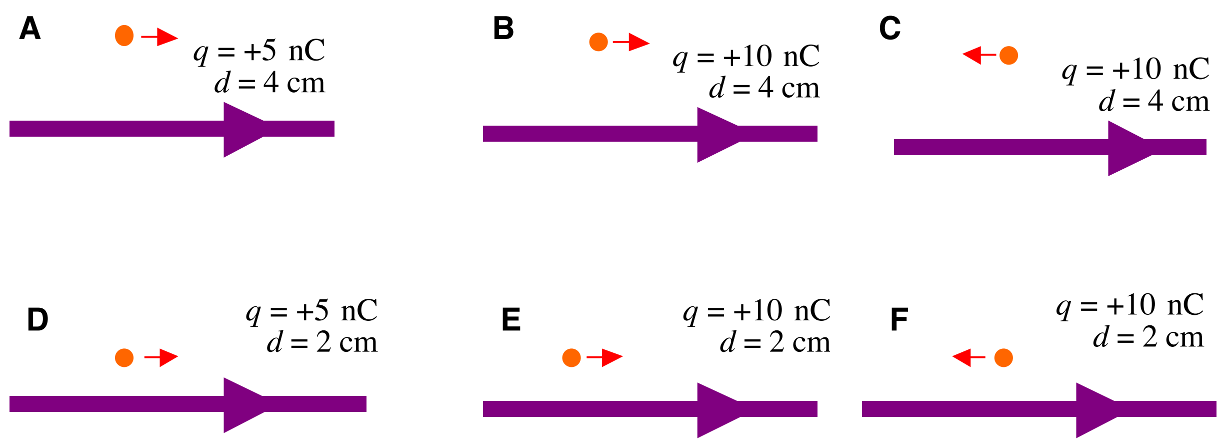
MFF 3A: CHARGED PARTICLE AND A STRAIGHT CURRENT-CARRYING WIRE

MFF3a–RT1: Charged Particle and a Straight Current-Carrying Wire

The figures below show six charged particles that have been placed near identical current-carrying wires. These particles have the same mass, and they were all given the same initial speed at the points where they are shown. However, the charges on the particles and the distances from the wires vary.

Rank these situations from greatest to least on the basis of the strength (magnitude) of the acceleration that each charge is experiencing.



Greatest 1 __*EF*__ 2 ______ 3 __*BCD*_ 4 ______ 5 ______ 6 ___*A*__ Least

Or, the acceleration is the same for all six situations. ______

Or, the ranking for the accelerations cannot be determined. ______

Please carefully explain your reasoning.

Based on three ideas: first, the magnetic field generated by a long, straight wire; second, the magnetic force on a particle in a magnetic field; and third, the acceleration on a mass object. This leads to

$$a = (qv\mu_o I) / (2\pi dm)$$

Thus, $a \propto q / d$

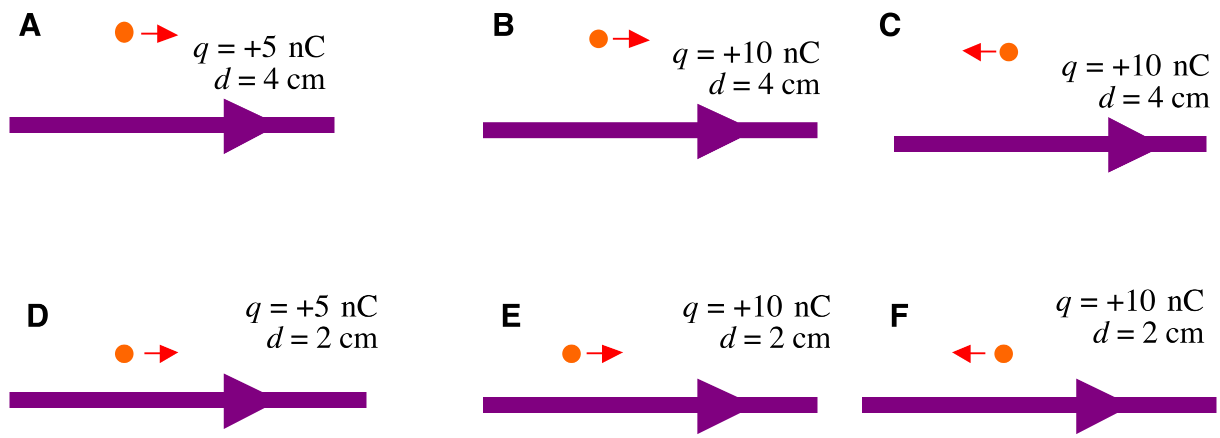
How sure were you of your ranking? (circle one)

Basically Guessed				Sure					Very Sure
1	2	3	4	5	6	7	8	9	10

MFF3A–RT2: CHARGED PARTICLE AND A STRAIGHT CURRENT-CARRYING WIRE

The figures below show six charged particles that have been placed near identical current-carrying wires. These particles have the same mass, and they were all given the same initial speed at the points where they are shown. However, the charges on the particles and the distances from the wires vary.

Rank these situations from greatest to least on the basis of the strength (magnitude) of the force on each charge.



Greatest 1 __*EF*__ 2 ______ 3 __*BCD*_ 4 ______ 5 ______ 6 ___*A*__ Least

Or, the force is the same for all six situations. ______

Or, the ranking for the forces cannot be determined. ______

Please carefully explain your reasoning.

Based on two ideas: first, the magnetic field generated by a long, straight wire; and second, the magnetic force on a particle in a magnetic field. This leads to

$$F = (qv\mu_o I) / (2\pi d)$$

Thus, $F \propto q / d$

How sure were you of your ranking? (circle one)

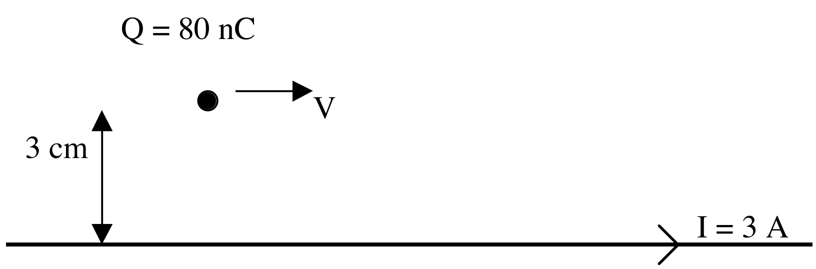
Basically Guessed				Sure					Very Sure
1	2	3	4	5	6	7	8	9	10

MFF3A–WBT1: CHARGED PARTICLE AND A STRAIGHT CURRENT-CARRYING WIRE

Draw and describe a physical arrangement to which the equation below could apply.

$$F = \frac{\mu_o\left(8.00\times10^{-8}C\right)\left(640\text{ m/s}\right)\left(3A\right)}{\left(3.00\times10^{-2}m\right)\left(2\pi\right)}$$

One possible solution is a positively charged particle (of charge 80 nC) traveling at 640 m/s parallel to a long, straight, current-carrying wire (of 3 A). The particle is 3 cm from the wire traveling parallel to the wire. This calculation is for the magnitude of the magnetic force felt by the particle due to the wire.



MFF3a–CCT1: Charged Particle and a Straight Current-Carrying Wire

Consider the following statements made by three students.

