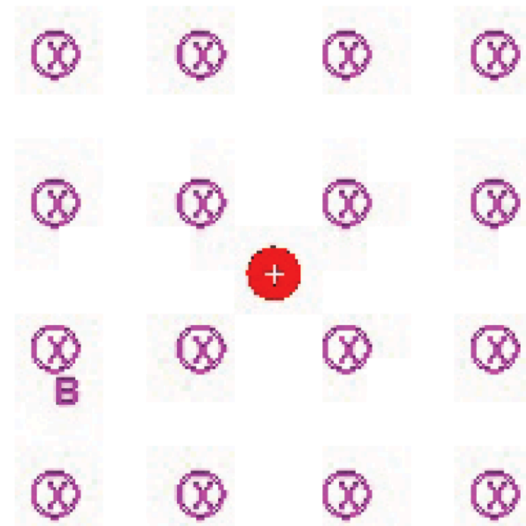
Practice with the right-hand rule

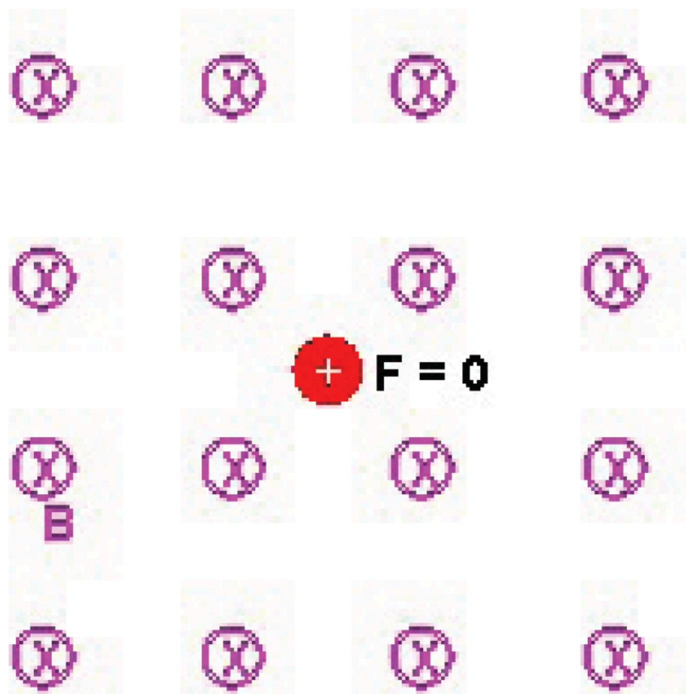
In what direction is the force on a positive charge that is moving out if the screen in a uniform magnetic field directed into the screen?



1. up
2. down
3. left
4. right
5. into the screen
6. out of the screen
7. a combination of two of the above
8. the force is zero
9. this case is ambiguous - we can't say for certain

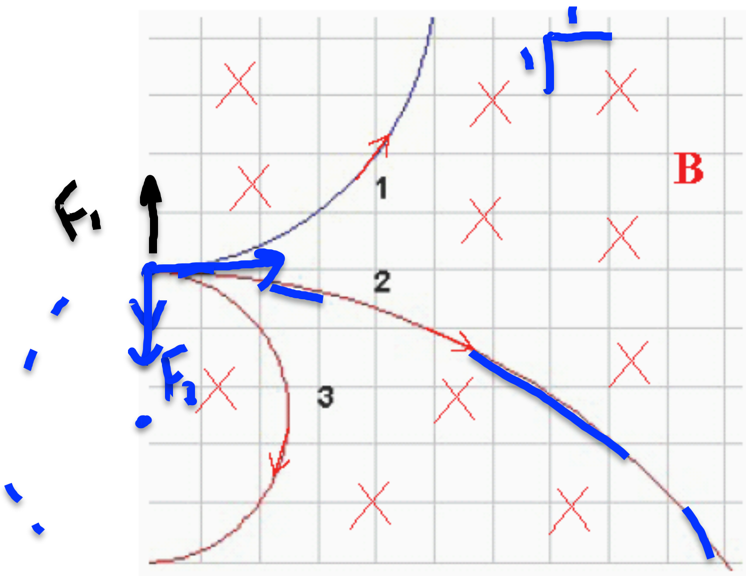
Practice with the right-hand rule

Magnetic field exert no force on a charge moving in *parallel* to the field.



Where is an electron?

If the magnetic field is directed in the screen, find which particle has a negative charge and which has a positive charge?



Which particle is POSITIVE?

1

2

3

4 1,2

5 1,3

6 2,3

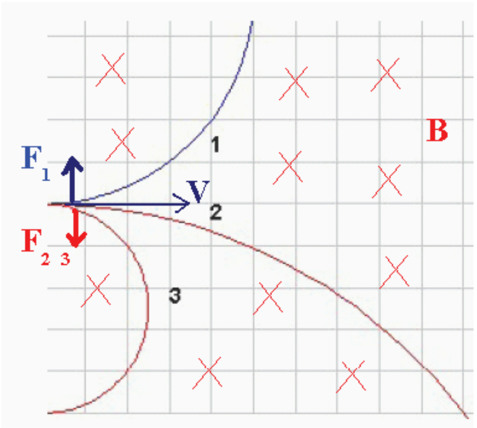
7 1,2,3

8 None

Where is an electron?

If the magnetic field is directed in the screen, find which particle has a negative charge and which has a positive charge?

We can use the right- hand rule to find it out, but first we need to show the velocities and forces in the picture. If we apply the rule to a particle and the ***actual*** force has the same dire3ction as the thumb, that particle is *positively* charged.



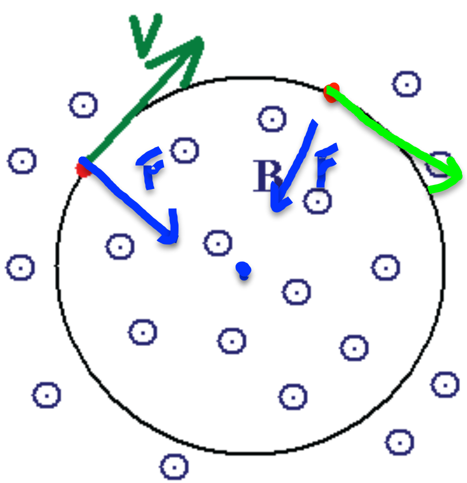
For the particle #1: an index finger is to the right, a middle finger is in the screen, a thumb points up, as the force does, so the charge # 1 is positive.

Charges #2 and #3 are negative.

A proton in a magnetic field

A proton moving at the speed of v encounters magnetic field B which is perpendicular to the velocity of the proton.

The proton is moving culturally in the field.



The work done by the magnetic field on the proton is:

1) positive

2) negative

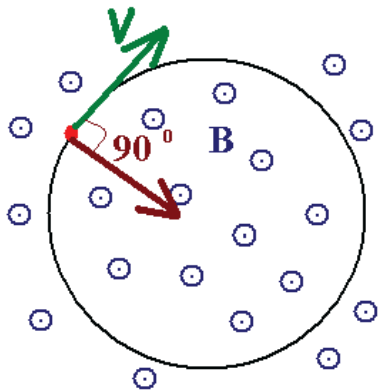
3) zero

4) not enough information to answer

A proton in a magnetic field

A proton moving at the speed of v encounters magnetic field B which is perpendicular to the velocity of the proton.

The proton is moving culturally in the field.



The work done by the magnetic field on the proton is:

3) zero

The work done by a force on an object is

$$W = P{*}t;$$

Here, P is a power of the force

$$P = v{*}F{*}\cos(\theta_{angle\text{-}between\text{-}F\text{-}and\text{-}v})$$

By the right-hand rule a magnetic force is *always* **perpendicular** to the velocity of a particle!

$$F_{magnetic} \perp v \quad \Rightarrow \quad \theta_{angle\text{-}between\text{-}F\text{-}and\text{-}V} = 90^0 \quad \Rightarrow \quad \cos(90^0) = 0 \text{ !!}$$

Magnetic force does not do any work! => does not change the kinetic energy => does not change the magnitude of the velocity (only its direction)!

