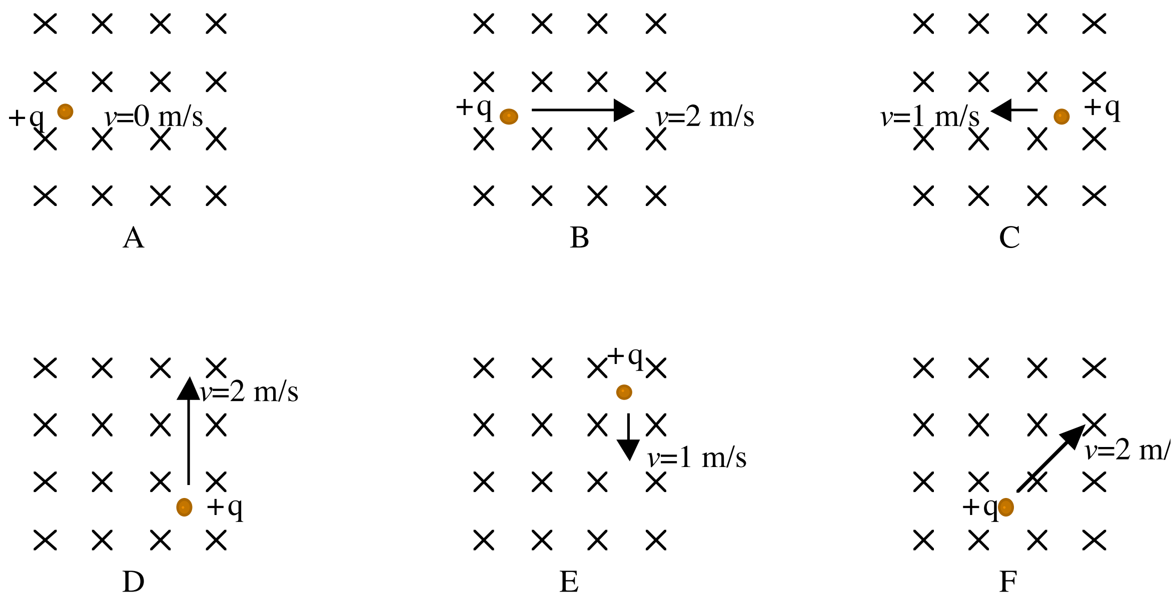
MFF 2A: CHARGED PARTICLE AND A UNIFORM MAGNETIC FIELD

MFF2a—RT1: Charged Particle and a Uniform Magnetic Field

The figures below show positively charged particles in a magnetic field. All magnetic fields are uniform and have the same strength. Magnetic fields whose directions are into the paper are represented by **x** and those that come out of the paper are represented by •.

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



Greatest 1 __*BDF*__ 2 ______ 3 ______ 4 __*CE*____ 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 $F_B = qvB\sin\theta$. Since all charges are +q and the B is the same for all 6 cases, $F_B \propto v\sin\theta$.

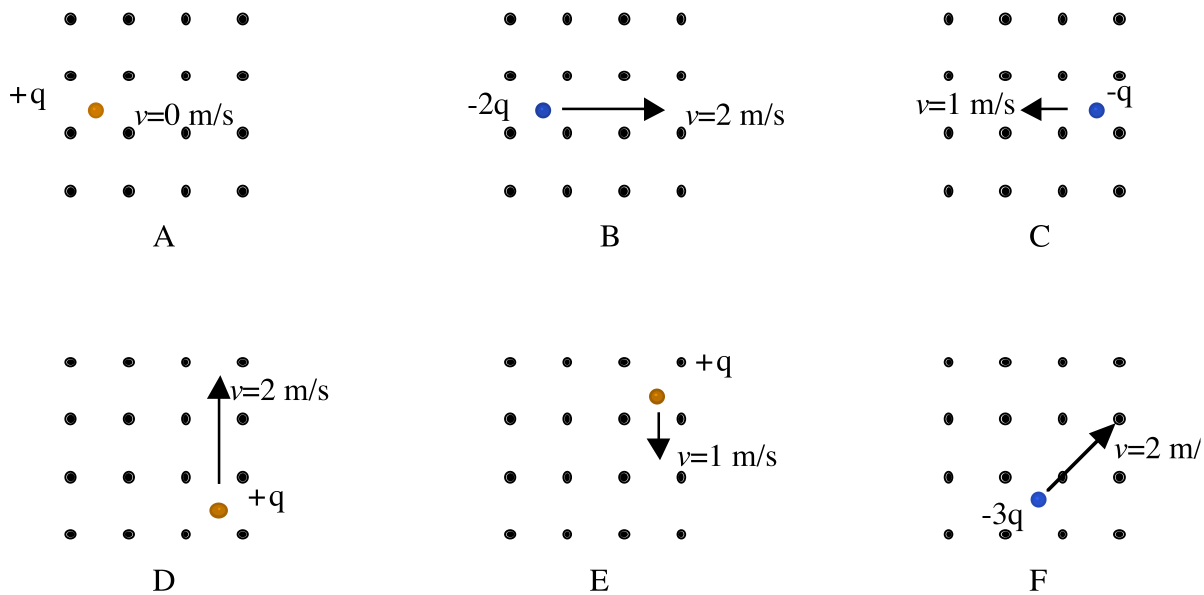
How sure were you of your ranking? (circle one)

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

MFF2a—RT2: Charged Particle and a Uniform Magnetic Field

The figures below show charged particles in a magnetic field. All magnetic fields are uniform and have the same strength. Magnetic fields whose directions are into the paper are represented by **x** and those that come out of the paper are represented by •.

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



Greatest 1 ___*F*___ 2 __*B*____ 3 __*D*____ 4 __*CE*____ 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 $F_B = qvB\sin\theta$. Since the B is the same for all 6 cases, $F_B \propto q\, v \sin\theta$.