***Student I:* "When an electric charge moves near a long straight wire that is carrying a current, there is no acceleration if the charge is moving perpendicular to the wire."**

***Student II:* "When an electric charge moves near a long straight wire that is carrying a current, there is an acceleration when the charge moves perpendicular toward, or away from, or parallel to the wire."**

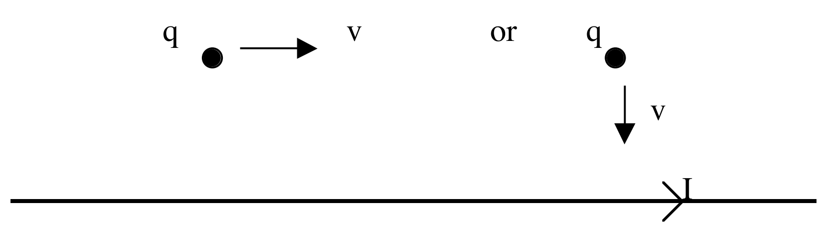
***Student III:* "When an electric charge moves near a long straight wire that is carrying a current, there is no acceleration if the charge is moving parallel to the wire."**

Which, if any, of these three students do you believe is correct?

Student I _______ Student II __*X*___ Student III _______ None of them _______

Explain fully why you chose as you did.

Student II's statement is correct. If the particle is moving parallel or perpendicular to the wire (as shown in the figure below), it will feel a magnetic force and hence an acceleration.
[Note: if the particle is moving relative to the wire in any direction (other than a circle about the wire), it will feel a magnetic force due to the current-carrying wire.]



MFF3A–CCT2: CHARGED PARTICLE AND A STRAIGHT CURRENT-CARRYING WIRE

Consider the following statements made by three students.

***Student I:** "When an electric charge moves near a long straight wire that is carrying a current, there is no force if the charge is moving perpendicular to the wire."*

***Student II:** "When an electric charge moves near a long straight wire that is carrying a current, there is a force when the charge moves perpendicular toward, or away from, or parallel to the wire."*

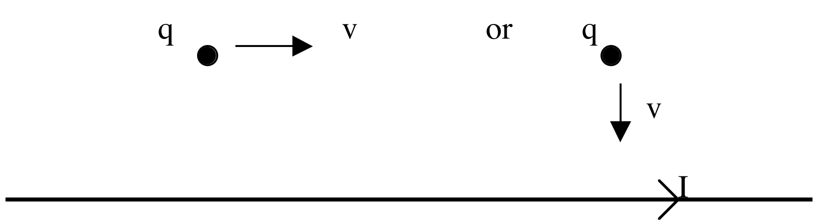
***Student III:** "When an electric charge moves near a long straight wire that is carrying a current, there is no force if the charge is moving parallel to the wire."*

Which, if any, of these three students do you believe is correct?

Student I _______ Student II ___*X*___ Student III _______ None of them _______

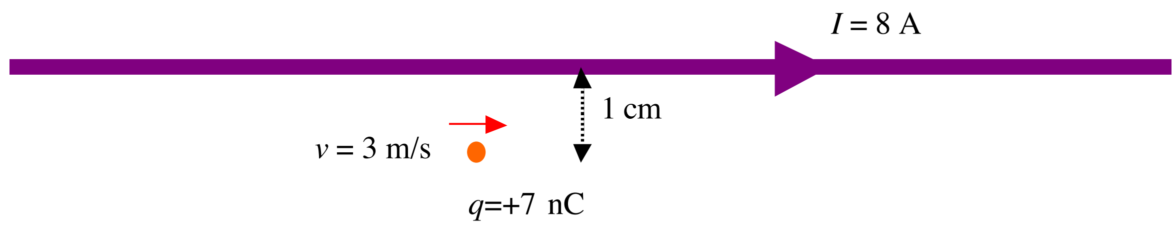
Explain fully why you chose as you did.

Student II's statement is correct. If the particle is moving parallel or perpendicular to the wire (as shown in the figure below), it will feel a magnetic force. [Note: if the particle is moving relative to the wire in any direction (other than a circle about the wire), it will feel a magnetic force due to the current-carrying wire.]



MFF3a–WWT1: Charged Particle and a Straight Current-Carrying Wire

As shown in the figure below, a particle with a net electric charge of +7 nC is initially located a distance of 1 cm from a long straight wire that is carrying a current of 8 A. The charge has a mass of 6×10^{-6} kg, and it is moving initially at 3 m/s parallel to the wire.



"***The force on the charged particle by the magnetic field is zero because the velocity is parallel to the current in the wire.***"

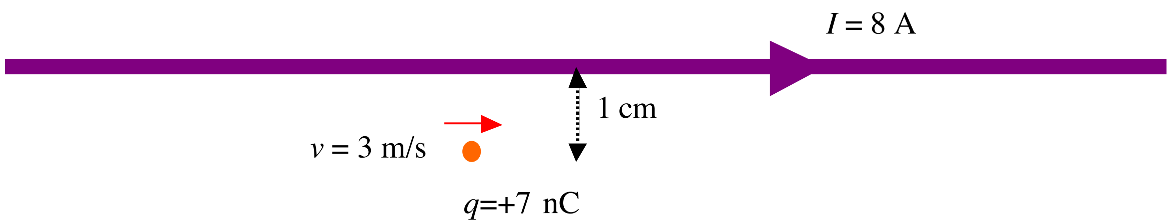
What, if anything, is wrong with the above statement about this situation? If something is wrong, explain the error and how to correct it. If the statement is legitimate as it stands, explain why it is valid.

The force on the charged particle is not zero, but is $F = qvB$, where $B = \mu_o I/2\pi r$. So, the correct statement would be:

"The force on the charged particle by the magnetic field is not zero because the velocity is parallel to the current in the wire."

MFF3a–WWT2: Charged Particle and a Straight Current-Carrying Wire

As shown in the figure below, a particle with a net electric charge of +7 nC is initially located a distance of 1 cm from a long straight wire that is carrying a current of 8 A. The charge has a mass of 6 x 10^{-6} kg, and it is moving initially at 3 m/s parallel to the wire.



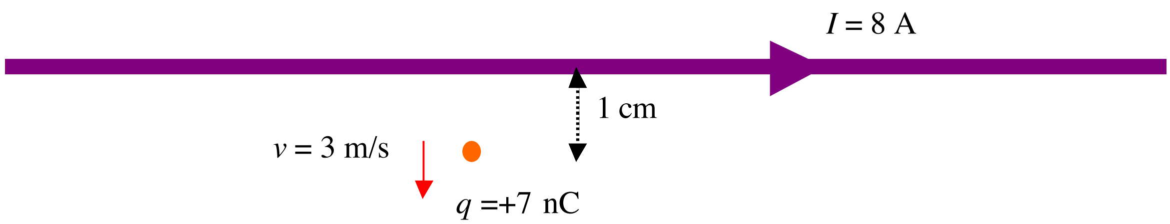
"The force on the charged particle by the magnetic field is initially toward the wire because the velocity is perpendicular to the magnetic field produced by the wire."

What, if anything, is wrong with the above statement about this situation? If something is wrong, explain the error and how to correct it. If the statement is legitimate as it stands, explain why it is valid.

There is nothing wrong with this statement – it is correct.

MFF3A–TT1: CHARGED PARTICLE AND A STRAIGHT CURRENT-CARRYING WIRE

As shown in the figure below, a particle with a net electric charge of +7 nC is initially located a distance of 1 cm from a long straight wire that is carrying a current of 8 A. The charge has a mass of 6 x 10^{-6} kg, and it is moving initially at 3 m/s away from the wire.