The magnetic force always remains perpendicular to the velocity and is directed toward the center of the circular path.

$$F = ma \qquad a = a_c = \frac{v^2}{r}$$

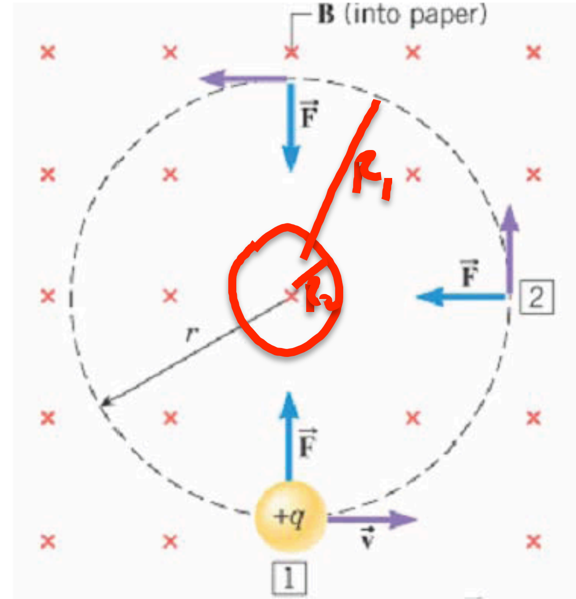
$$E_k = \frac{mv^2}{2}$$

$$F = m\frac{v^2}{r}$$

$$F = |qvB\sin(90^0)| = |q|vB$$

$$|q|vB = m\frac{v^2}{r}$$

$$r = \frac{mv}{|q|B}$$



E_{kin1} vs E_{kin2}

=

>

<

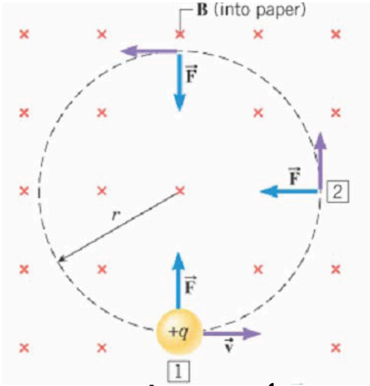
Two identical particles circulate in the same magnetic field. The particle with a larger radius has … E_{kin}

1.= 2. > 3. <

Charges moving perpendicular to the field

The radius of the circular path is:

$$r = \frac{mv}{|q|B}$$



The time for the object to go once around the period, *T*) is:

identical same B

larger r ... T

$$T = \frac{2\pi r}{v} = \frac{2\pi mv/|q|B}{v} = \frac{2\pi m}{|q|B}$$

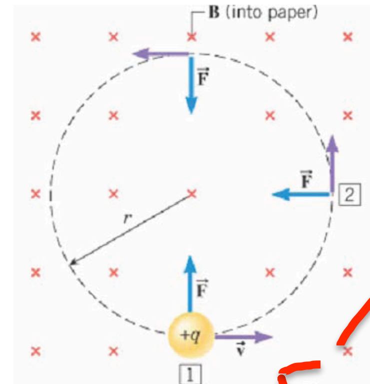
Interestingly, the time is *independent* of the speed.(and radius)

The faster the speed, the larger the radius,
but the period is unchanged.

Charges moving perpendicular to the field

The radius of the circular path is:

$$r = \frac{mv}{|q|B}$$



The time for the object to go once around the period, T) is:

$$T = \frac{2\pi r}{v} = \frac{2\pi mv/|q|B}{v} = \frac{2\pi m}{|q|B}$$

$E_K = \frac{mv^2}{2}$

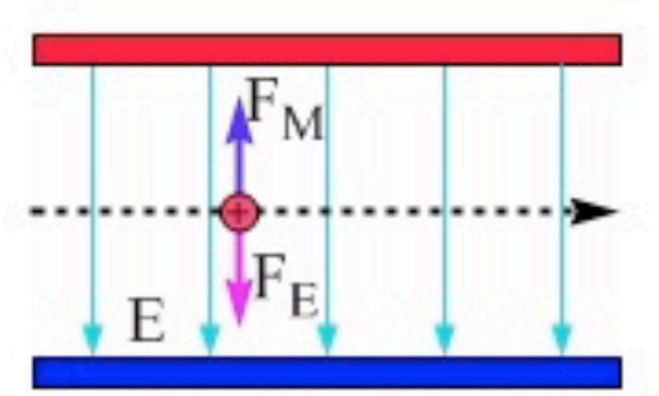
Two identical particles travel in the same magnetic field. The particle with the larger kinetic energy has …. T

1.Larger 2. Smaller 3. The same

Magnetic field in the velocity selector

In what direction is the magnetic field in the velocity selector, if the positive charges pass through undeflected? The electric field is directed down.

1. up
2. down
3. left
4. right
5. into the screen
6. out of the screen

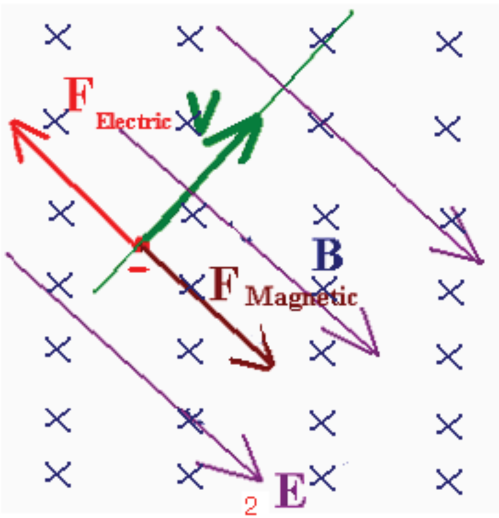


An electron in an electromagnetic field

$$F_{magnetic} = - F_{electric}$$

V = const!

The forces have to have the same magnitude and opposite direction!



$$|F_{magnetic}| = |F_{electric}|$$

$$|evB\sin(90^0)| = |eE|$$

$$\boxed{E = v_* B} \quad (!)$$

The answer does *not* depend on the value of the charge!

For the *electron* the electric field has the direction *opposite* to the force (because $\boldsymbol{F} = e\boldsymbol{E}$, and $e < 0$).

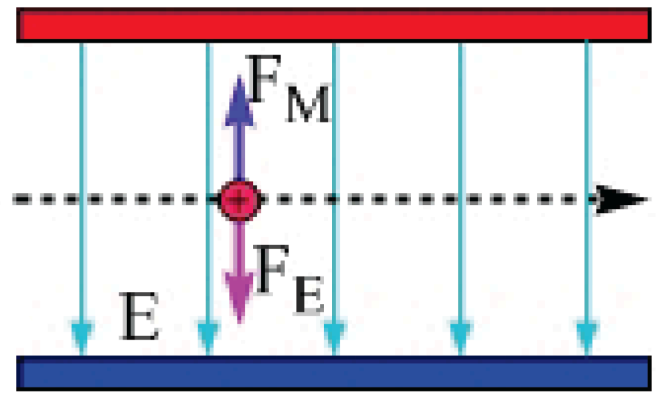
Magnetic field in the velocity selector

The right-hand rule tells us that the magnetic field is directed into the screen

$E = v_* B$

A positive charge traveling ***faster*** than E/B deflects …

1. Up
2. down

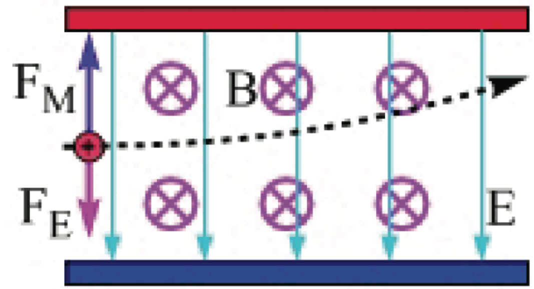


There is a uniform magnetic field, directed perpendicular to the page, between the plates.

