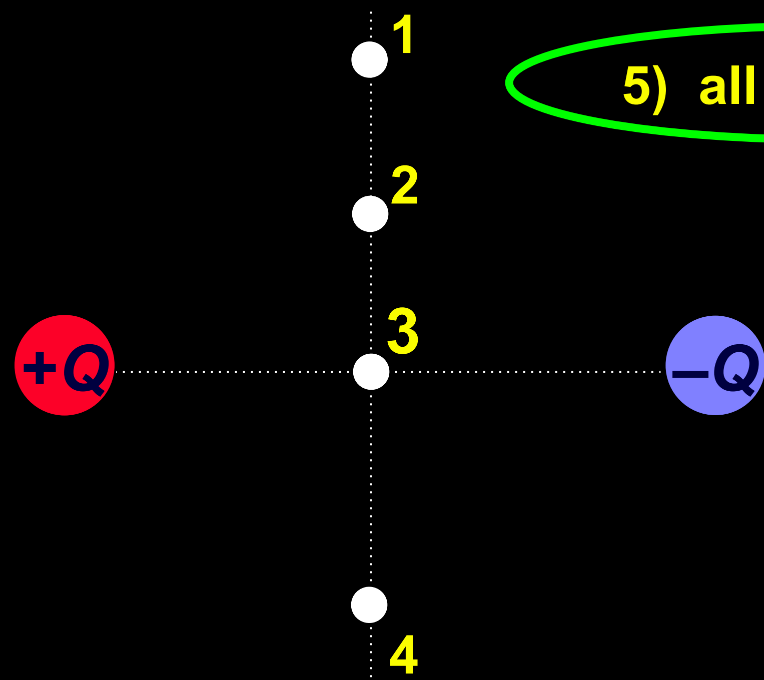
At which point does $V = 0$?



5) all of them

33) Equipotential Surfaces I

At which point does $V = 0$?



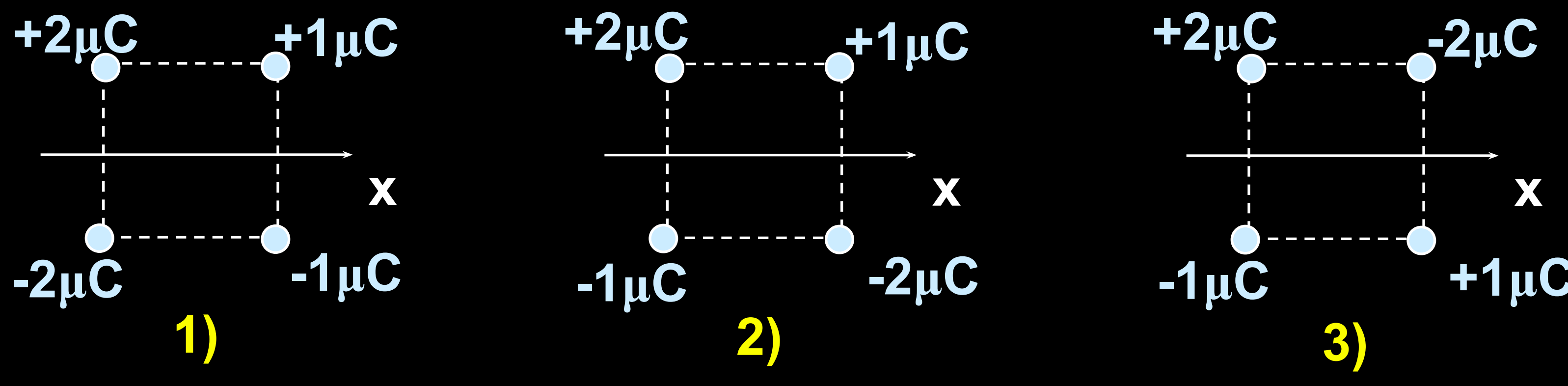
5) all of them

All of the points are equidistant from both charges. Since the charges are equal and opposite, their contributions to the potential cancel out everywhere along the mid-plane between the charges.

Follow-up: What is the direction of the electric field at all 4 points?