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

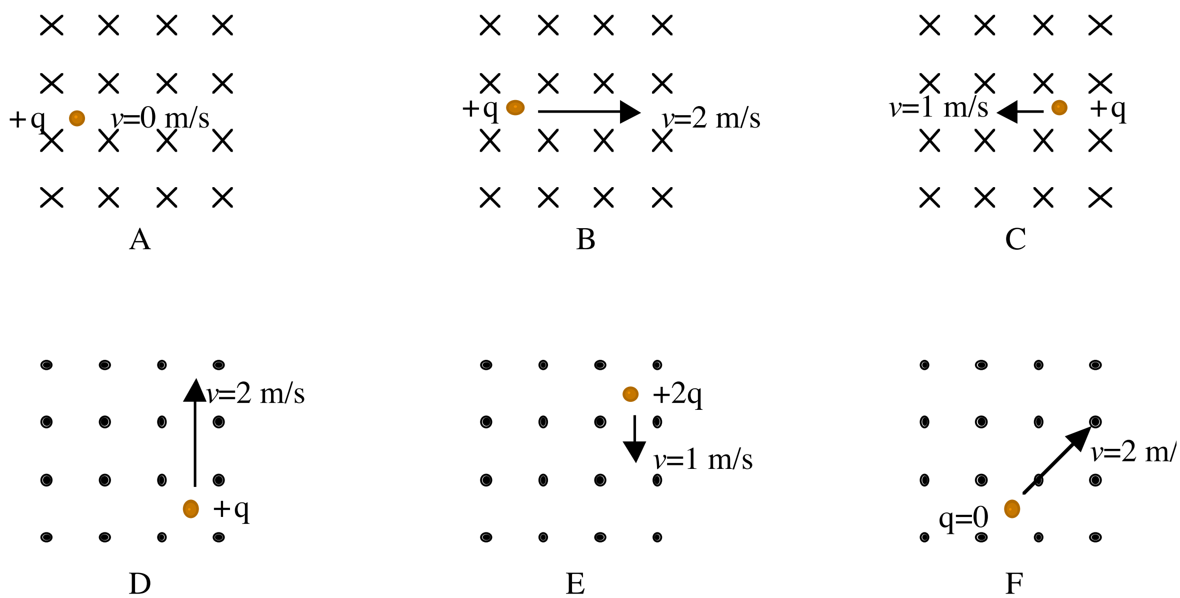
Basically Guessed | Sure | Very Sure

1 2 3 4 5 6 7 8 9 10

MFF2a—RT3: Charged Particle and a Uniform Magnetic Field

The figures below show particles in a magnetic field. All magnetic fields are uniform and have the same strength. Magnetic fields whose directions are into the paper are represented by **x** and those that come out of the paper are represented by •.

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



Greatest 1 __*BDE*____ 2 ______ 3 ______ 4 ___*C*___ 5 ___*AF*___ 6 ______ 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 $F_B = qvB\sin\theta$. Since B is the same for all 6 cases, $F_B \propto q\, v \sin\theta$.

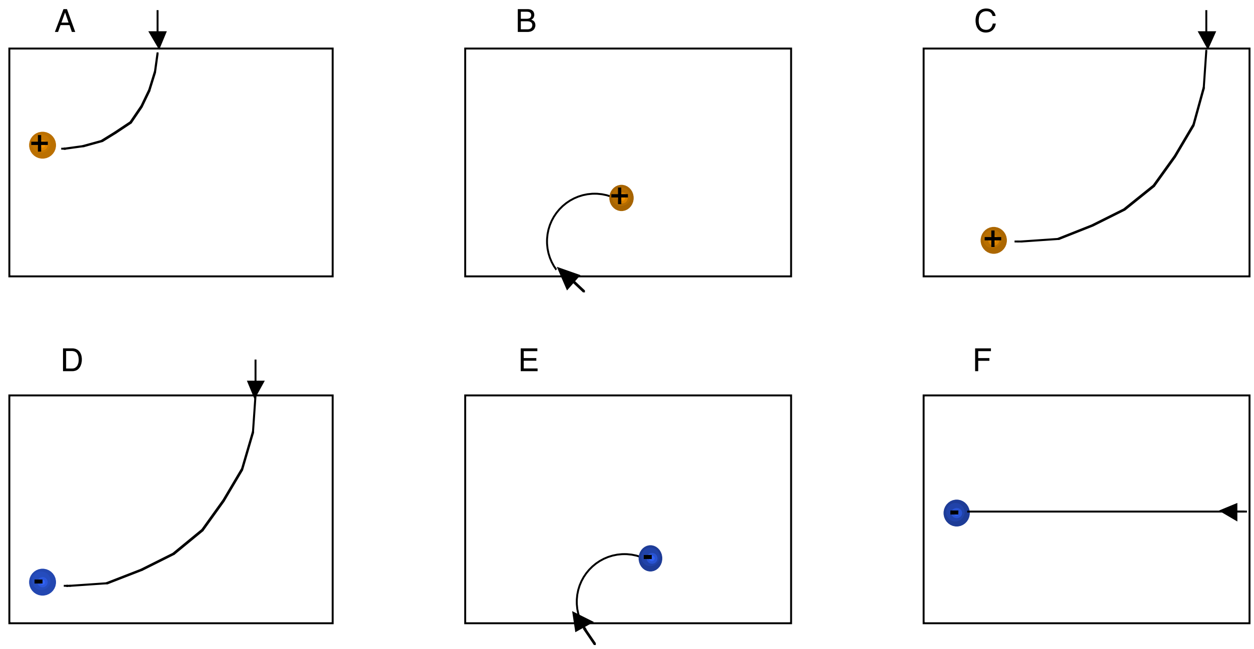
How sure were you of your ranking? (circle one)

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

MFF2a—RT4: Charged Particle and a Uniform Magnetic Field

Shown below are six situations where equal mass electrically charged particles are moving through regions of space in which there may be magnetic fields. In each figure, we are shown the sign of the charge and the path the charge follows through the region. (These are top views looking down on horizontally moving charges.) All of the charges start with the same initial velocity in the region.