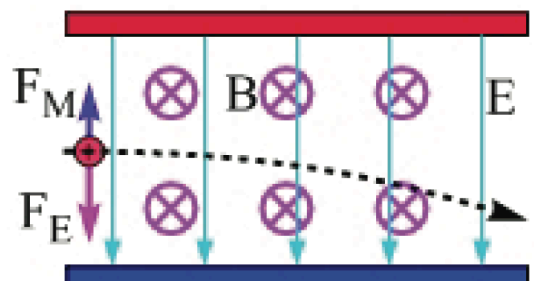
Faster ions in the velocity selector

For ions with a larger speed, the magnetic force exceeds the electric force and those ions are deflected up of the beam. The opposite happens for slower ions, so they are deflected down out of the beam.

$$E = v_* B$$



(a) fast particles

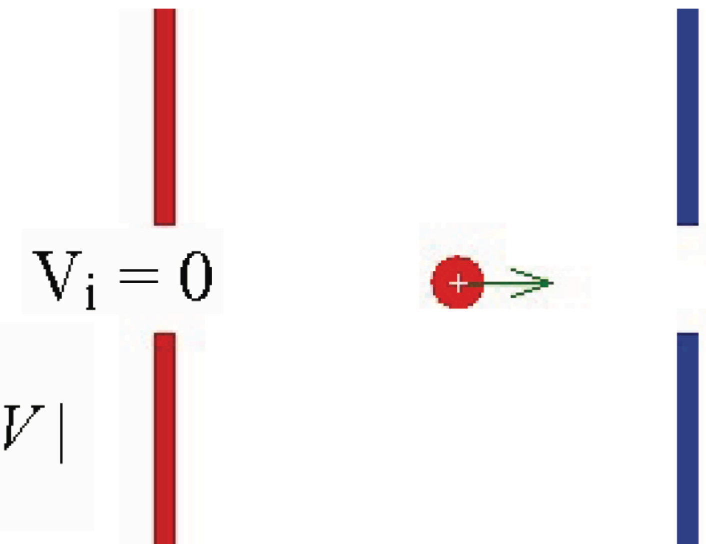


(b) slow particles

Step 1: The Accelerator

The simplest way to accelerate ions is to place them between a set of charged parallel plates. The ions are repelled by one plate and attracted to the other. If we cut a hole in the second plate, the ions emerge with a kinetic energy determined by the potential difference between the plates.

K = $|\, q\, \Delta V \,|$



$$\frac{mV_f^2}{2} = K = W_E = |\, q \cdot \Delta V \,|$$

Step 2: The Velocity Selector

Simulation

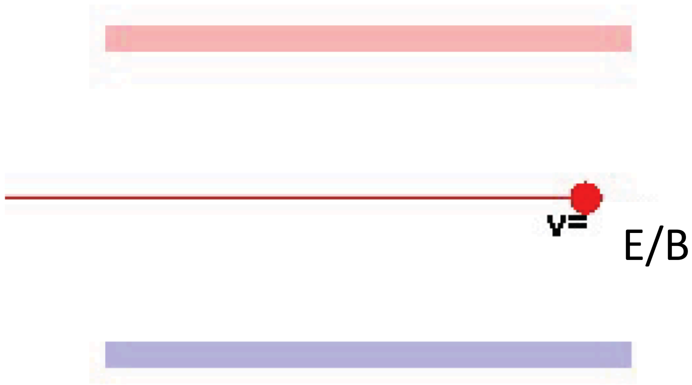
To ensure that the ions arriving at step 3 have the same velocity, the ions pass through a velocity selector, a region with uniform electric and magnetic fields.

The electric field comes from a set of parallel plates, and exerts a force of $\vec{F}_E = q\vec{E}$ on the ions.

The magnetic field is perpendicular to both the ion velocity and the electric field. The magnetic force, $F_M = qvB$, exactly balances the electric force when:

$$qE = qvB \quad \Rightarrow \quad E = vB$$

Ions with a speed of $v = \frac{E}{B}$ pass straight through.

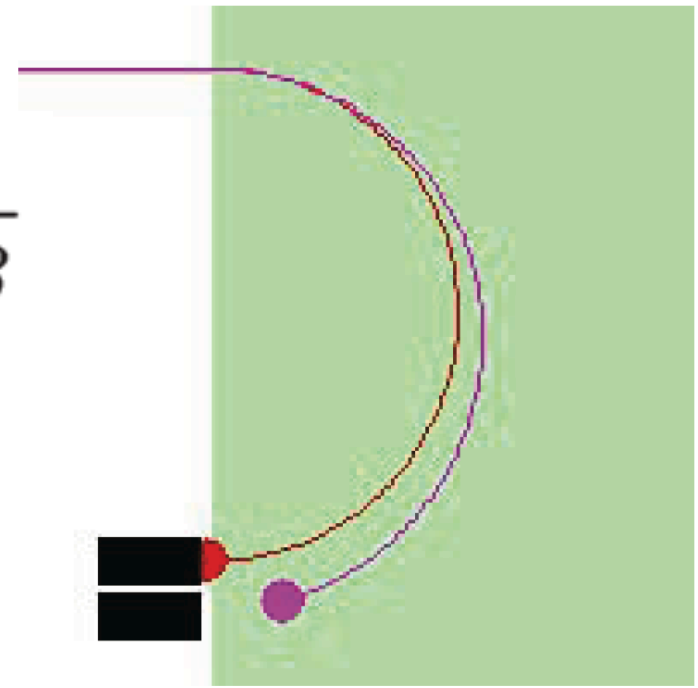


Magnetic field in the mass separator

In what direction is the magnetic field in the mass separator? The paths shown are for positive charges.

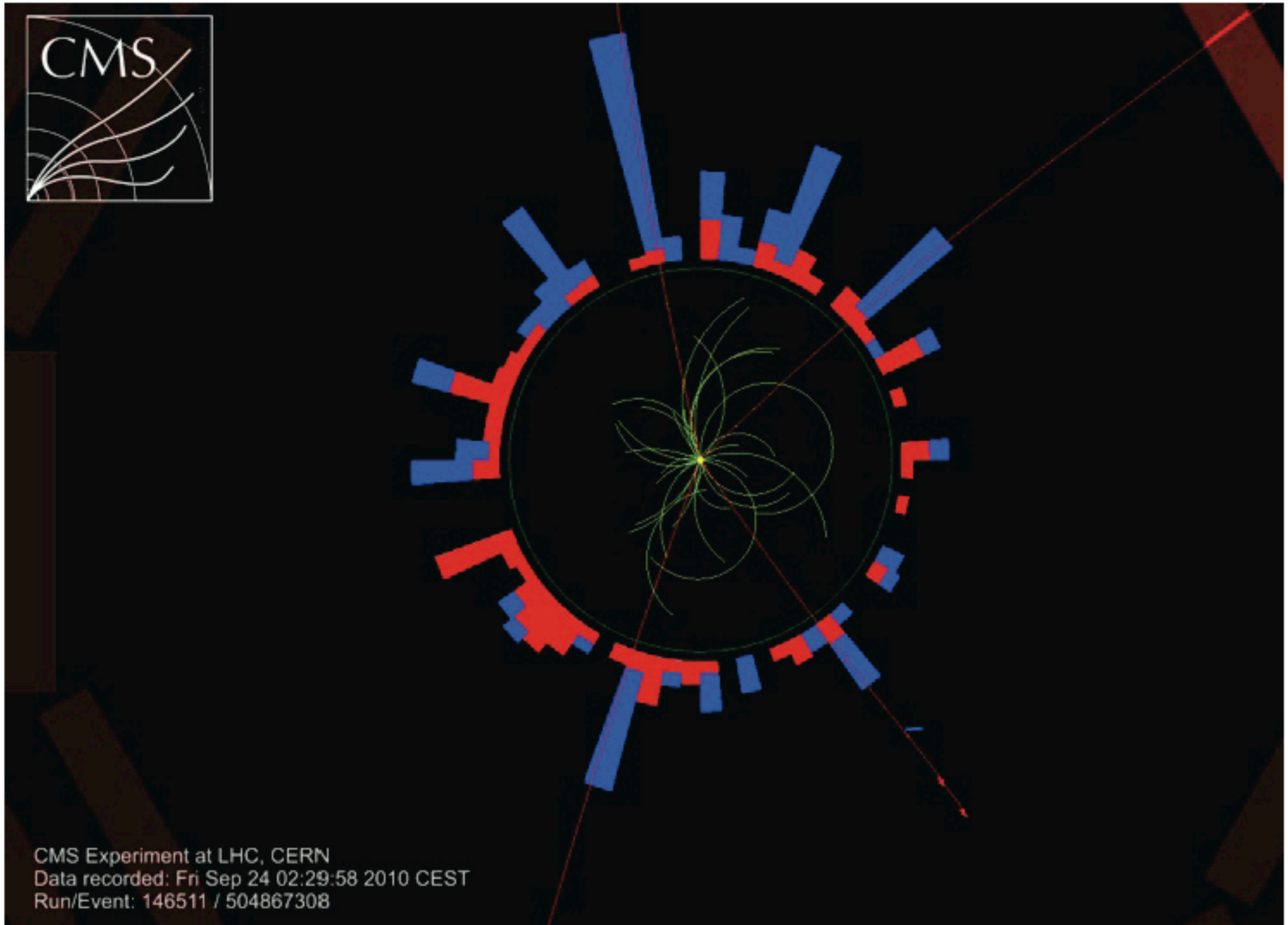
1. up
2. down
3. left
4. right
5. into the screen
6. out of the screen