34) Equipotential Surfaces II

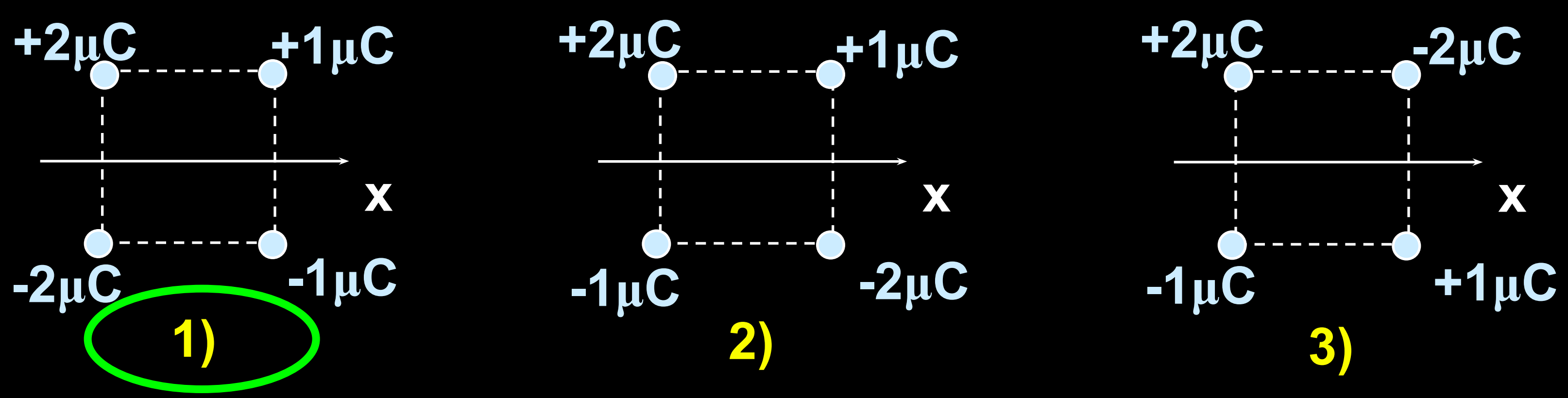
Which of these configurations gives $V = 0$ at all points on the x-axis?



4) all of the above   5) none of the above

34) Equipotential Surfaces II

Which of these configurations gives $V = 0$ at all points on the x-axis?

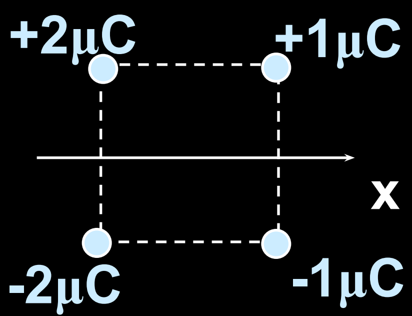


4) all of the above 5) none of the above

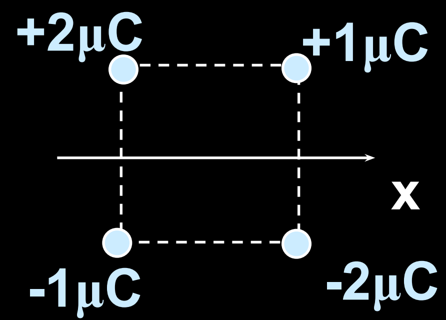
Only in case (1), where opposite charges lie directly across the *x*-axis from each other, do the potentials from the two charges above the *x*-axis cancel the ones below the *x*-axis.

35) Equipotential Surfaces III

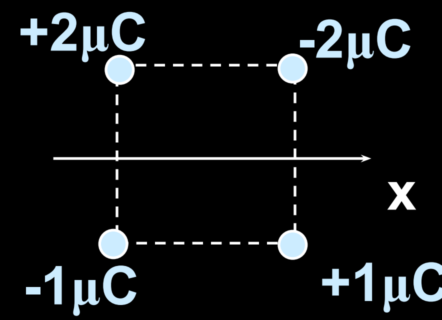
Which of these configurations gives *V* = 0 at all points on the *y*-axis?



1)



2)

