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NEW JERSEY CENTER
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Algebra Based Physics

Magnetism

2016-02-02

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The Nature of Magnetism



<https://www.njctl.org/video/?v=1xlz9BqPObY>



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History

Magnets were first discovered over 2000 years ago by the Chinese and the Greeks and were used for various non scientific purposes.

The name was coined by the Greeks, as certain magnetic rocks (magnetite) were found in the province of Magnesia.

Unlike electrical effects due to the rubbing of various substances, like amber, to separate the electrical charges so there would be attractive and repulsive forces, these magnets came out of the ground already attracting and repelling certain materials.

History

It wasn't until after the 1000 A.D. that Chinese, European and Persian mariners separately used magnets for navigation.

When a magnetic material, shaped in the form of a needle and floated on the surface of water, it always pointed in the same direction - towards the north.

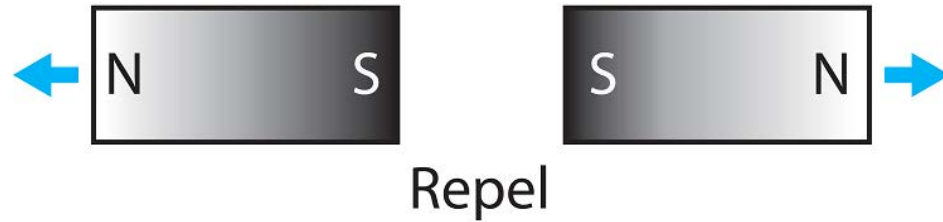
Always being able to tell which direction was north was a critical factor in ushering in the age of exploration.

It wasn't until 1600 when this phenomenon was explained by William Gilbert.

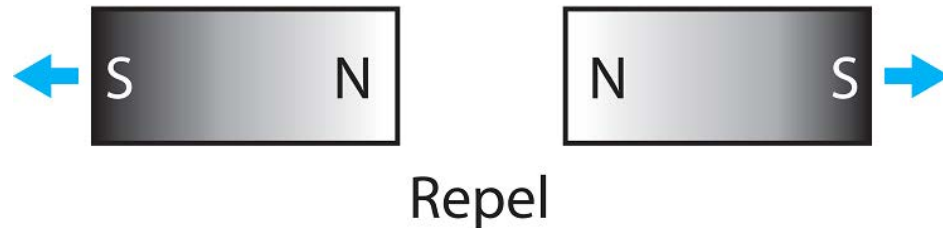
But first, the nature of magnetism will be discussed.

Properties of a Magnet

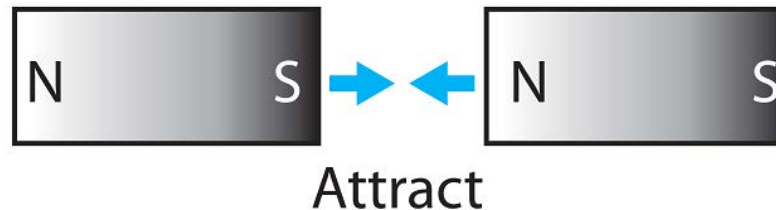
Magnets have two ends (poles) called north and south.



Like poles repel; unlike poles attract.



This attraction or repulsion is the magnetic force.