$$r = \frac{mv}{|q|B}$$



If we know speed, R and B, we can calculate q/m !

ρ-φ view (zoom)


CMS
CMS Experiment at LHC, CERN
Data recorded: Fri Sep 24 02:29:58 2010 CEST
Run/Event: 146511 / 504867308

Possible paths of a charge in a magnetic field

If the velocity of a charge is parallel to the magnetic field, the charge moves with constant velocity because there's no net force.

If the velocity is perpendicular to the magnetic field, the path is circular because the force is always perpendicular to the velocity.

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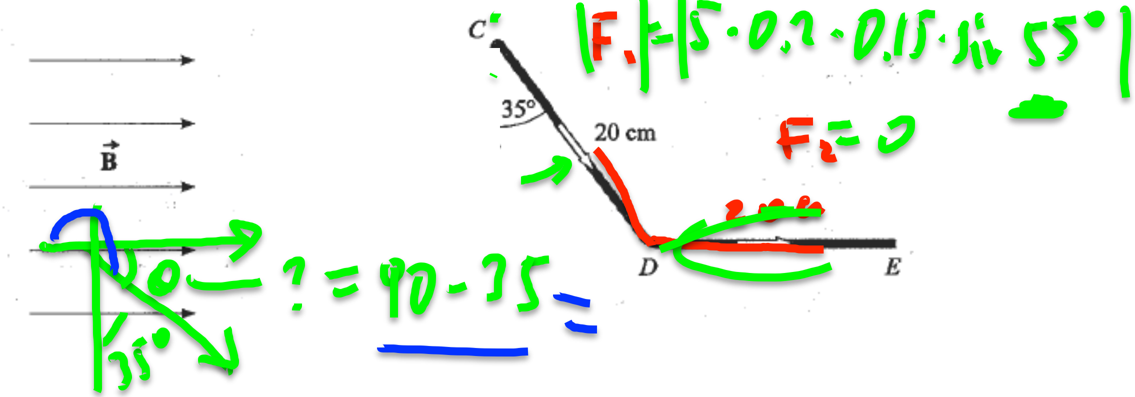
Physics Options

(and the magnetic force is the only force acting on the particle!!)

Find the net force on the wire shown in the picture below if B = 0.15 T. Assume the current in the wire to be 5.0 A.

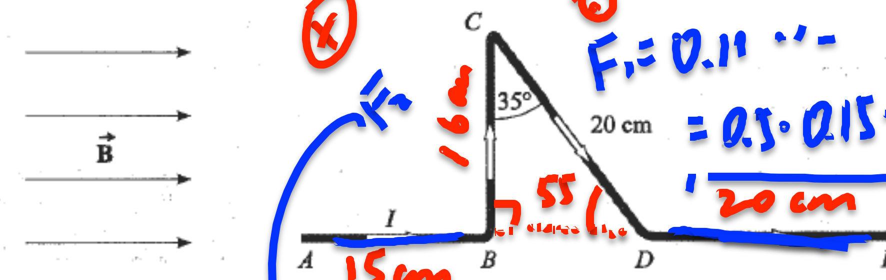
$$|F| = ILB\,|\sin\theta|$$



1. 0 N
2. 0.6 N
3. 0.12 N
4. 0.18 N
5. ??

Find the net force on the wire shown in the picture below if B = 0.15 T. Assume the current in the wire to be 5.0 A.

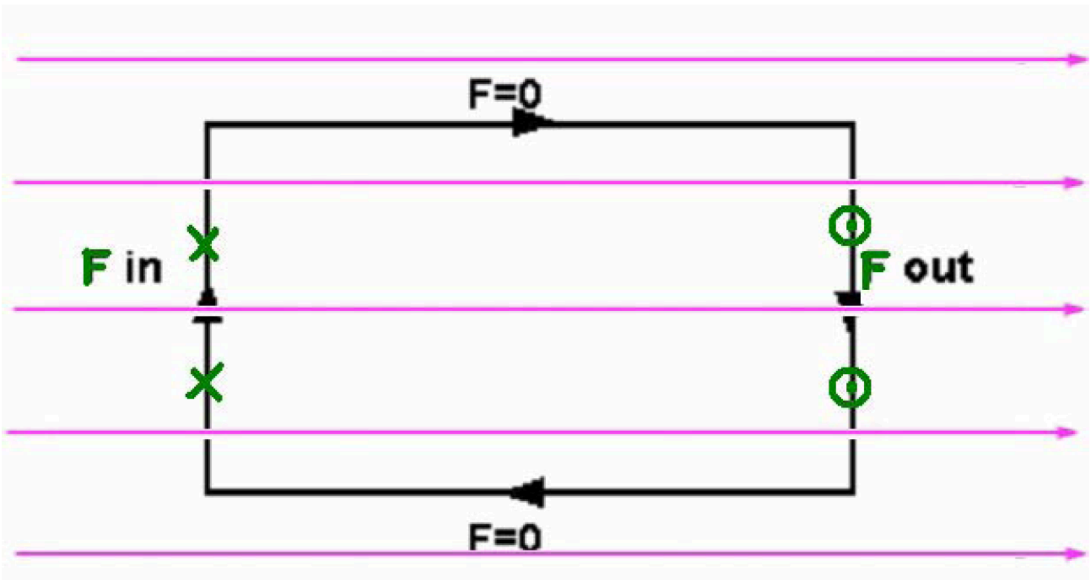
$$|F| = ILB|\sin\theta|$$



1. 0 N 2. 0.6 N 3. 0.12 N 4. 0.18 N 5. ??

Is there a net anything on the loop?

Is the net force on the loop still zero? Is there a net anything on the loop?



The net force is still zero, but there is a net torque that tends to make the loop spin.

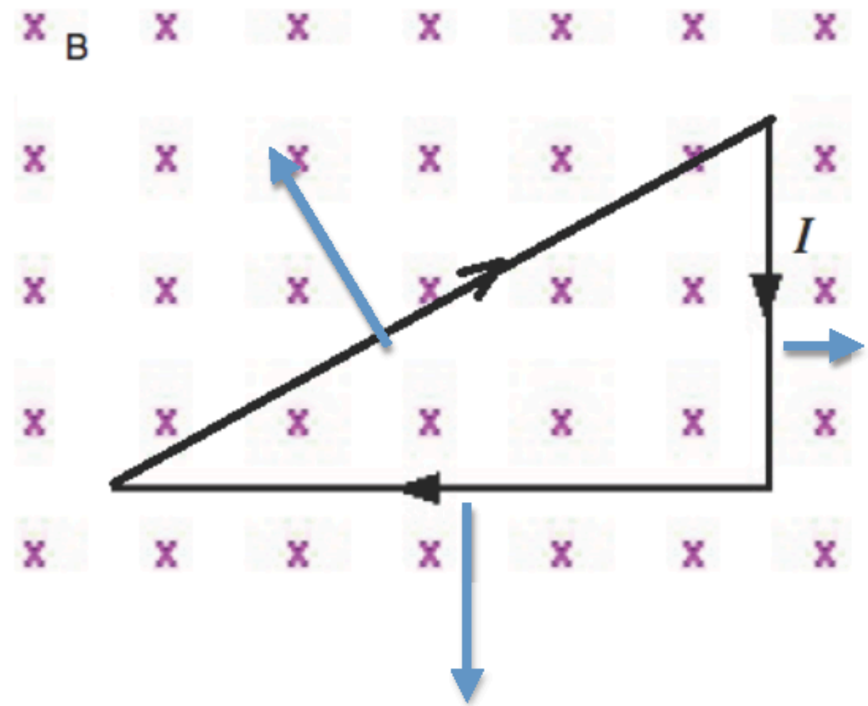
The force on a current-carrying loop

A wire loop carries a clockwise current in a uniform magnetic field directed into the page.