Rank these situations, from greatest to least, on the basis of the strength of the upward directed magnetic field in the region. (Downward directed fields rank lower than upward directed fields.)



Greatest 1 ___*E*____ 2 ____*D*___ 3 ____*F*___ 4 ___*C*____ 5 ___*A*____ 6 ___*B*___ Least

OR, The magnetic field in all six of these cases has the same strength. ________

OR, The magnetic field is zero in all six of these cases. ________

Carefully explain your reasoning.

Based on F_B=qvxB and F=mv2/r. B ∝ 1/qr. The smaller the r, the larger the B. Direction of B is determined by RHR.

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

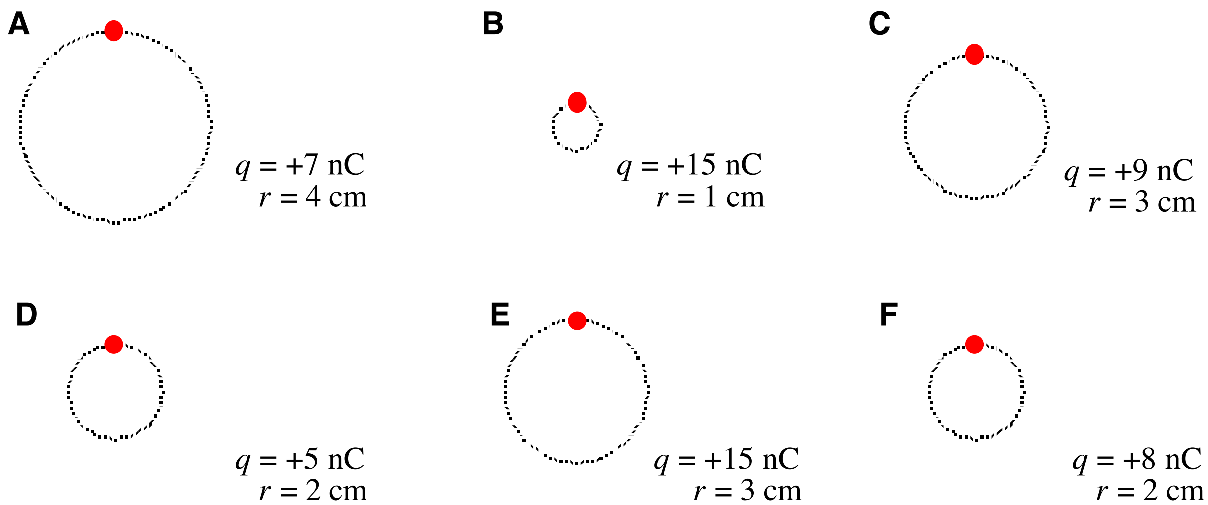
Basically Guessed Sure Very Sure

1 2 3 4 5 6 7 8 9 10

MFF2a—RT5: Charged Particle and a Uniform Magnetic Field

The figures below show the circular paths of six charged particles that have been injected into six different but uniform magnetic fields. The particles have the same mass, and they were all given the same initial speed before they entered the field. However, the charges on the particles and the radii of their paths vary.

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



Greatest 1 __*B*____ 2 ___*DF*___ 3 ______ 4 __*CE*____ 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 $a_c = v^2/r$. Since v is the same for all, $a_c \propto 1/r$.

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

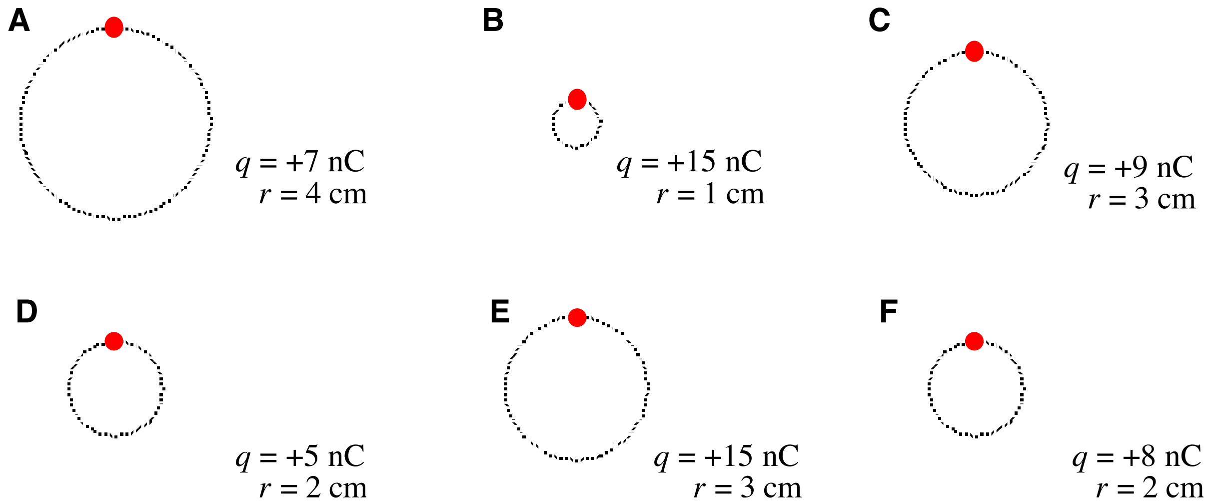
Basically Guessed — Sure — Very Sure

1 2 3 4 5 6 7 8 9 10

MFF2a—RT6: Charged Particle and a Uniform Magnetic Field

The figures below show the circular paths of six charged particles that have been injected into six different but uniform magnetic fields. The particles have the same mass, and they were all given the same initial speed before they entered the field. However, the charges on the particles and the radii of their paths vary.