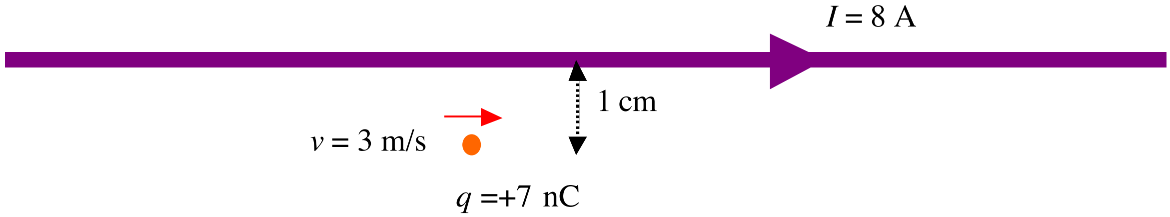
There is at least one error in the statement below. Identify the error(s) and explain how to correct it.

"The force on the charged particle by the magnetic field is zero because the velocity is parallel to the magnetic field produced by the wire."

There are two errors in this statement. First, the force will not be zero, it will be nonzero. Second, the velocity is perpendicular (not parallel) to the magnetic field.

MFF3A–TT2: CHARGED PARTICLE AND A STRAIGHT CURRENT-CARRYING WIRE

As shown in the figure below, a particle with a net electric charge of +7 nC is initially located a distance of 1 cm from a long straight wire that is carrying a current of 8 A. The charge has a mass of 6 x 10^{-6} kg, and it is moving initially at 3 m/s parallel to the wire.



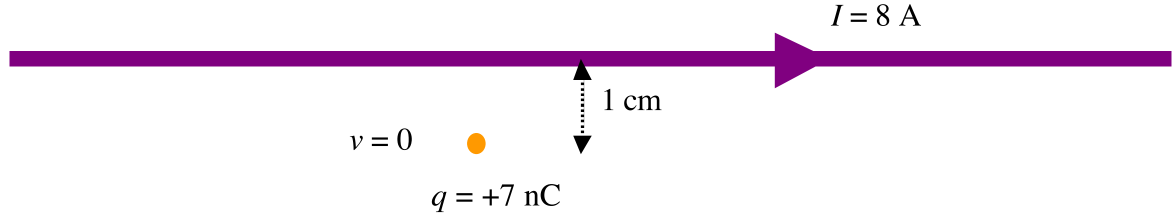
There is at least one error in the statement below. Identify the error(s) and explain how to correct it (them).

"***The force on the charged particle by the magnetic field is zero because the velocity is parallel to the magnetic field produced by the wire.***"

There are two errors in this statement. The force on the charged particle is non-zero, not zero. Also, the particle's velocity is not parallel to the magnetic field.

MFF3A–PET1: CHARGED PARTICLE AND A STRAIGHT CURRENT-CARRYING WIRE

As shown in the figure below, a particle with a net electric charge of +7 nC is initially located at rest a distance of 1 cm from a long straight wire carrying a current of 8 A.

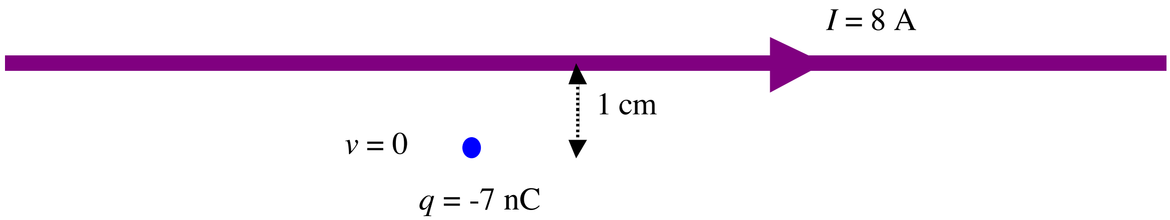


What will happen to the positively charged particle when it is released? Explain fully.

Nothing will happen. For the particle to feel a magnetic force, it needs to have a non-zero velocity as well as a charge and be traveling in a magnetic field cutting across magnetic field lines.

MFF3A–PET2: CHARGED PARTICLE AND A STRAIGHT CURRENT-CARRYING WIRE

As shown in the figure below, a particle with a net electric charge of - 7 nC is initially located at rest a distance of 1 cm from a long straight wire carrying a current of 8 A.

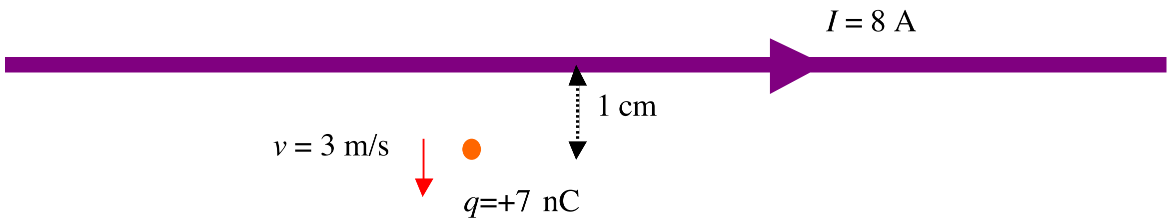


What will happen to the negatively charged particle when it is released? Explain fully.

Nothing will happen. For the particle to feel a magnetic force, it needs to have a non-zero velocity as well as a charge and be traveling in a magnetic field cutting across magnetic field lines.

MFF3a–PET3: Charged Particle and a Straight Current-Carrying Wire

As shown in the figure below, a particle with a net electric charge of +7 nC is initially located a distance of 1 cm from a long straight wire that is carrying a current of 8 A.

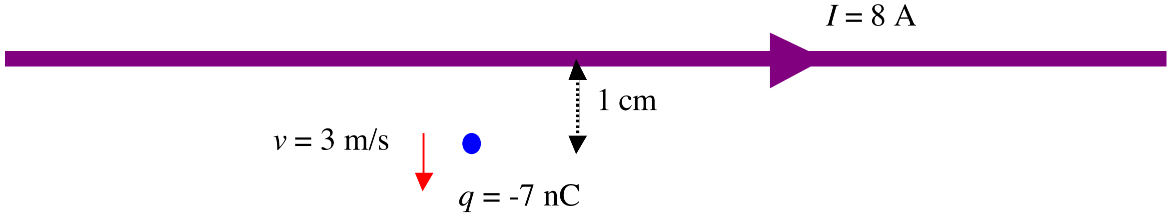


What will happen to the charged particle when it is released moving at 3 m/s away from the wire as shown? Explain fully.

The particle will feel a magnetic force perpendicular to the direction of its velocity and to the magnetic field; i.e., it will feel a magnetic force directed toward the right (parallel to the wire) initially.

MFF3A–PET4 CHARGED PARTICLE AND A STRAIGHT CURRENT-CARRYING WIRE

As shown in the figure below, a particle with a net electric charge of -7 nC is initially located at a distance of 1 cm from a long straight wire carrying a current of 8 A.

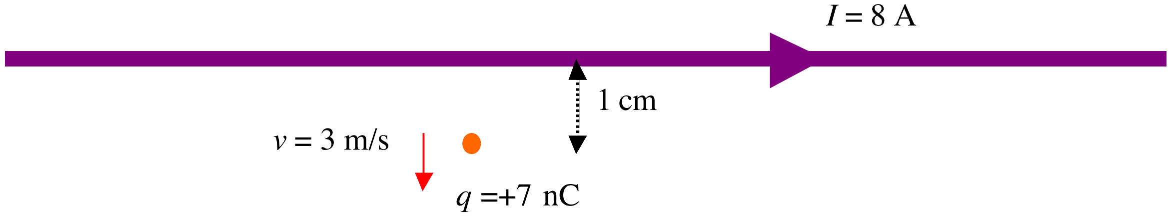


What will happen to the charged particle when it is released moving at 3 m/s away from the wire as shown? Explain fully.