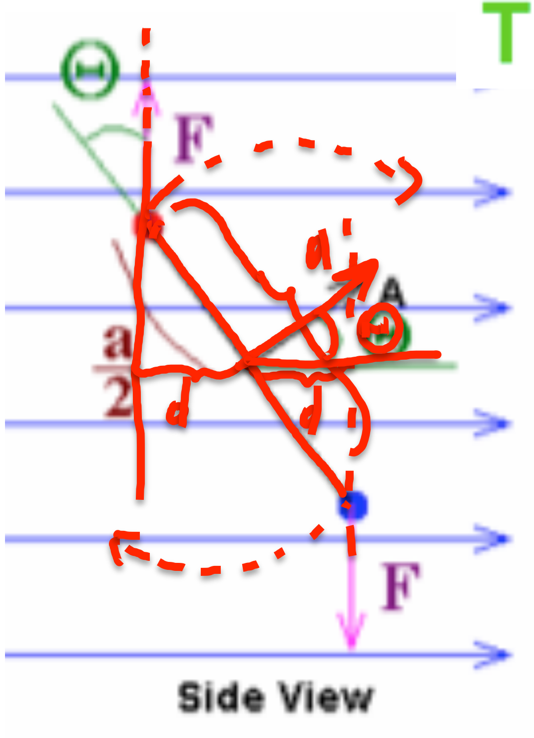
In what direction is the net force on the loop?

The net force is zero

For ANY shape, as long as the field is uniform.



The torque on a current loop



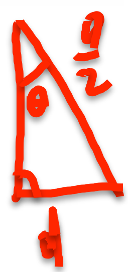
$\tau_1 = F \cdot d$

$\tau_2 = F \cdot d$

$\tau_{net} = \tau_1 + \tau_2 = 2 \cdot F \cdot d = 2 \cdot F \cdot \frac{a}{2} \cdot \sin\theta =$

↓

$I \cdot B \cdot b \cdot \sin 90°$



$d = \frac{a}{2} \cdot \sin\theta$

$= I\, B\, a \cdot b \cdot \sin\theta =$

$= I\, B \cdot A \cdot \sin\theta$

The torque on a current loop

$$\tau_{max} = IAB$$

This is the maximum possible torque, when the field is in the plane of the loop.

When the field is perpendicular to the loop the torque is zero.

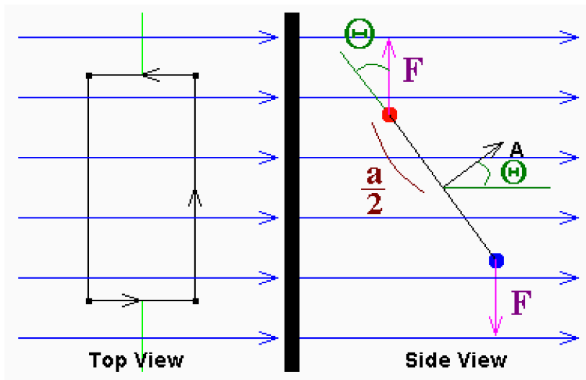
In general, the torque is given by:

$$\tau = IAB\sin\theta$$

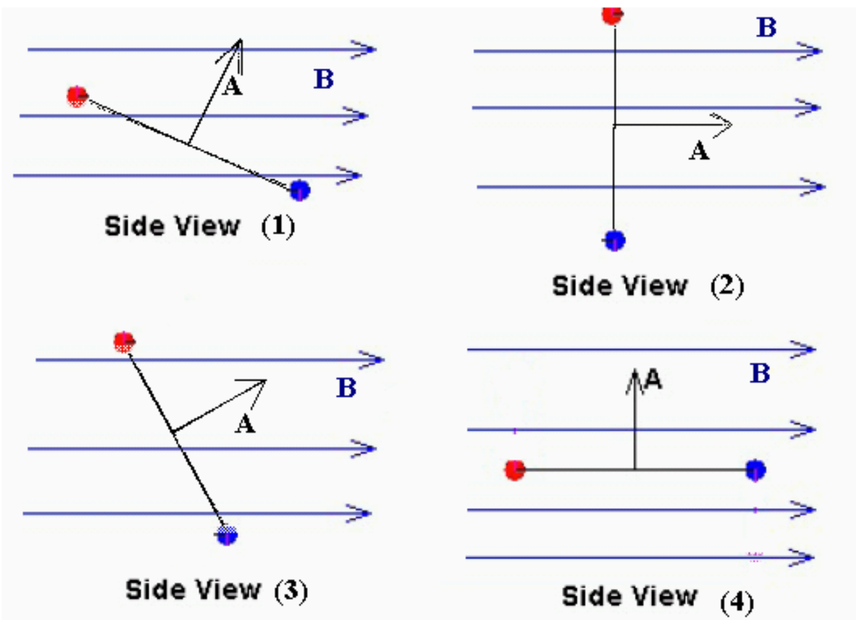
where θ is the angle between the area vector, ***A***, (*which is perpendicular to the plane of the loop*) and the magnetic field, ***B***.

$$\tau = \{F \cdot \frac{a}{2} \cdot \sin\theta\} \cdot 2$$

$$F = IbB$$



A loop in a magnetic field



$$\tau = IAB\sin\theta$$

Four pictures show the instantaneous position of a square loop in a DC motor.

Rank the picture by the magnitude of the torque from the field on the loop from the greatest to the smallest.

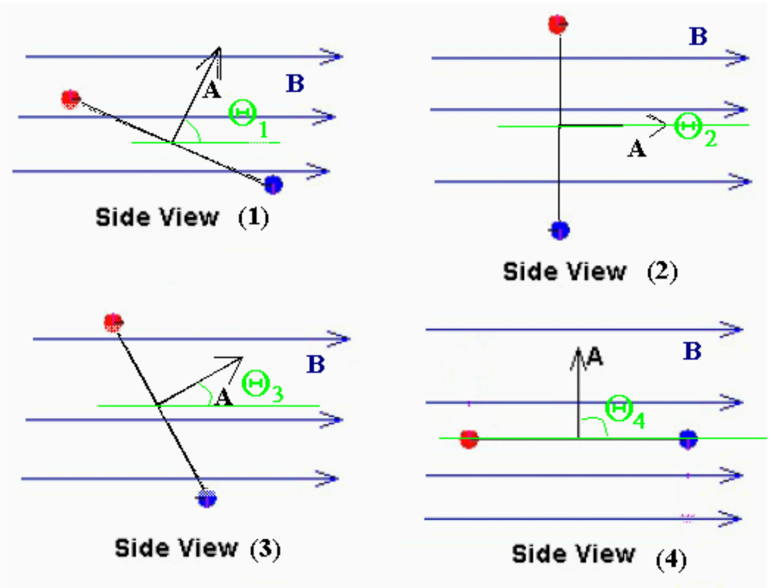
A. 1 > 2 > 3 > 4

B. 4 > 3> 2 > 1

C. 4 > 1 > 3 > 2

D. 2 > 1 > 3 > 4

A loop in a magnetic field



Four pictures show the instantaneous position of a square loop in a DC motor.

Rank the picture by the magnitude of the torque from the field on the loop from the greatest to the smallest.