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



Greatest 1 ___*B*___ 2 ___*DE*___ 3 ______ 4 ___*CE*___ 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 $F=mv^2/r$. Since m and v are the same in all cases, then $F \propto 1/r$.

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

Basically Guessed / Sure / Very Sure

1 2 3 4 5 6 7 8 9 10

MFF2a—WBT1: Charged Particle and a Uniform Magnetic Field

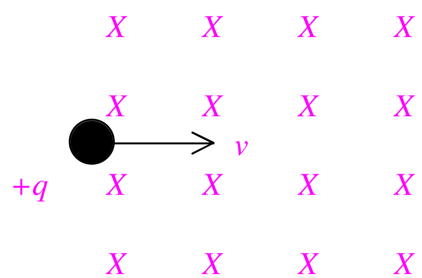
Draw and describe a physical arrangement to which the equation below could apply.

$$6.49\text{x}10^{-12}\text{N} = (1.602\text{x}10^{-19}\text{C})(2.50\text{x}10^{7}\text{m/s})(1.62\text{T})$$

One possible arrangement would be for:

$$q = 1.602x10^{-19}C$$
$$v = 2.50x10^{7}m/s$$
$$B = 1.62T$$
$$F = 6.49x10^{-12}N$$

with a diagram of



A positive charged particle traveling with velocity v has just entered a uniform magnetic field B. The particle is initially moving in the +x-direction with the magnetic field in the –z-direction and feels a force F.

MFF2A—WBT2: CHARGED PARTICLE AND A UNIFORM MAGNETIC FIELD

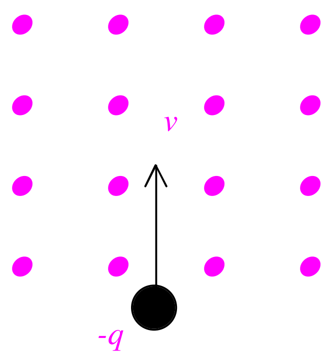
Draw and describe a physical arrangement to which the equation below could apply.

$$-6.49\text{x}10^{-12}\,\hat{\mathbf{i}}\text{N} = (-1.602\text{x}10^{-19}\text{C})(2.50\text{x}10^{7}\,\hat{\mathbf{j}}\text{m/s})\,\mathbf{x}\,(1.62\hat{\mathbf{k}}\text{T})$$

One possible arrangement would be for:

$$q = -1.602x10^{-19}C$$
$$v = 2.50x10^{7}\,\hat{j}m/s$$
$$B = 1.62\hat{k}T$$
$$F = -6.49x10^{-12}\hat{i}N$$

with a diagram of



A negative charged particle moving with velocity v has just entered a uniform magnetic field B. The particle is moving in the +y-direction with the magnetic field in the +z-direction and feels a magnetic force F.

MFF2a—WBT3: Charged Particle and a Uniform Magnetic Field

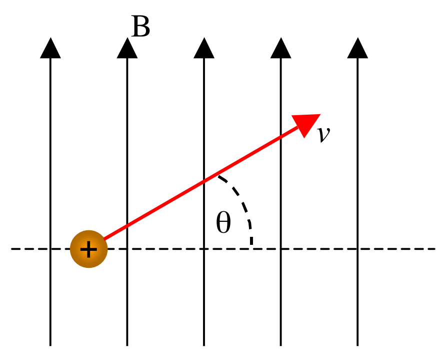
Draw and describe a physical arrangement to which the equation below could apply.

$$7.20\text{x}10^{-12}\,\text{N} = (3.20\text{x}10^{-19}\,\text{C})(1.50\text{x}10^{7}\,\text{m/s})(3.00\text{T})\sin 30^{\circ}$$

One possible arrangement would be for:

$$q = 3.20x10^{-19}C$$
$$v = 1.50x10^{7}m/s$$
$$B = 3.00T$$
$$\theta = 30^{\circ}$$
$$F = 7.20x10^{-12}N$$

with a diagram of



A positive charged particle traveling with speed v has just entered a uniform magnetic field B. The particle is moving at an angle of 30° to the +x-direction with the magnetic field in the +y-direction and feels a magnetic force F.

MFF2a—WBT4: Charged Particle and a Uniform Magnetic Field

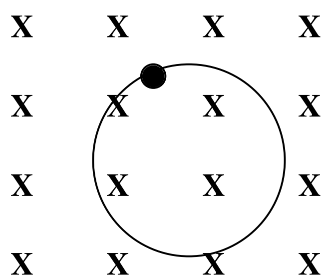
Draw and describe a physical arrangement to which the equation below could apply.

$$r = \frac{(1.67x10^{-27}\,kg)(5.00x10^{7}\,m/s)}{(1.602x10^{-19}\,C)(2.00T)}.$$

One possible arrangement would be for:

$$q = 1.602x10^{-19}C$$
$$v = 5.00x10^{7}m/s$$
$$B = 2.00T$$
$$m = 1.67x10^{-27}kg$$

with a diagram of



A positive charged particle is moving at speed v in circular motion in a uniform magnetic field B. The particle (which is a proton) is moving in the xy plane with the magnetic field in the –z-direction and has a circular path of radius r .

MFF2a—WBT5: Charged Particle and a Uniform Magnetic Field

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

$$15\ \mathrm{T} = \frac{(3.6\ \mathrm{x}10^{-2}\ \mathrm{kg} \bullet \mathrm{m/s})}{(6.0\ \mathrm{x}10^{-4}\mathrm{C}) \bullet (4.0\ \mathrm{m})}$$

One possible arrangement would be for:

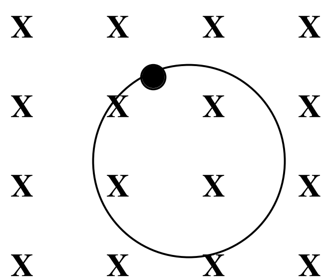
$$q = 6.0x10^{-4}C$$

$$p = mv = 3.6x10^{-2}mkg/s$$

$$r = 4.0m$$

$$B = 15T$$

with a diagram of



A positive charged object is moving with a known momentum p in circular motion in a uniform magnetic field B. The particle is moving in the xy plane with the magnetic field in the –z-direction and is in a circular path of radius r.