The negative particle will feel a magnetic force perpendicular to the direction of its velocity and to the magnetic field; i.e., it will feel a magnetic force directed toward the left (parallel to the wire) initially.

MFF3A–M/MCT1: CHARGED PARTICLE AND A STRAIGHT CURRENT-CARRYING WIRE

As shown in the figure below, a particle with a net electric charge of +7 nC is initially located a distance of 1 cm from a long straight wire that is carrying a current of 8 A. The charge has a mass of 6 x 10^{-6} kg, and it is moving initially at 3 m/s away from the wire.



Given below is a calculation for the magnetic field (magnitude) at this point.

$$B = \frac{mv}{Qr} = \frac{(6 \text{ x} 10^{-6} kg)(3m/s)}{(7 \text{ x} 10^{-9} C)(1 \text{ x} 10^{-2} m)}$$

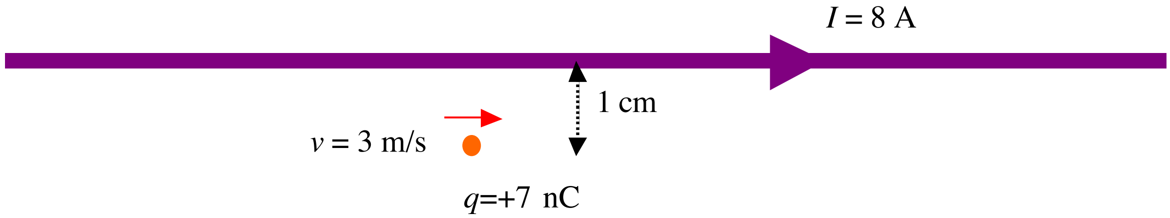
Is this calculation meaningful (i.e., it tells us something legitimate about this situation) or is it meaningless (i.e., the value calculated is either nonsense, or it tells us nothing legitimate about this situation)?

Although this equation is a correct way to calculate a magnetic field, it is not correct for this case. This equation would be the correct way of calculating the magnetic field for a circular path of a particle in a uniform magnetic field.
For this case, one would need to use

$$B = \mu_o I / 2\pi r$$

MFF3A–M/MCT2: CHARGED PARTICLE AND A STRAIGHT CURRENT-CARRYING WIRE

As shown in the figure below, a particle with a net electric charge of +7 nC is initially located a distance of 1 cm from a long straight wire that is carrying a current of 8 A. The charge has a mass of 6 x 10^{-6} kg, and it is moving initially at 3 m/s parallel to the wire.



Given below is a calculation for the magnetic field (magnitude) at this point.

$$B = \frac{mv}{Qr} = \frac{(6 \text{ x}10^{-6} kg)(3m/s)}{(7 \text{ x}10^{-9} C)(1 \text{ x}10^{-2} m)}$$

Is this calculation meaningful (i.e., it tells us something legitimate about this situation) or is it meaningless (i.e., the value calculated is either nonsense, or it tells us nothing legitimate about this situation)?

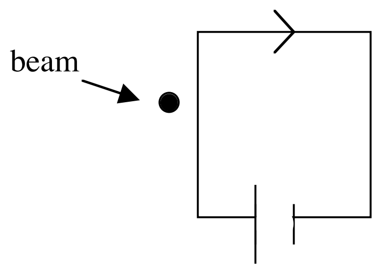
Although this equation is a correct way to calculate a magnetic field, it is not correct for this case. This equation would be the correct way of calculating the magnetic field for a circular path of a particle in a uniform magnetic field.
For this case, one would need to use

$$B = \mu_o I / 2\pi r$$

MFF3A–CODT1: CHARGED PARTICLE AND A STRAIGHT CURRENT-CARRYING WIRE

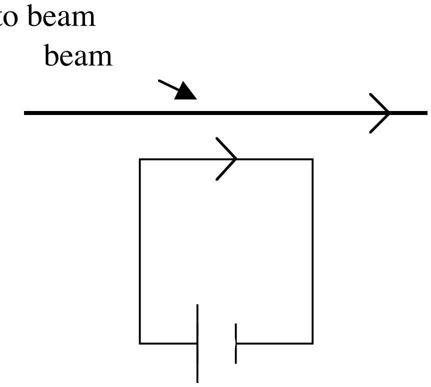
Set up a demonstration oscilloscope with the beam of the electrons coming out toward the class. Then demonstrate and discuss the effect on the beam by the North and South pole of a bar magnet. Demonstrate and discuss the magnetic field around a wire that is carrying a current (use DC power supply and magna probes). Then hook up a rectangular wire to a DC power supply (don't turn it on), and align the rectangular loop perpendicular and parallel to the axis of the beam (see Figures below). Ask the students whether there will be any deflection in either orientation (or both orientations) when a DC current is supplied by the power supply.

Perpendicular to beam



There is a no net deflection of the beam. In the figure the two vertical wires create a B parallel, or anti-parallel to the beam and the two horizontal wires tend to negate each other.

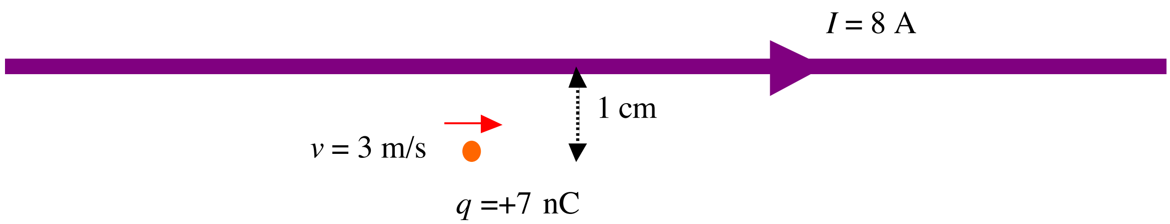
Parallel to beam



There is a net deflection of the beam toward the top of the page.

MFF3A–QRT1: CHARGED PARTICLE AND A STRAIGHT CURRENT-CARRYING WIRE

As shown in the figure below, a particle with a net electric charge of +7 nC is initially located a distance of 1 cm from a long straight wire that is carrying a current of 8 A. The charge has a mass of 6 x 10^{-6} kg, and it is moving initially at 3 m/s parallel to the wire.



If we double the charge on the particle, what will happen to the initial acceleration?

The acceleration will also double.

If we change the charge on the particle to negative, what will happen to the initial acceleration?

The initial acceleration will be the same in magnitude, but opposite in direction.

If we double the initial distance away from the wire, what will happen to the initial acceleration?

The initial acceleration will be halved.

If we double the mass of the particle, what will happen to the initial acceleration?

The acceleration will be halved.

If we double the velocity of the particle, what will happen to the initial acceleration?

The initial acceleration will be doubled.

If we reduce the magnitude of the current, what will happen to the initial acceleration?