The magnitude of the torque is:

$$\tau = | IAB \sin\theta |$$

All the variables (I, A, B) except the angle θ are the same.

Form the picture: $\theta_4 > \theta_1 > \theta_3 > \theta_1$ => **C. 4 > 1 > 3 > 2**

(P.S. $\theta_4 = 90^0$ => the strongest torque; $\theta_1 = 0$ => the smallest torque)

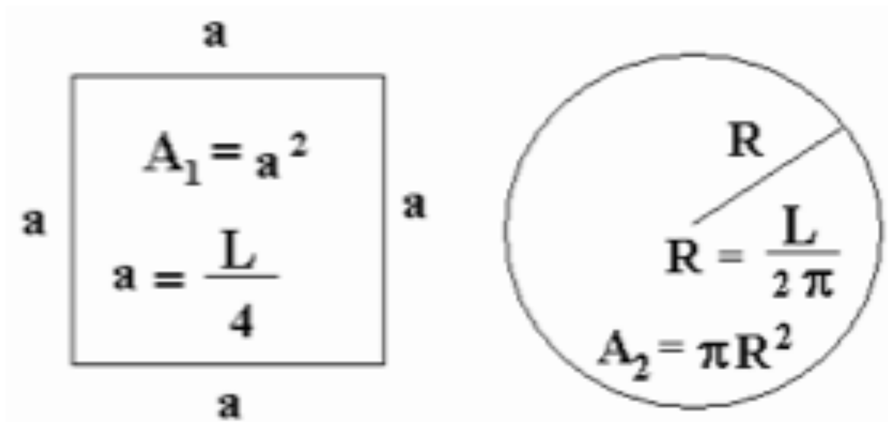
Take a wire of the length of L and make a square loop of it.

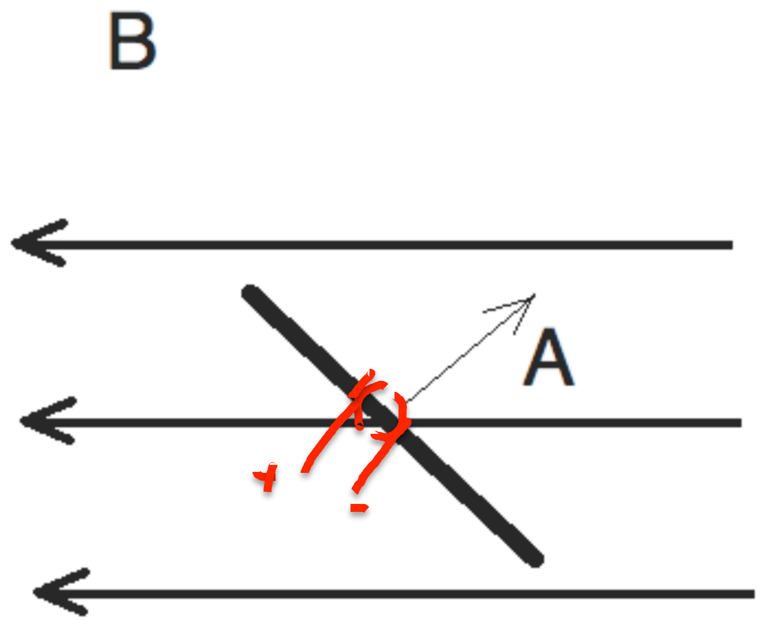
Take another ware of the same length and make a circular loop of it.

If both wire are in the same magnetic field and having the same current, which wire experience the larger strongest torque on it?

$$\tau_{max} = IAB$$

$$\frac{\tau_1}{\tau_2} = \frac{IA_1B}{IA_2B} = \frac{A_1}{A_2} < 1$$





The picture shows magnetick field B (points to the left) and a loop with a current in it so the area vector A points as shown.

If we release the loop from rest, in which direction is it going to start rotating?

1. clockwise

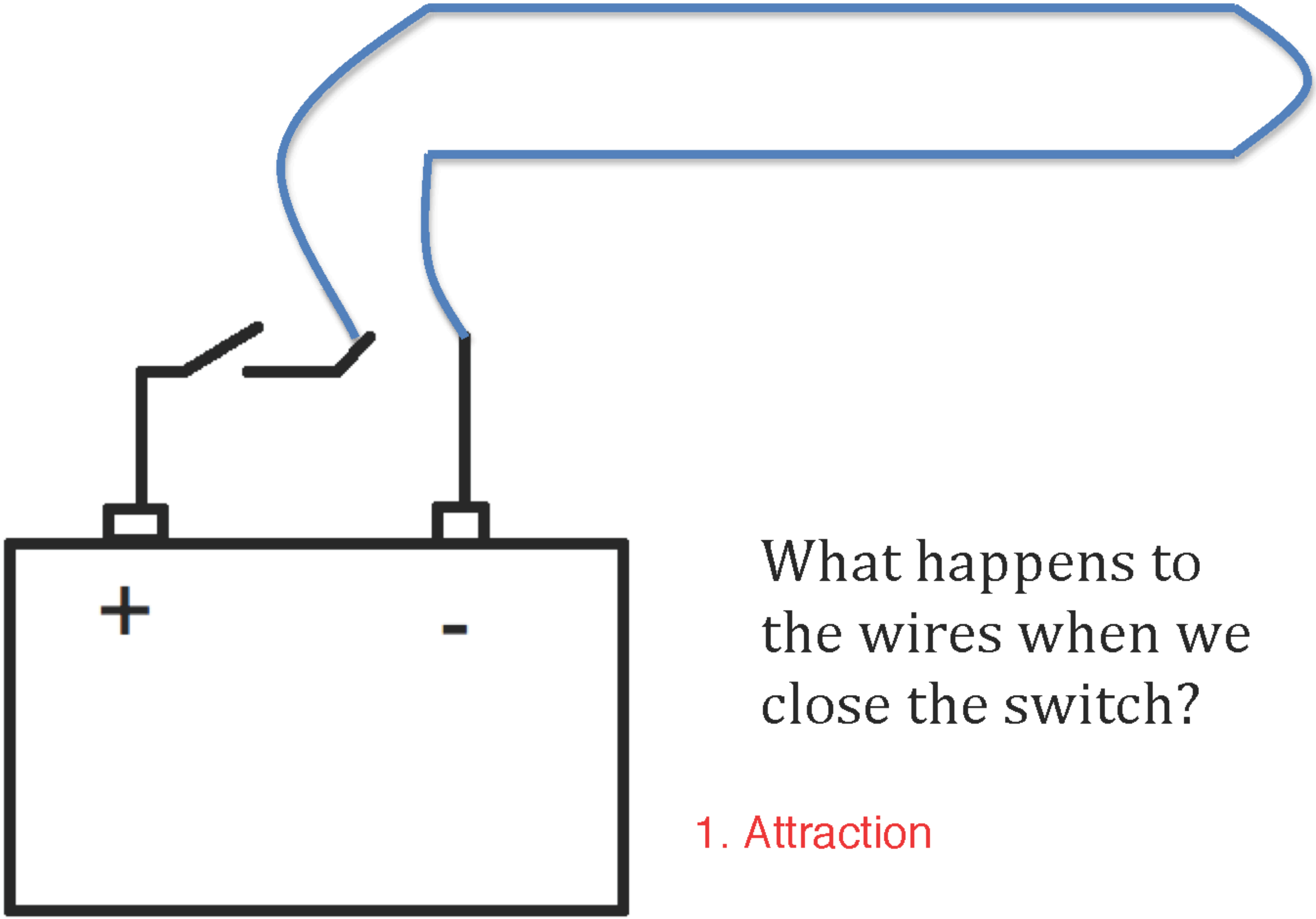
2. counterclockwise

Describe the motion of the loop.

A flat rectangular coil of 25 loops is suspended in a uniform magnetic field of 0.20 T. The plane of the coil is parallel to the direction of the field. The dimensions of the coil are 15 cm perpendicular to the field lines and 12 cm parallel to them. What is the current in the coil if there is a torque of 5.4 N· m acting on it?