MFF2a—WBT6: Charged Particle and a Uniform Magnetic Field

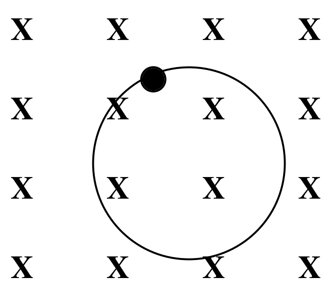
Draw and describe a physical arrangement to which the equation below could apply.

$$13.3\ \text{T} = \frac{(6.00\ \text{x}10^{-6}\,\text{kg}) \bullet (300.0\text{m/s})}{(9.00\ \text{x}10^{-6}\,\text{C}) \bullet (15.0\ \text{m})}$$

One possible arrangement would be for:

$$q = 9.00x10^{-6}C$$
$$v = 300.0m/s$$
$$r = 15.0m$$
$$m = 6.00x10^{-6}kg$$
$$B = 13.3T$$

with a diagram of



A positive charged body of mass m is moving at speed v in circular motion in a uniform magnetic field B. The particle is moving in the xy plane with the magnetic field in the –z-direction and has a circular path of radius r.

MFF2a—WBT7: Charged Particle and a Uniform Magnetic Field

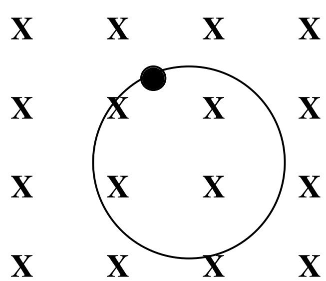
Draw and describe a physical arrangement to which the equation below could apply.

$$6.3\ \mathrm{T} = \frac{2\pi \bullet (6.0\ \mathrm{x}10^{-9}\ \mathrm{kg})}{(3.0\ \mathrm{x}10^{-9}\ \mathrm{C}) \bullet (2.0\ \mathrm{s})}$$

One possible arrangement would be for:

$$q = 3.0x10^{-9}C$$
$$B = 6.3T$$
$$m = 6.0x10^{-9}kg$$
$$T = 2.0s$$

with a diagram of



A positive charged particle is moving in circular motion in a uniform magnetic field B. The particle is moving in the xy plane with the magnetic field in the –z-direction and completes one revolution every 2.0 s.

MFF2a—WBT8: Charged Particle and a Uniform Magnetic Field

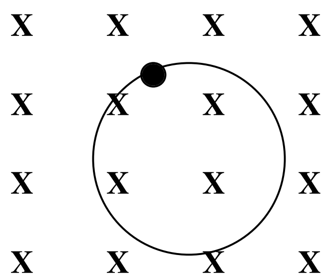
Draw and describe a physical arrangement to which the equation below could apply.

$$6.3\text{ T} = \frac{2\pi \bullet (5.0\text{Hz}) \bullet (6.0 \text{ x}10^{-9}\text{kg})}{(3.0 \text{ x}10^{-8}\text{C})}$$

One possible arrangement would be for:

$$q = 3.0x10^{-8}C$$
$$B = 6.3T$$
$$m = 6.0x10^{-9}kg$$
$$f = 5.0Hz$$

with a diagram of



A positive charged particle is moving in circular motion in a uniform magnetic field B. The particle is moving in the xy plane with the magnetic field in the –z-direction and completes its rotation with a frequency of 5.0 Hz.

MFF2a—CCT1: Charged Particle and a Uniform Magnetic Field

Consider the following statements made by three students.

Student I: "For a particle to feel a magnetic force, it only needs to be within a magnetic field."

Student II: "For a particle to feel a magnetic force, it needs to be charged and within a magnetic field."

Student III: "For a particle to feel a magnetic force, the particle must be charged and moving within the magnetic field."

Which, if any, of these three students do you believe is correct? Explain fully why you chose as you did.

Student III is closest to the correct answer. To be completely correct the student needed to say the particle would cut across "magnetic field lines".

MFF2a—CCT2: Charged Particle and a Uniform Magnetic Field

Consider the following statements made by three students.

Student I: "For a particle to feel a magnetic force, it must be charged and moving in a magnetic field."

Student II: "For a particle to feel a magnetic force, it must be charged and moving in a magnetic field cutting across the magnetic field."

Student III: "A moving charged particle will experience a magnetic force only if it moves perpendicular to the field."

Which, if any, of these three students do you believe is correct? Explain fully why you chose as you did.

Student II is correct. A moving charged particle will experience a magnetic force only if it has a component of its velocity perpendicular to the field.

MFF2a—WWT1: Charged Particle and a Uniform Magnetic Field

"A proton moving to the east enters a magnetic field pointed up, i.e., away from the center of the Earth. The proton feels a magnetic force whose direction is toward the north."

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.

If the direction of the magnetic force is changed to toward the south, then the statement would be correct.

MFF2A—WWT2: CHARGED PARTICLE AND A UNIFORM MAGNETIC FIELD

"An electron moving to the east enters a magnetic field. Since the electron feels a magnetic force whose direction is north, the direction of the magnetic field must be (out of the horizontal plane.)"

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.

This is a correct statement.

MFF2a—WWT3: Charged Particle and a Uniform Magnetic Field

What, if anything, is wrong with the following statement? 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.

"A neutron moving to the west enters a magnetic field pointed up and out of the horizontal plane . The neutron feels no magnetic force while in the magnetic field."

This is a correct statement since the neutron has no electrical charge.