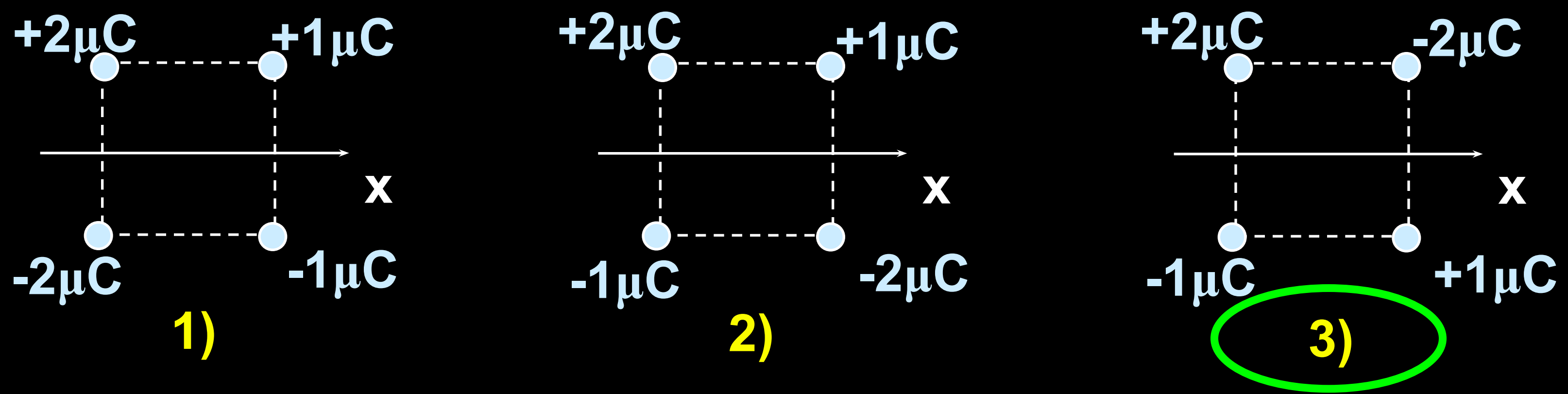


3)

4) all of the above   5) none of the above

35) Equipotential Surfaces III

Which of these configurations gives $V = 0$ at all points on the *y*-axis?



4) all of the above **5) none of the above**

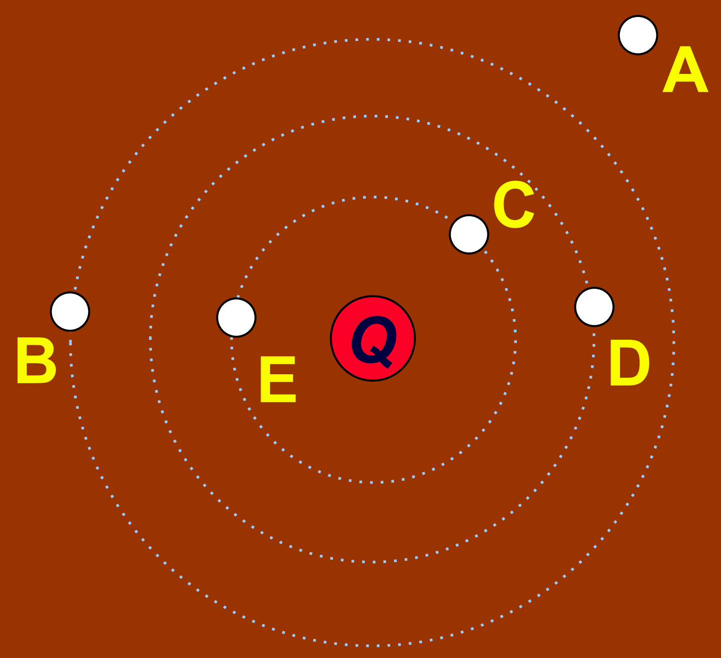
Only in case (3), where opposite charges lie directly across the *y*-axis from each other, do the potentials from the two charges above the *y*-axis cancel the ones below the *y*-axis.

Follow-up: Where is $V = 0$ for configuration #2?

36) Equipotential of Point Charge

Which two points have the **same** potential?

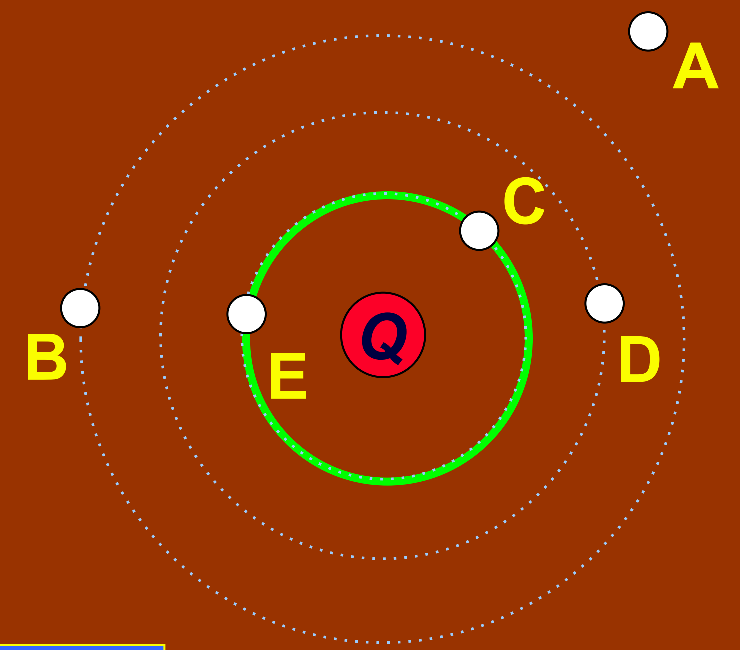
1) A and C
2) B and E
3) B and D
4) C and E
5) no pair