1. 60 A **2. 90 A** **3. 120 A** **4. 150 A**

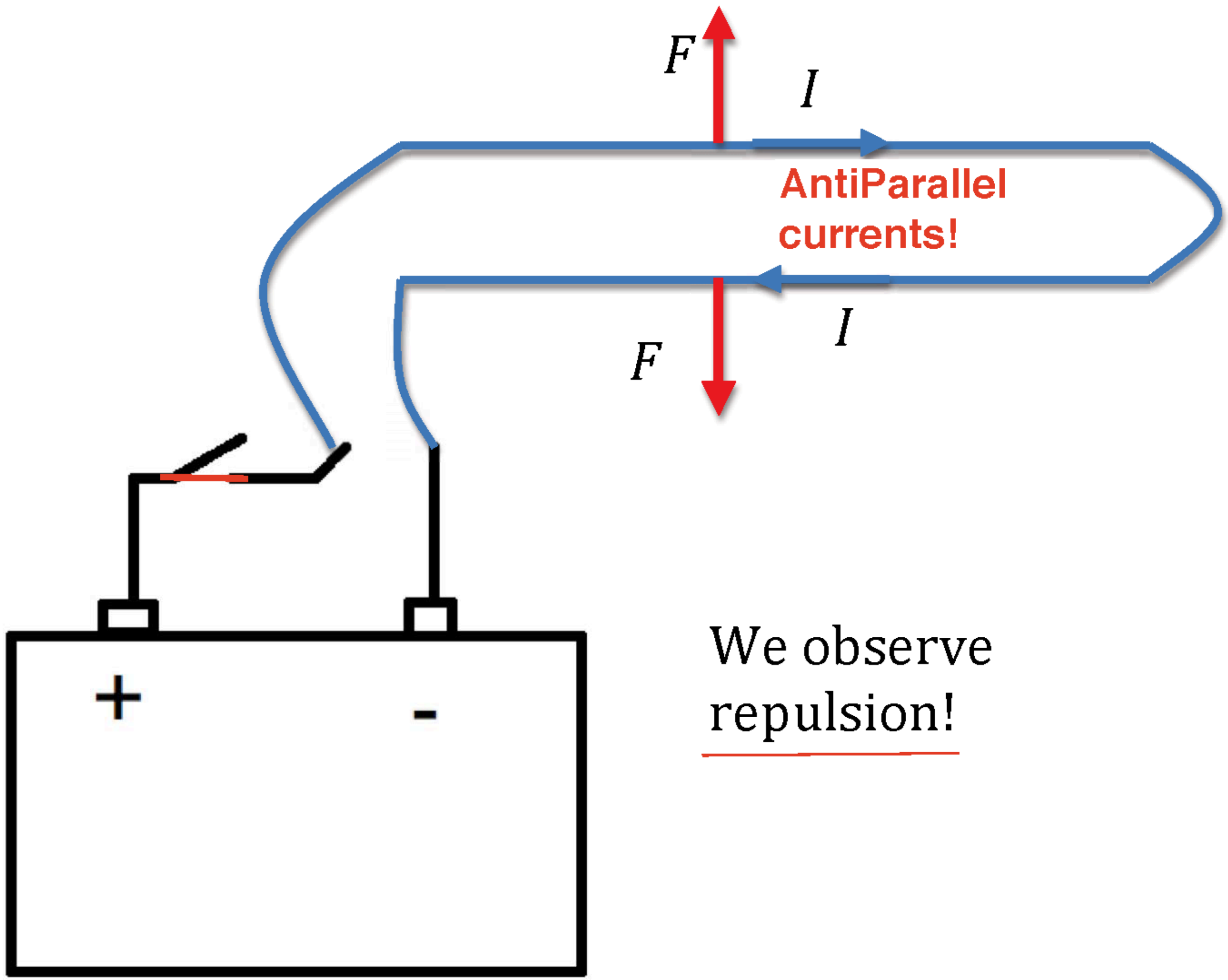
$$\tau = IAB\sin\theta$$



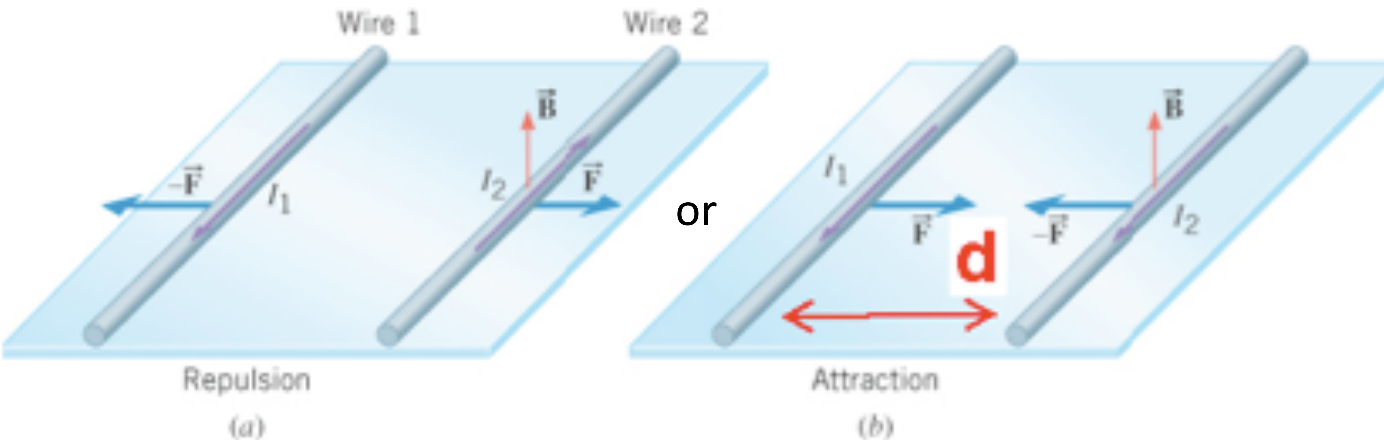
What happens to the wires when we close the switch?

1. Attraction

2. Repulsion



We observe
repulsion!



Wires ≠ charges!

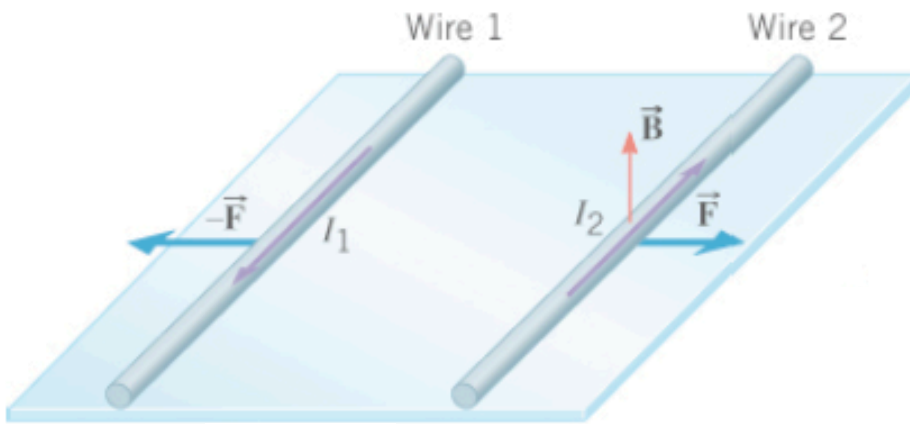
$$\frac{\mu_0}{2\pi}$$

A "universal" constant

For two straight wires:

$$|F| \propto B_1 I_2 \propto B_2 I_1 \propto \frac{I_1 I_2}{d} = C\frac{I_1 I_2}{d}$$

(per unit length, i.e. per 1 m)



$$|F| = \frac{\mu_0}{2\pi}\frac{I_1 I_2}{d}L$$

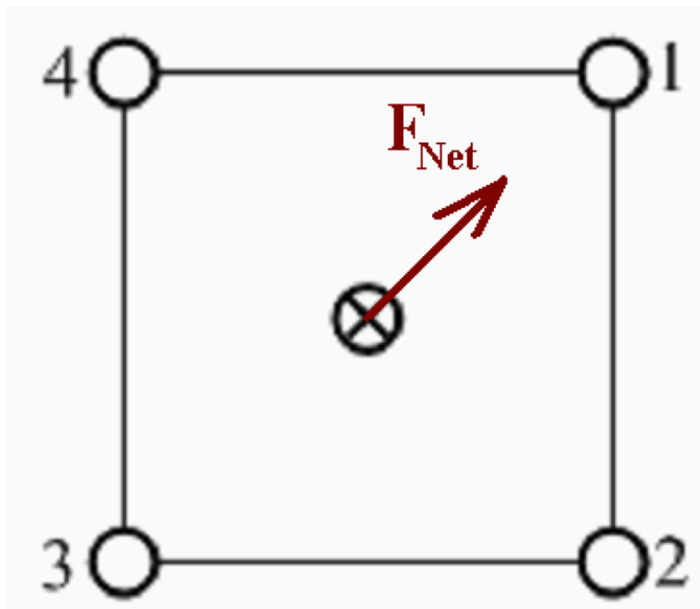
If we double the current in the second wire but increase the distance between the wires four times, find the change in the force between the wires.