MFF2a–WWT4: Charged Particles and a Uniform Magnetic Field

What, if anything, is wrong with the following statement? 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.

"Two particles that have the same mass and electric charge enter the same uniform magnetic field traveling the same speed at far apart different locations, so they do not effect each other. The radius of the circular path for these particles will be the same."

This statement is correct if they both enter the uniform magnetic field at the same angle of approach. If they do not enter at the same angle of approach, then the statement is not true.

Note that $F = qvB\sin\theta$ and $F = mv^2/r$; so, $r = mv / (qB\sin\theta)$.

MFF2a—TT1: Charged Particle and a Uniform Magnetic Field

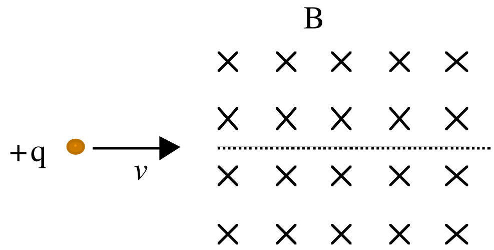
There is at least one error in the statement below. Identify the error(s) and explain how to correct it.

"A proton moving to the east enters a magnetic field. Since the proton feels a magnetic force whose direction is north, the direction of the magnetic force must be down (into the horizontal plane.)"

The statement would be correct if the "direction of the magnetic force…" is changed to the "direction of the magnetic field…".

MFF2a—TT2: Charged Particle and a Uniform Magnetic Field

As shown in the figure below, a proton is moving to the right at a velocity v when it enters a magnetic field. The magnetic field is uniform and into the paper. (The magnetic field is indicated by x's). The path of the proton in the magnetic field is indicated by the dotted line.

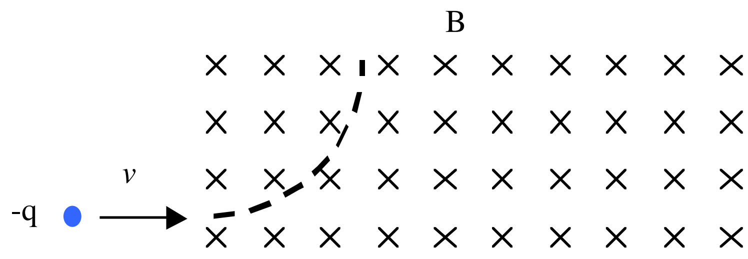


There is at least one error in the diagram and/or statement above. Identify the error(s) and explain how to correct it.

The path of the proton inside the magnetic field should be curved upward.

MFF2a—TT3: Charged Particle and a Uniform Magnetic Field

As shown in the figure below, an electron is moving to the right at a velocity v when it enters a magnetic field. The magnetic field is uniform and into the paper. (The magnetic field is indicated by x's.) The path of the electron in the magnetic field is indicated by the dotted curve.

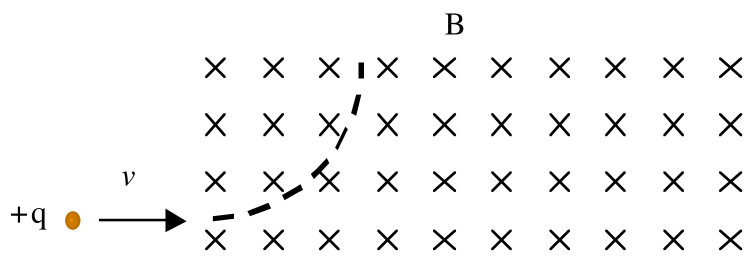


There is at least one error in the diagram and/or statement above. Identify the error(s) and explain how to correct it.

The path of the electron once it is inside the magnetic field, should be curved downwards.

MFF2A—LMCT1: CHARGED PARTICLE AND A UNIFORM MAGNETIC FIELD

The figure below shows a charged particle moving at a constant velocity about to enter a region in which there is a uniform magnetic field. The magnetic field is into the paper. When the charged particle enters the magnetic field, it feels a magnetic force.



A number of changes in this situation will be described below. For each change, you are to identify how the change will affect, if it will, the magnetic force felt by the particle shortly after entering the field.

The possible answers are:

A. This change will alter only the direction of the force felt by the particle.

B. This change will only increase the magnitude of the magnetic force felt by the particle.

C. This change will only decrease the magnitude of the magnetic force felt by the particle.

D. This change will alter both the magnitude and direction of the magnetic force felt by the particle.

E. This change will not affect the magnetic force felt by the particle.

Each change below refers to the original situation stated above:

The particle is replaced by a larger magnitude, positively charged particle. ___*B*____

The particle is replaced by a negatively charged particle. ___*A*____

The particle is replaced by an neutral particle. ___*D*____

The particle enters the region moving at a slower initial velocity. ___*C*____

The particle enters the region moving at a faster initial velocity. ___*B*____

The magnetic field is twice its original strength. ___*B*____

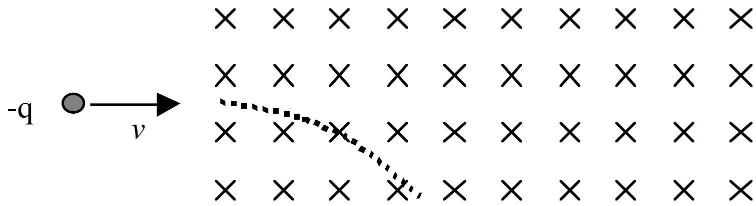
The magnetic field is one-third its original strength. ___*C*____

The direction of the magnetic field is parallel to the particle's initial velocity. ___*D*____

The direction of the magnetic field is 45° to the particle's initial velocity. ___*D*____

MFF2a—LMCT2: Charged Particle and a Uniform Magnetic Field

The figure below shows a charged particle moving at a constant velocity about to enter a region in which there is a uniform magnetic field. The magnetic field is into the paper. When the charged particle enters the magnetic field, it feels a magnetic force.