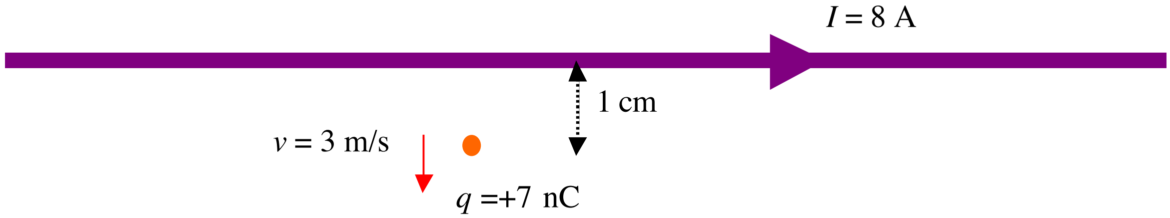
The initial acceleration will be reduced in magnitude.

If we reverse the direction of the current, what will happen to the initial acceleration?

The initial acceleration will be reversed in direction.

MFF3A–QRT2: CHARGED PARTICLE AND A STRAIGHT CURRENT-CARRYING WIRE

As shown in the figure below, a particle with a net electric charge of +7 nC is initially located a distance of 1 cm from a long straight wire that is carrying a current of 8 A. The charge has a mass of 6 x 10^{-6} kg, and it is moving initially at 3 m/s away from the wire.



If we double the charge on the particle, what will happen to the initial acceleration?

The initial acceleration will be double in magnitude.

If we change the charge on the particle to negative, what will happen to the initial acceleration?

The initial acceleration will be reversed in direction only.

If we double the initial distance away from the wire, what will happen to the initial acceleration?

The initial acceleration will be halved in magnitude.

If we double the mass of the particle, what will happen to the initial acceleration?

The initial acceleration will be halved in magnitude.

If we double the velocity of the particle, what will happen to the initial acceleration?

The initial acceleration will be doubled in magnitude.

If we reduce the magnitude of the current, what will happen to the initial acceleration?

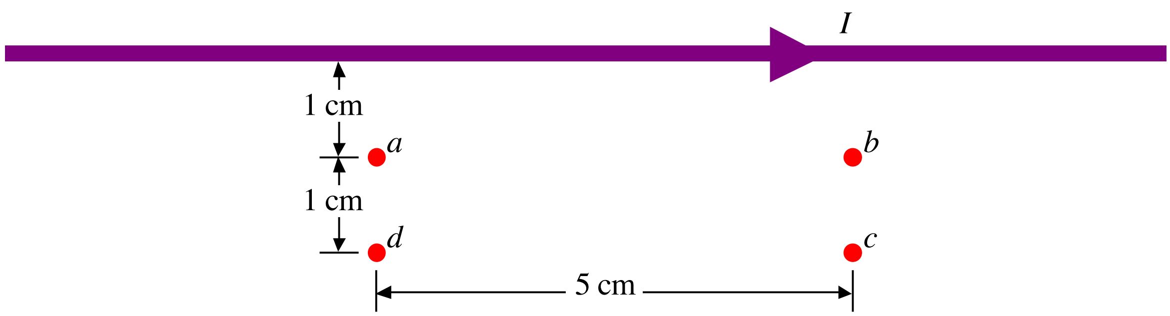
The initial acceleration will be reduced in magnitude.

If we reverse the direction of the current, what will happen to the initial acceleration?

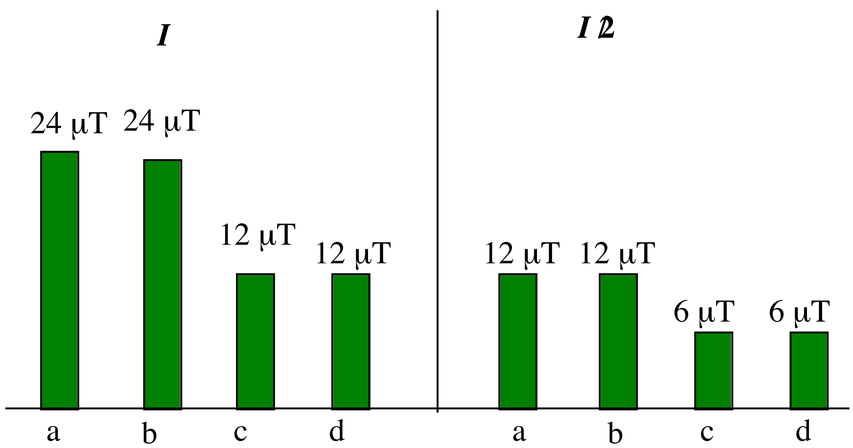
The initial acceleration will be reversed in direction only.

MFF3A–BCT1: CHARGED PARTICLE AND A STRAIGHT CURRENT-CARRYING WIRE

As shown in the figure below, a long straight wire is carrying a current. The magnetic field has a magnitude of 24 μT at point *a*.



Draw a bar chart (and label the height of each column) of the magnitude of the magnetic field at the points *a, b, c,* and *d* at this initial current and then when the current is reduced to half its initial value.

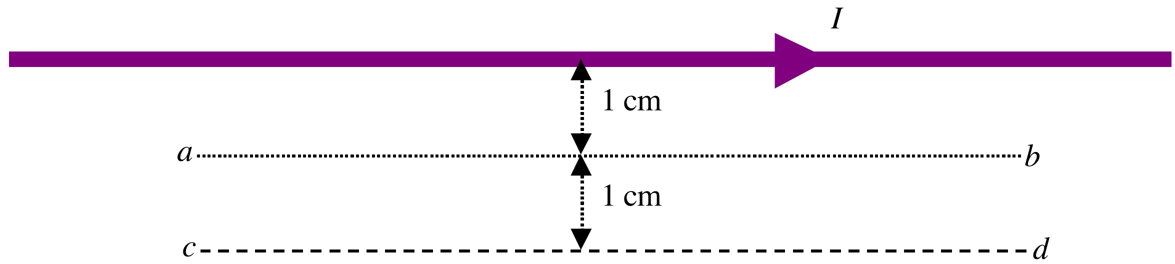


Explain the reasoning behind your bar chart:

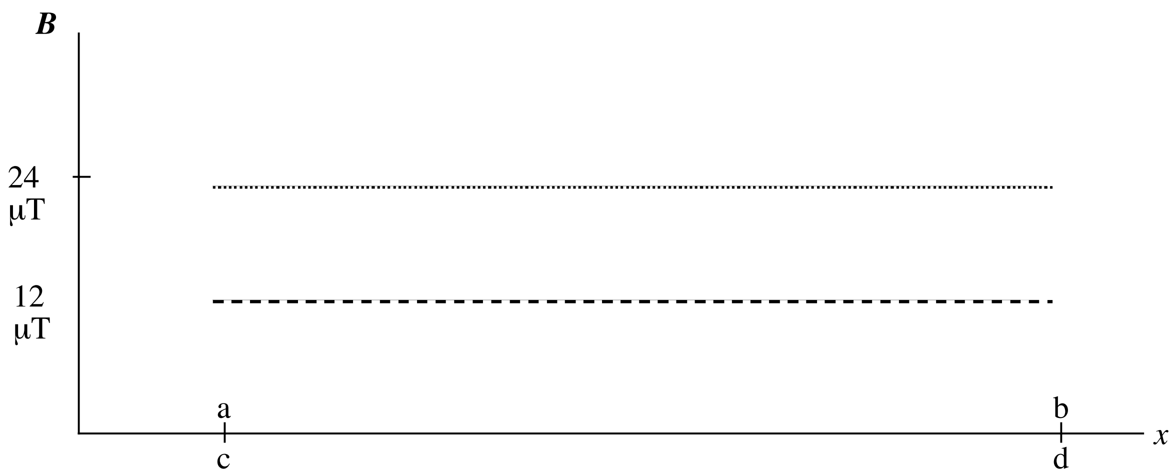
The magnetic field at points a, b, c, and d can be determined by $B = \mu_o I/2\pi r$. Since a and b are the same distance away from the wire, they would have the same magnitude of B. Since c and d are the same distance away from the wire (but twice the distance), they would have half the magnitude of a and b. With half the current in the wire, each magnitude of B would also be halved.