1. $F_f = F_i$
2. $F_f > F_i$
3. $F_f < F_i$

You can choose the direction of the currents at each corner.

How many configurations give a net force on the center wire that is directed toward the top-right corner?

1
2
3
4
5
6
7
8
9

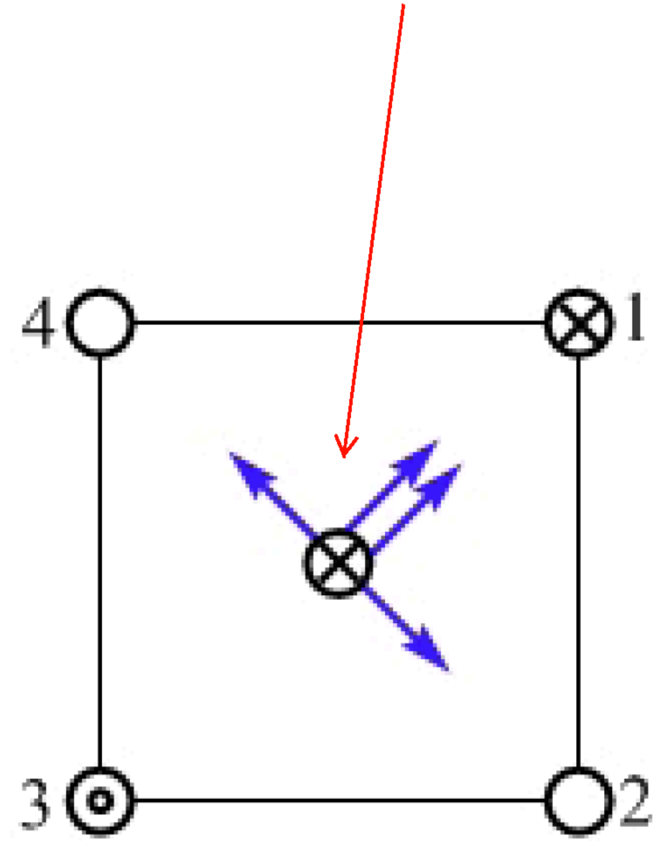


How many ways?

How many ways can we create this set of four forces?

Two. Wires 1 and 3 have to have the currents shown. Wires 2 and 4 have to match, so they either both attract or both repel.

Currents going the same way attract; opposite currents repel.

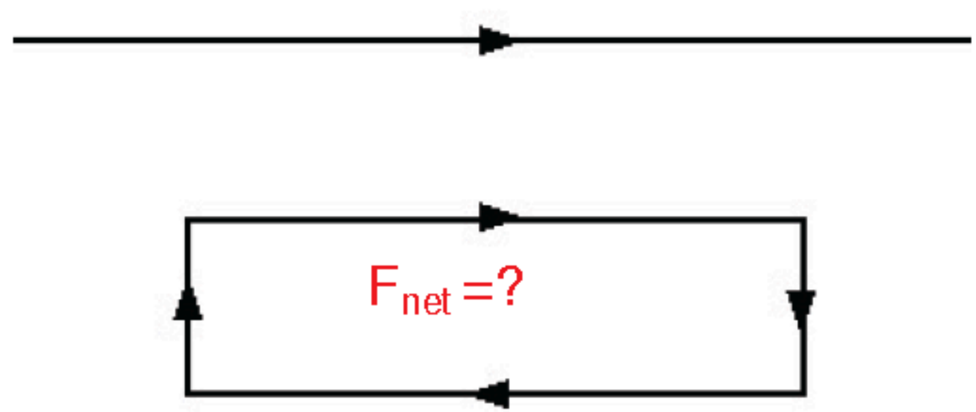


A loop and a wire

A loop with a clockwise current is placed below a long straight wire carrying a current to the right. In which direction is the net force exerted by the wire on the loop?

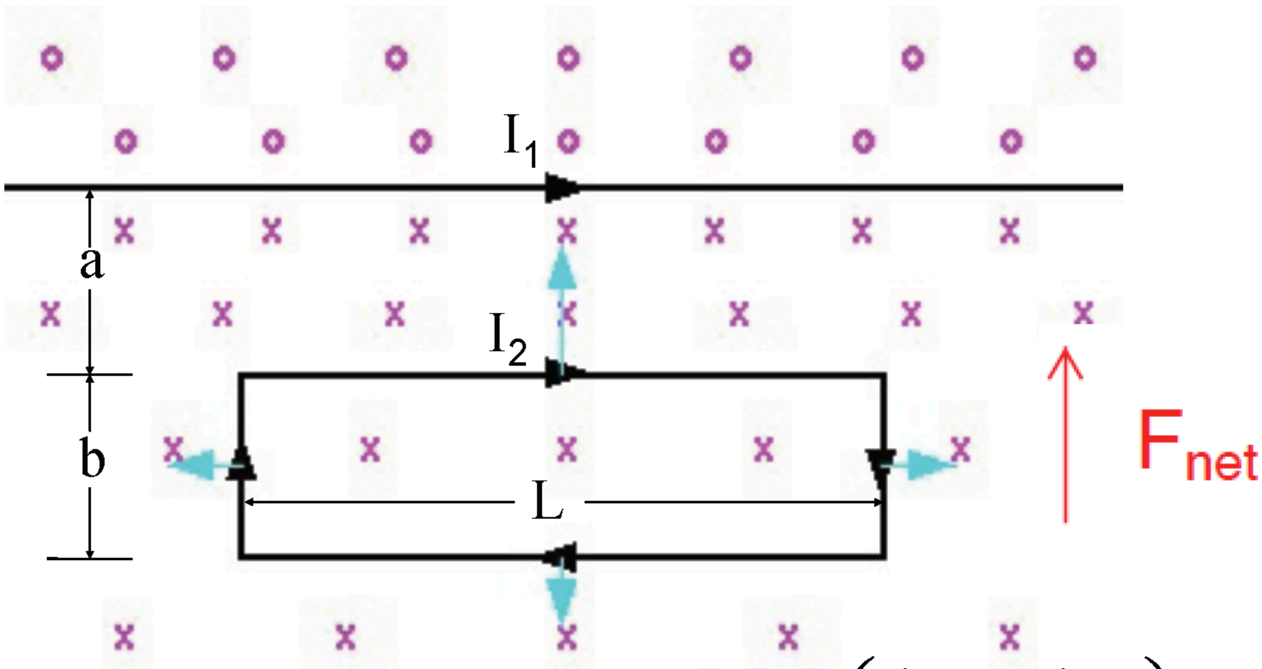
$$|F| = \frac{\mu_0}{2\pi}\frac{I_1 I_2}{d}L$$

1. Left
2. Right
3. Up
4. Down
5. Into the page
6. Out of the page
7. The net force is zero



A loop and a wire

The forces on the left and right sides cancel, but the forces on the top and bottom only partly cancel – the net force is directed up, toward the long straight wire.



$$F_{net} = \frac{\mu_0 I_1 I_2 L}{2\pi}\left(\frac{1}{a} - \frac{1}{a+b}\right)$$