A number of changes in this situation will be described below. For each change, you are to identify how the change will affect, if it will, the magnetic force felt by the charged particle shortly after entering the field.

The possible answers are:

A. This change will only alter the direction of the force felt by the charged particle.
B. This change will only increase the magnitude of the magnetic force felt by the charged particle.
C. This change will only decrease the magnitude of the magnetic force felt by the charged particle.
D. This change will alter both the magnitude and direction of the magnetic force felt by the charged particle.
E. This change will not affect the magnetic force felt by the charged particle.

Each change below refers to the original situation stated above:

The particle is replaced by a larger magnitude, negatively charged particle. ____*B*___

The charged particle is replaced by a positive charged particle. ____*A*___

The charged particle enters the region moving at a slower constant velocity. ____*C*___

The charged particle enters the region moving at a faster constant velocity. ____*B*___

The magnetic field is twice its original strength. ____*B*___

The magnetic field is one-third its original strength. ____*C*___

The direction of the magnetic field is opposite to the charged particle's initial velocity. ____*D*___

The direction of the magnetic field is 45° to the charged particle's initial velocity. ____*D*___

MFF2a—PET1: Charged Particle and a Uniform Magnetic Field

A proton is moving at a constant speed toward the east. Along the path of the proton is a region in which the magnetic field is uniform and is directed towards the north.

What will happen to the proton when it enters the magnetic field? Explain fully.

When the proton enters the uniform magnetic field, it will feel a magnetic force upwards out of the plane causing the path of the proton to curve upwards out of the plane.

MFF2A—PET2: CHARGED PARTICLE AND A UNIFORM MAGNETIC FIELD

An electron is moving at a constant speed toward the east. Along the path of the electron is a region in which the magnetic field is uniform and is directed towards the north.

What will happen to the electron when it enters the magnetic field? Explain fully.

When the electron enters the uniform magnetic field, it will feel a magnetic force downward into the plane causing the path of the electron to curve downward into the plane.

MFF2a—PET3: Charged Particle and a Uniform Magnetic Field

A proton is placed at rest in a region in which the magnetic field is uniform and is directed towards the north.

What will happen to the proton when it is released? Explain fully.

When the proton is released, it will stay where it is located feeling no magnetic force because the velocity is zero.

MFF2A—PET4: CHARGED PARTICLE AND A UNIFORM MAGNETIC FIELD

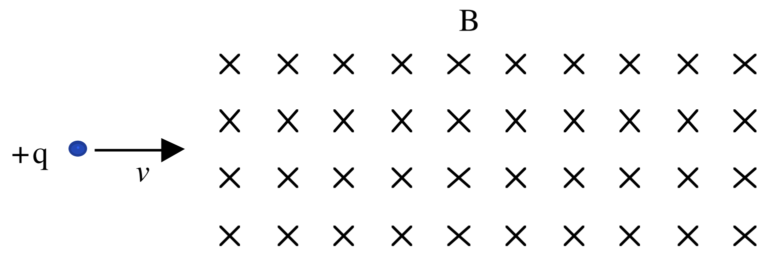
A proton is moving at a constant speed toward the east. Along the path of the proton is a region in which the magnetic field is uniform and is directed eastward as well.

What will happen to the proton when it enters the magnetic field? Explain fully.

When the proton enters the uniform magnetic field, it will not feel a magnetic force and will continue on its original path. This happens here because the angle between the proton's velocity and the magnetic field is 0, so sin0 = 0.

MFF2a—M/MCT1: Charged Particle and a Uniform Magnetic Field

The figure below shows a proton moving at 5.00×10^7 m/s about to enter a region in which there is a uniform magnetic field of 200 mT.



Given below is a student's calculation for the magnitude of the magnetic force on the proton once it enters the magnetic field.

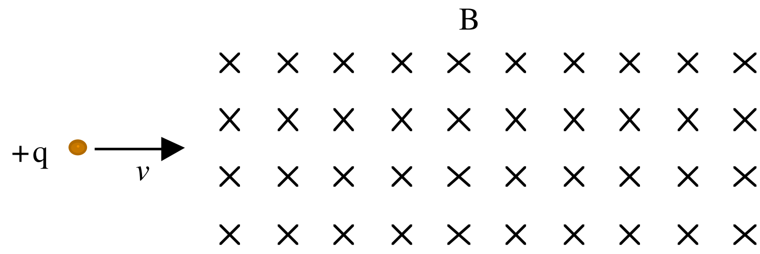
$$F_B = (1.602\text{x}10^{-19}\text{C})(5.00\text{x}10^{7}\text{ m/s})(.200\text{T})$$

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)?

This is a meaningful calculation of the magnitude of the magnetic force felt by the proton once it enters the uniform magnetic field.

MFF2a—QRT1: Charged Particle and a Uniform Magnetic Field

The figure below shows a proton entering a region of uniform magnetic field strength pointing into the paper.



(1) What is the direction of the magnetic force acting on the proton when it enters the magnetic field?

Toward the top of the page.

(2) What would be the path of the proton within the magnetic field?

Circular or curved toward the top of the page.

(3) What would the direction of the magnetic force be when the proton enters the field if the direction of the magnetic field was out of the paper?

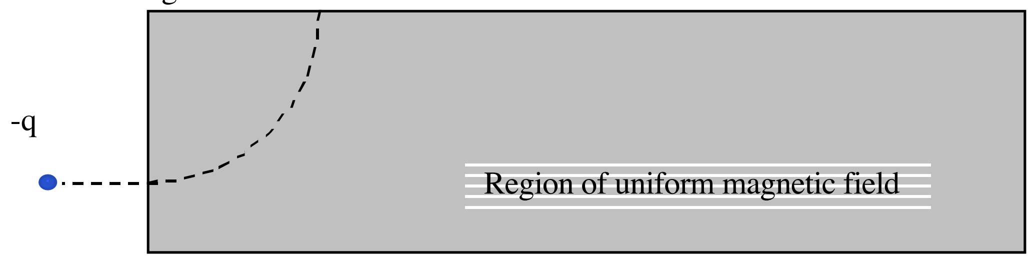
Towards the bottom of the page.