MFF3a–CRT1: Charged Particle and a Straight Current-Carrying Wire

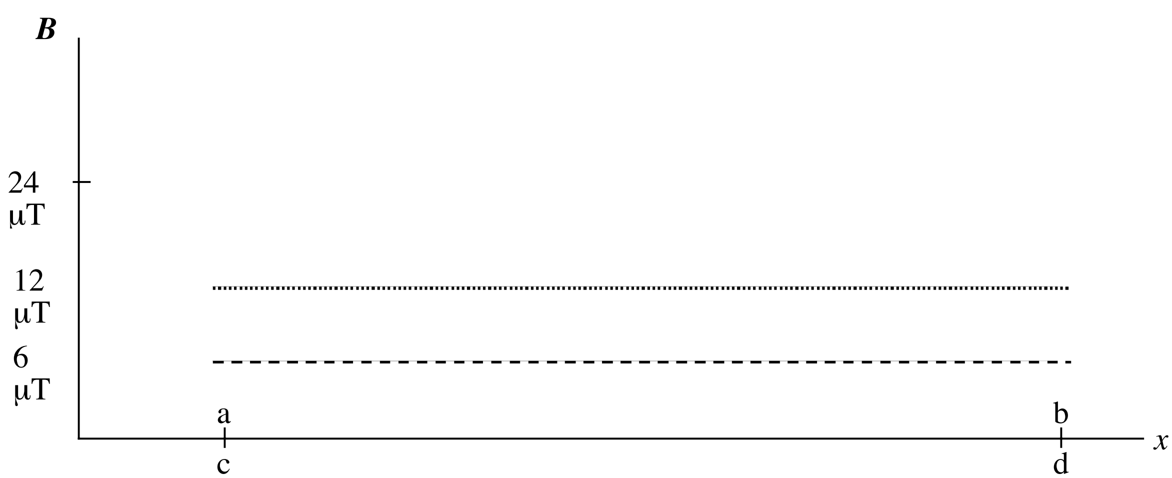
As shown in the figure below, a long straight wire is carrying a current. The magnetic field at point *a* has a magnitude of 24 μT.



Draw and label a graph of the magnitude of the magnetic field in the *x*-direction along the dotted line from a to b (as a dotted line on this graph) and also draw the magnitude of the magnetic field along the dashed line from c to d.

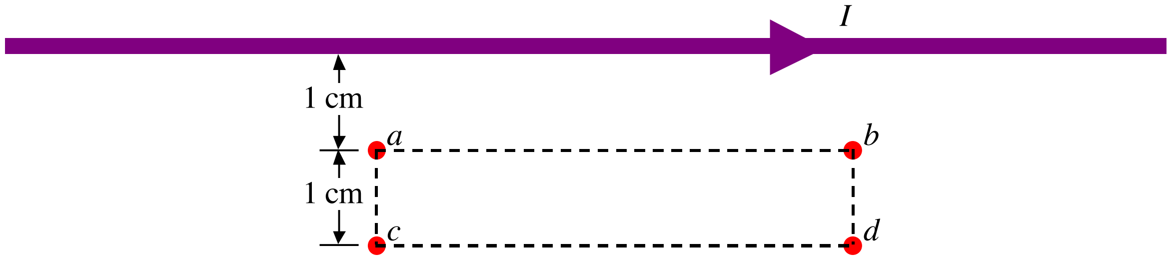


Redraw this graph if the current is reduced to half its value.

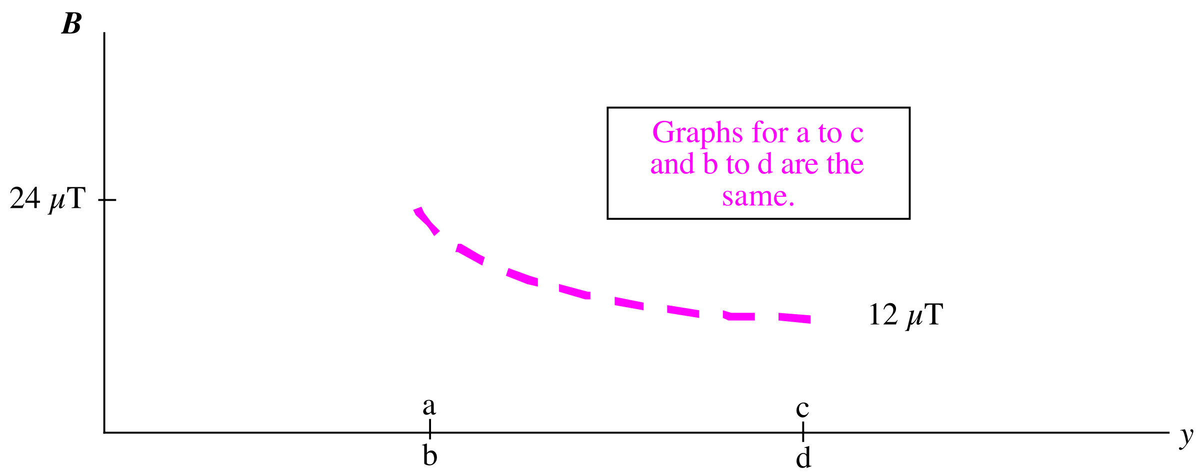


MFF3A–CRT2: CHARGED PARTICLE AND A STRAIGHT CURRENT-CARRYING WIRE

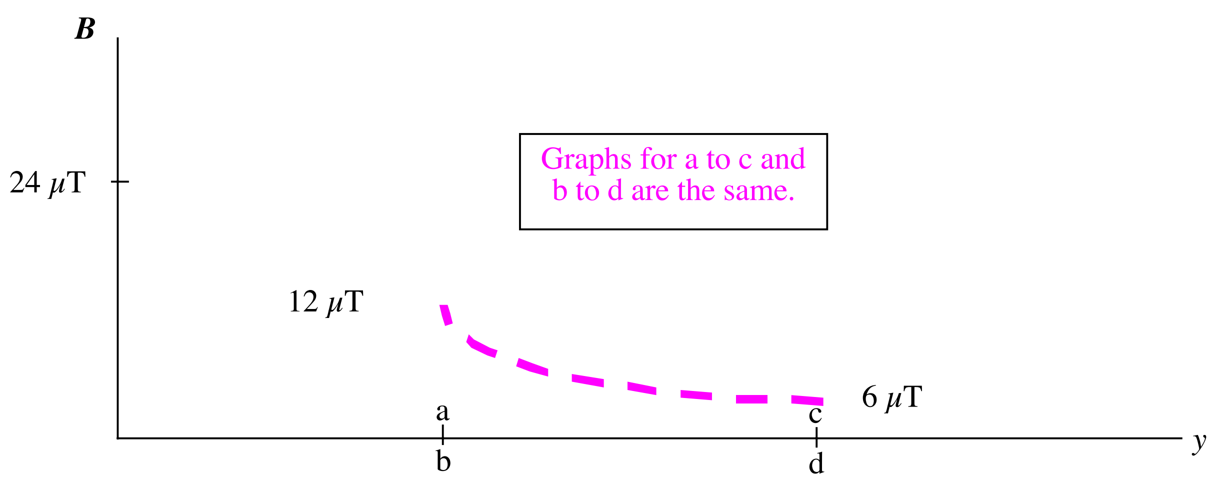
As shown in the figure below, a long straight wire is carrying a current. The magnetic field at point *a* has a magnitude of 24 μT.