36) Equipotential of Point Charge

Which two points have the same potential?

1) A and C
2) B and E
3) B and D
4) C and E
5) no pair



Since the potential of a point charge is:

$$V = k\frac{Q}{r}$$

only points that are at the same distance from charge Q are at the same potential. This is true for points C and E.

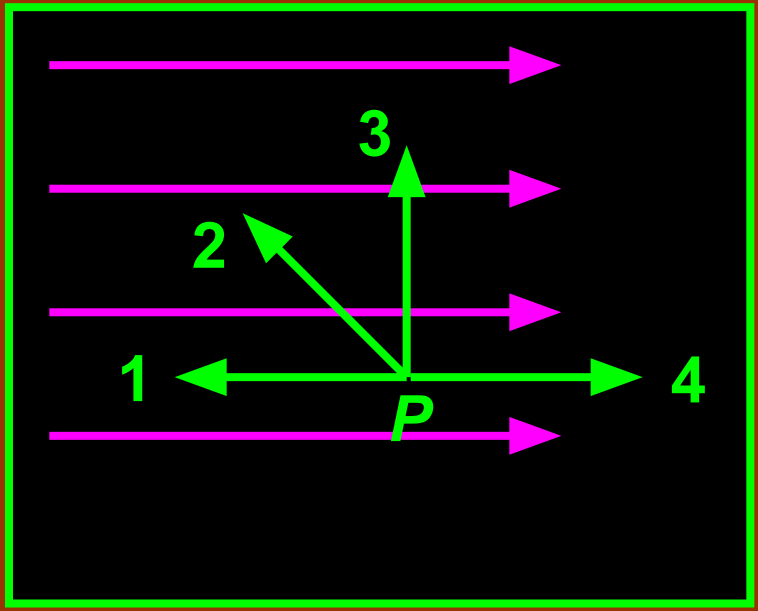
They lie on an *Equipotential Surface*.

Follow-up: Which point has the smallest potential?

37) Work and Electric Potential I

Which requires the *most work*, to move a positive charge from *P* to points 1, 2, 3 or 4 ? All points are the same distance from *P*.

1) $P \rightarrow 1$
2) $P \rightarrow 2$
3) $P \rightarrow 3$
4) $P \rightarrow 4$
5) all require the same amount of work

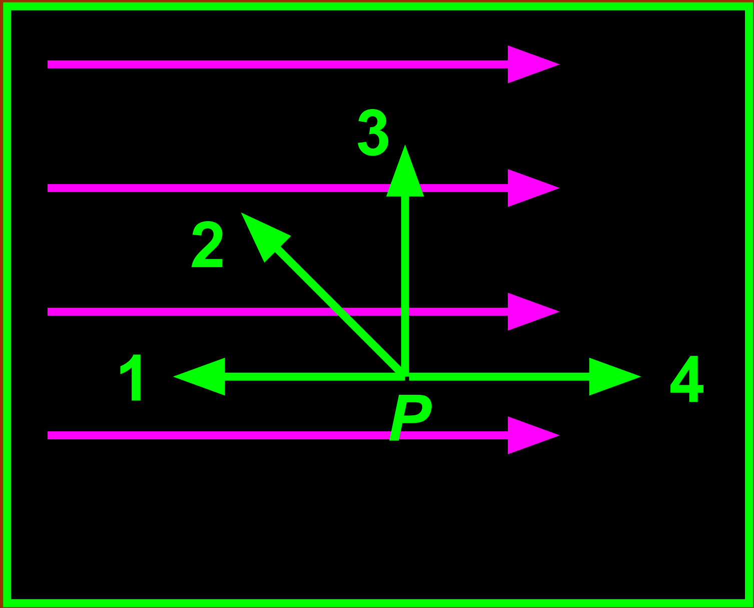


37) Work and Electric Potential I

Which requires the ***most work***, to move a **positive** charge from *P* to points 1, 2, 3 or 4 ? All points are the same distance from *P*.