(4) What would happen to the direction of the magnetic force and the path if we changed the charged particle from a proton to an electron?

The direction of the magnetic force would be opposite that for the proton and the path would curve toward the bottom of the page.

MFF2a—QRT2: Charged Particle and a Uniform Magnetic Field

The figure below shows the motion of a negatively charged particle in a region of uniform magnetic field strength.



(1) What is the direction of the magnetic field acting on the particle?

Out of the paper

(2) If we double the speed of the original particle entering the uniform magnetic field, what will happen to the path of the particle in the uniform magnetic field?

It will curve out of the paper toward the reader at a greater curvature (smaller radius)

(3) If we double the magnitude of the uniform magnetic field, what will happen to the path of the particle in the uniform magnetic field?

Same as (2)

(4) If we change the original particle to a negatively charged particle of twice the charge of the original particle, what will happen to the path of this negatively charged particle in the uniform magnetic field?

It would curve out of the paper toward the reader at a greater curvature (smaller radius)

(5) If we change the original particle to a positive particle, what would be the direction of the magnetic field acting on the positive particle?

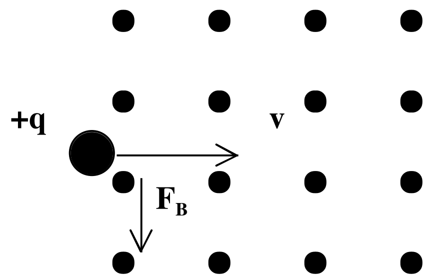
Into the paper

MFF2a—CRT1: Charged Particle and a Uniform Magnetic Field

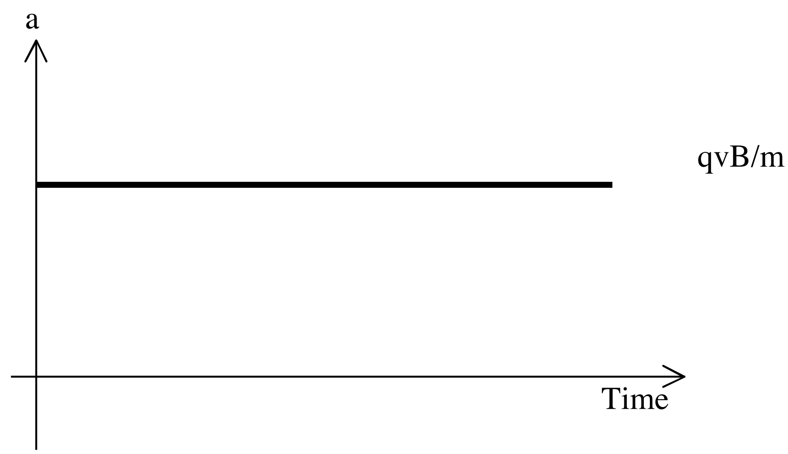
The equation below represents at an instant the magnetic force on a charged particle moving in a uniform magnetic field.

$$-6.49\text{x}10^{-12}\,\hat{\mathbf{j}}\text{N} = (1.602\text{x}10^{-19}\text{C})(2.50\text{x}10^{7}\,\hat{\mathbf{i}}\text{m/s})\,\mathbf{x}\,(1.62\hat{\mathbf{k}}\text{T})$$

Draw an appropriate diagram showing the magnetic field, the particle's velocity and the force on the particle at this instant.



Graph the magnitude of the acceleration of the charged particle versus time while it is in the magnetic field.

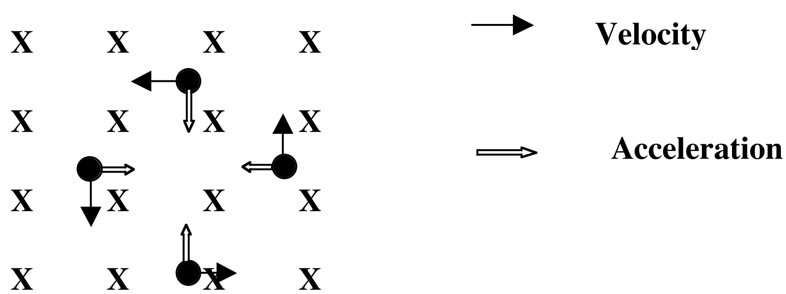


MFF2a—CRT2: Charged Particle and a Uniform Magnetic Field

The equation below represents the radius of the circular path for a charged particle moving in a uniform magnetic field.

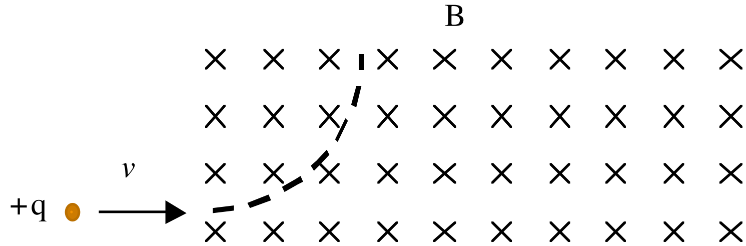
$$r = \frac{(1.67x10^{-27}\,kg)(5.00x10^{7}\,m/s)}{(1.602x10^{-19}\,C)(2.00T)}.$$

Draw a motion diagram, i.e., show the position, with the corresponding velocity and acceleration vectors for four equally separated time intervals, for this particle in the field.



MFF2a—CRT3: Charged Particle and a Uniform Magnetic Field

Shown below is the path of a proton moving at 2 x 10^6 m/s in a magnetic field of uniform strength 2 T.



Draw an appropriate graph of the magnitude of the magnetic force on the proton versus time that the proton feels while in the magnetic field.