Draw and label a graph of the magnitude of the magnetic field in the *y*-direction along the dotted line from a to c (as a dotted line on this graph) and also draw the magnitude of the magnetic field along the dashed line from b to d.

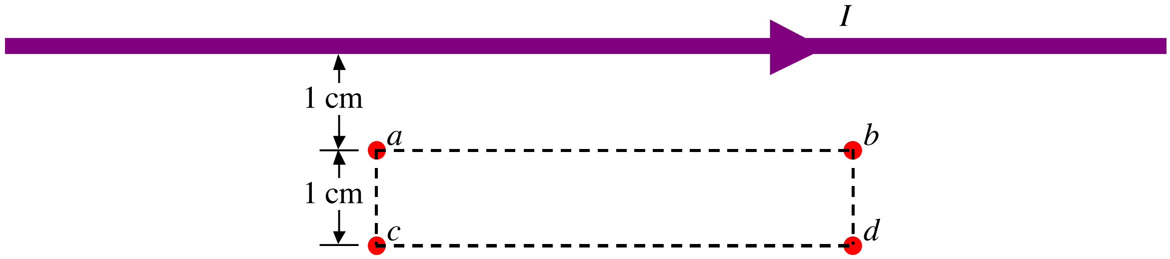


Redraw this graph if the current is reduced to half its value.

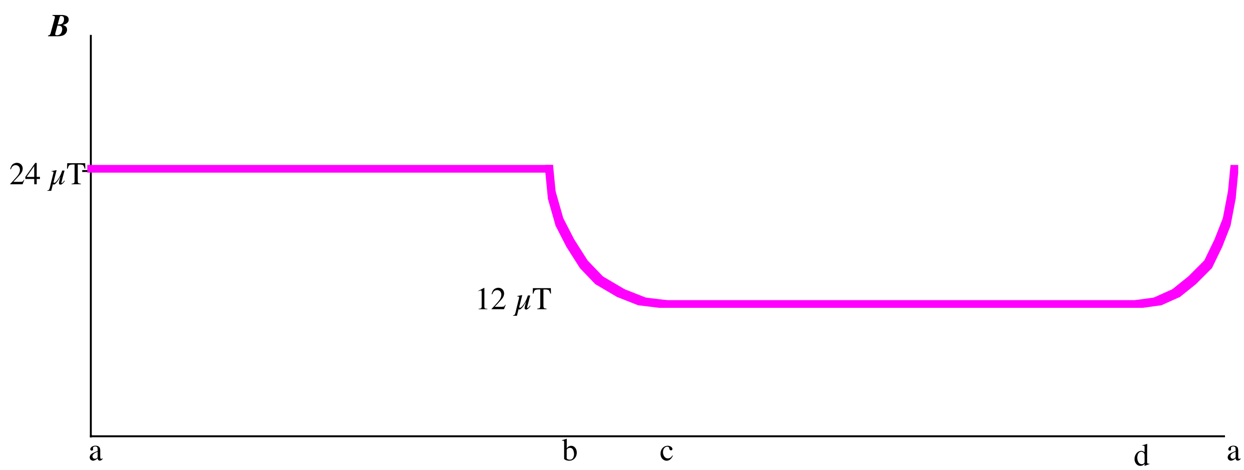


MFF3A–CRT3: CHARGED PARTICLE AND A STRAIGHT CURRENT-CARRYING WIRE

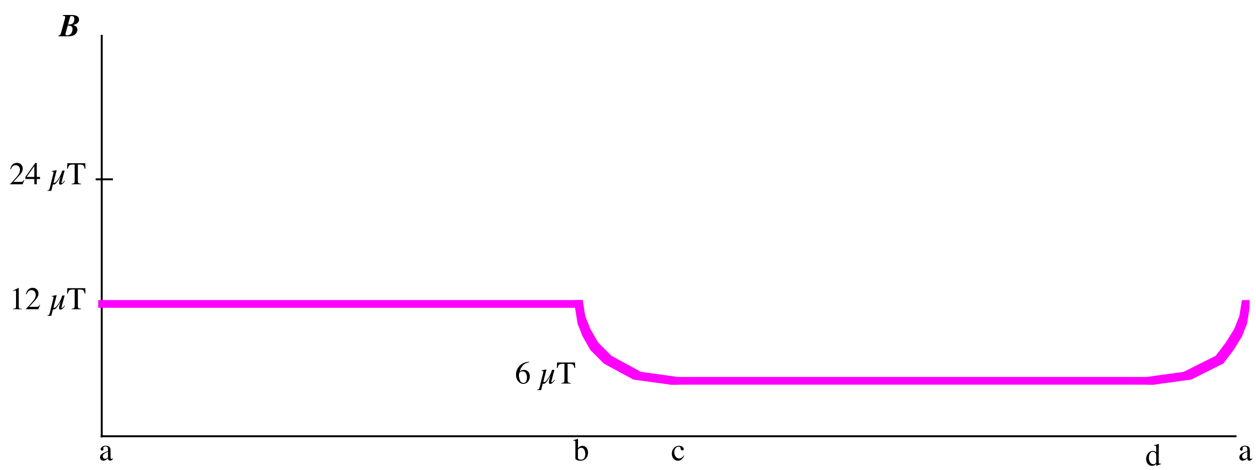
As shown in the figure below, a long straight wire is carrying a current. The magnetic field at point *a* has a magnitude of 24 μT.



Draw and label a graph of the magnitude of the magnetic field along the dashed line path from a to b to c to d and back to a.

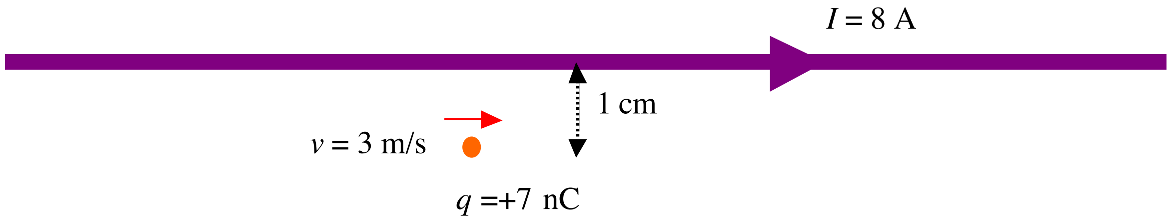


Redraw this graph if the current is reduced to half its value.



ffMFF3a–LMCT1: Charged Particle and a Straight Current-Carrying Wire

As shown in the figure below, a particle with a net electric charge of +7 nC is initially located a distance of 1 cm from a long straight wire that is carrying a current of 8 A. The charge has a mass of 6 x 10^{-6} kg, and it is moving initially at 3 m/s parallel to the wire.



Descriptions of a number of changes in this situation are presented below. How does the change affect, if it does, the initial acceleration of the charged particle?