1) *P* → 1
2) *P* → 2
3) *P* → 3
4) *P* → 4
5) all require the same amount of work

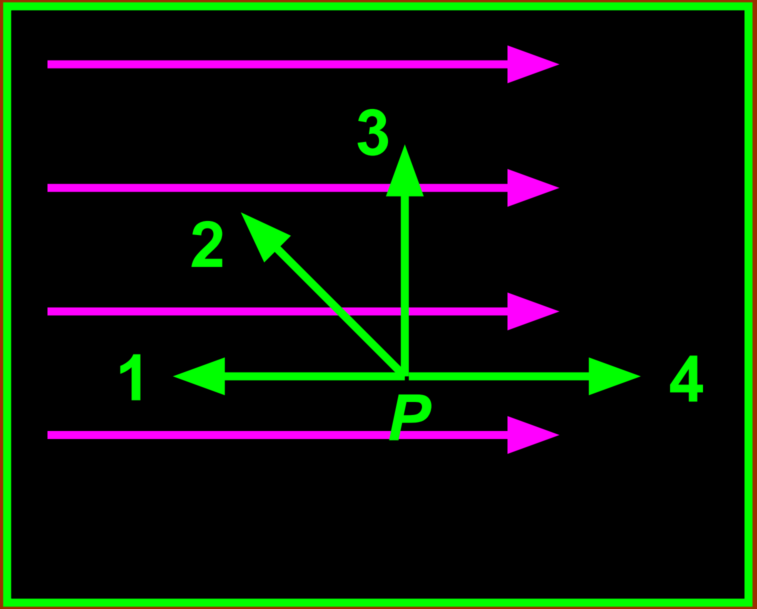
For **path #1**, you have to push the positive charge ***against*** the *E* field, which is **hard to do**. By contrast, path #4 is the easiest, since the field does all the work.



38) Work and Electric Potential II

Which requires *zero work*, to move a positive charge from *P* to points 1, 2, 3 or 4 ? All points are the same distance from *P*.

1) $P \rightarrow 1$
2) $P \rightarrow 2$
3) $P \rightarrow 3$
4) $P \rightarrow 4$
5) all require the same amount of work

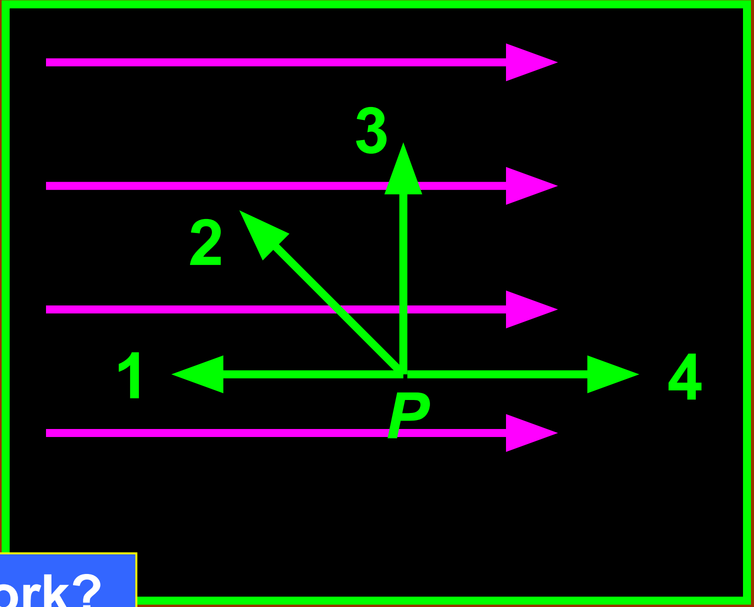


38) Work and Electric Potential II

Which requires *zero work*, to move a positive charge from *P* to points 1, 2, 3 or 4 ? All points are the same distance from *P*.

1) $P \rightarrow 1$
2) $P \rightarrow 2$
3) $P \rightarrow 3$
4) $P \rightarrow 4$
5) all require the same amount of work

For path #3, you are moving in a direction perpendicular to the field lines. This means you are moving along an equipotential, which requires no work (by definition).



Follow-up: Which path requires the least work?