The possible answers are:

A. This change would not affect the initial acceleration.

B. This change would increase the strength (magnitude) of the initial acceleration but not affect its direction.

C. This change would decrease the strength of the initial acceleration but not affect its direction.

D. This change would alter the direction of the initial acceleration but would not affect its strength.

E. This change would alter both the strength and direction of the initial acceleration.

Each change below refers to the original situation stated above:

The charge on the particle is doubled. ___*B*____

The mass of the particle is doubled. ___*C*____

The initial velocity of the particle is doubled. ____*B*____

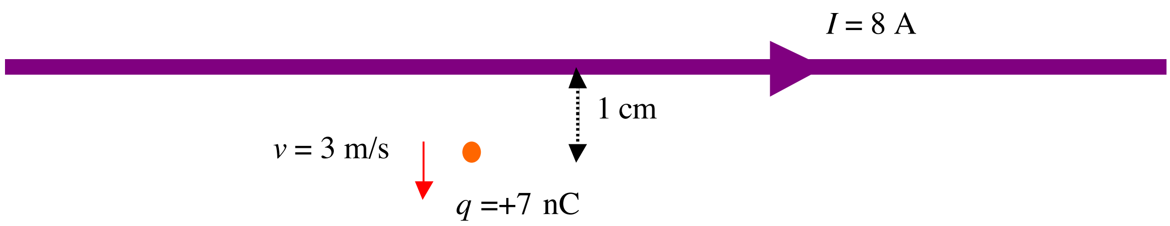
The wire is moved farther away from the charged particle. ___*C*____

The direction of the current in the wire is reversed. ___*D*____

The current is reversed and the wire is moved farther away from the particle. __*E*____

MFF3a–LMCT2: Charged Particle and a Straight Current-Carrying Wire

As shown in the figure below, a particle with a net electric charge of +7 nC is initially located a distance of 1 cm from a long straight wire that is carrying a current of 8 A. The charge has a mass of 6 x 10^{-6} kg, and it is moving initially at 3 m/s away from the wire.



Descriptions of a number of changes in this situation are presented below. How does the change affect, if it does, the initial acceleration of the charged particle?

The possible answers are:

A. This change would not affect the initial acceleration.

B. This change would increase the strength (magnitude) of the initial acceleration but not affect its direction.

C. This change would decrease the strength of the initial acceleration but not affect its direction.

D. This change would alter the direction of the initial acceleration but would not affect its strength.

E. This change would alter both the strength and direction of the initial acceleration.

Each change below refers to the original situation stated above:

The current in the wire is doubled. ___*B*____

The charge on the particle is doubled. ___*B*____

The mass of the particle is doubled. ___*C*____

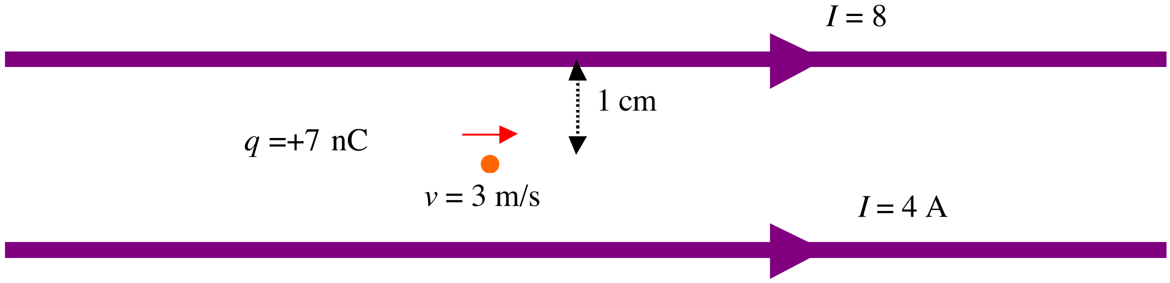
The initial velocity of the particle is doubled. ___*B*____

The wire is moved farther away from the charged particle. ___*C*____

The direction of the current in the wire is reversed. ___*D*____

MFF3a–LMCT3: Charged Particle and Straight Current-Carrying Wires

As shown in the figure below, a particle with a net electric charge of +7 nC is initially located midway between two long straight parallel wires that are carrying currents of 4 A and 8 A. The particle is initially at a distance of 1 cm from each wire. The charge has a mass of 6 x 10^{-6} kg and it is moving initially at 3 m/s parallel to the wires.



Descriptions of a number of changes in this situation are presented below. How does the change affect, if it does, the initial acceleration of the charged particle?

The possible answers are:

A. This change would not affect the initial acceleration.

B. This change would increase the strength (magnitude) of the initial acceleration but not affect its direction.

C. This change would decrease the strength of the initial acceleration but not affect its direction.

D. This change would alter the direction of the initial acceleration but not affect its strength.

E. This change would alter both the strength and direction of the initial acceleration.

Each change below refers to the original situation stated above:

The current in both wires is doubled. ___*B*____

The direction of the current in the lower wire is reversed. ___*B*____

The charge on the particle is doubled and the mass is doubled. ___*A*____

The charge on the particle is changed to negative. ___*D*____

The mass of the particle is doubled. ___*C*____

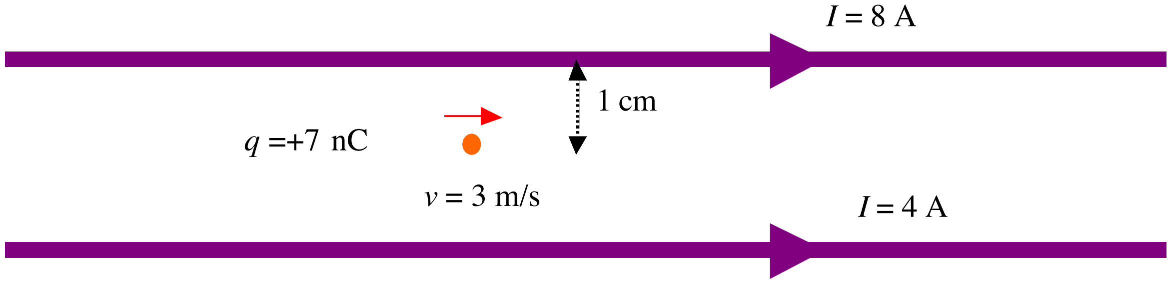
The initial velocity of the particle is doubled. ___*B*____

The wires are both moved farther away from the charged particle. ___*C*____

The current in the lower wire is changed to 10 A. ___*E*____

MFF3A–LMCT4: CHARGED PARTICLE AND STRAIGHT CURRENT-CARRYING WIRES

As shown in the figure below, a particle with a net electric charge of +7 nC is initially located midway between two long straight parallel wires that carrying currents of 4A and 8A. The particle is initially at a distance of 1 cm from each wire. The charge has a mass of 6 x 10^{-6} kg and it is moving initially at 3 m/s parallel to the wires.



Descriptions of a number of changes in this situation are presented below. How does the change affect, if it does, the initial force on the charged particle?

The possible answers are:

A. This change would not affect the initial force on the charged particle.

B. This change would increase the strength (magnitude) of the initial force on the charged particle, but not affect its direction.

C. This change would decrease the strength of the initial force on the charged particle but not affect its direction.

D. This change would alter the direction of the initial force on the charged particle but would not affect its strength.

E. This change would alter both the strength and direction of the initial force on the particle.

Each change below refers to the original situation stated above:

The current in both wires is doubled. ___*B*____

The direction of the current in the lower wire is reversed. ___*B*____

The charge on the particle is doubled and the mass is doubled. ___*A*____

The charge on the particle is changed to negative. ___*D*____

The mass of the particle is doubled. ___*C*____

The initial velocity of the particle is doubled. ___*B*____

The wires are both moved farther away from the charged particle. ___*C*____

The current in the lower wire changed to 10 A. ___*E*____