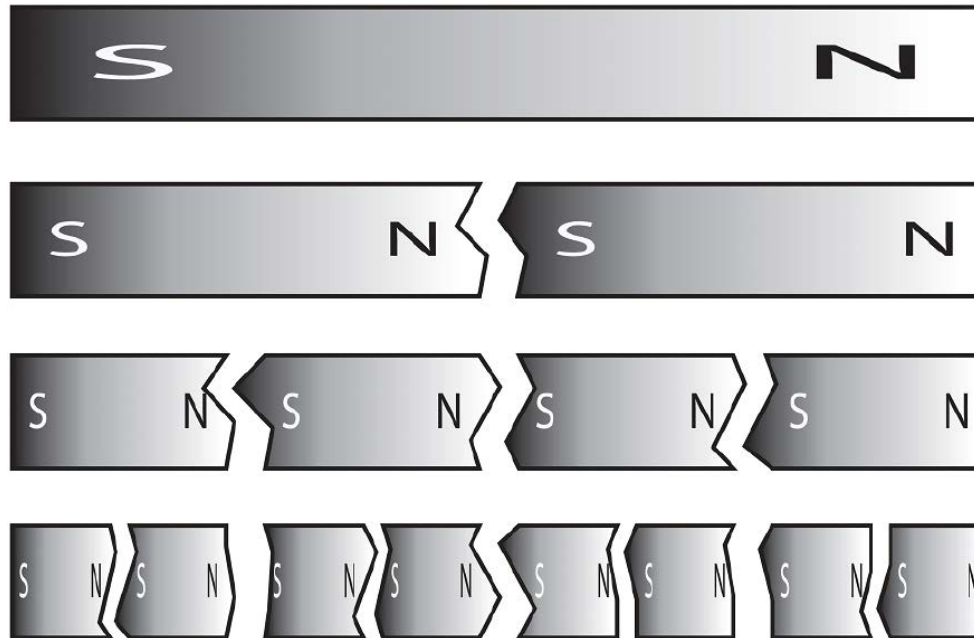


These are examples of bar magnets.

Magnetic Poles

When a magnet is cut in half, each piece still has a north and a south pole. No matter how many times the magnet is cut, the pieces still have a north and south pole.

This works all the way down to the atomic level!



Magnetic Poles and Electric Charges

The behavior of magnetic poles (north and south) are similar to electric charges (positive and negative) where opposite poles/charges attract and like poles/charges repel.

There are two significant differences between these effects.

One, certain materials are naturally magnetic, where electrical properties result from physical rubbing.

And secondly - there are independent positive and negative charges, but magnetic materials always contain a north and a south pole.

1 What are the two kinds of magnetic poles?

- A North and Negative.
- B South and Positive.
- C Postive and Negative.
- D North and South.

Answer



<https://www.njctl.org/video/?v=fpooBJ6kwuw>



2 Which of the following combination of magnetic poles will exert an attractive force on each other?

- A North and North.
- B North and South.
- C South and South.

Answer



<https://www.njctl.org/video/?v=TXWHzmbWYRs>



3 It is possible to find a magnet that only has a north pole.

Yes

No

Answer



<https://www.njctl.org/video/?v=ZR7T2GtOsA>



Magnetic Fields



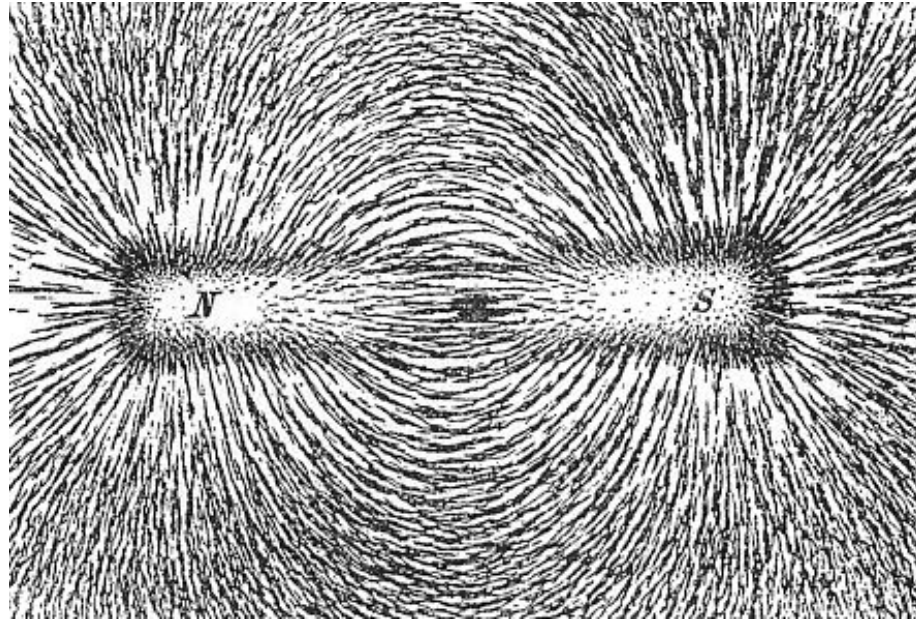
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Magnetic Fields

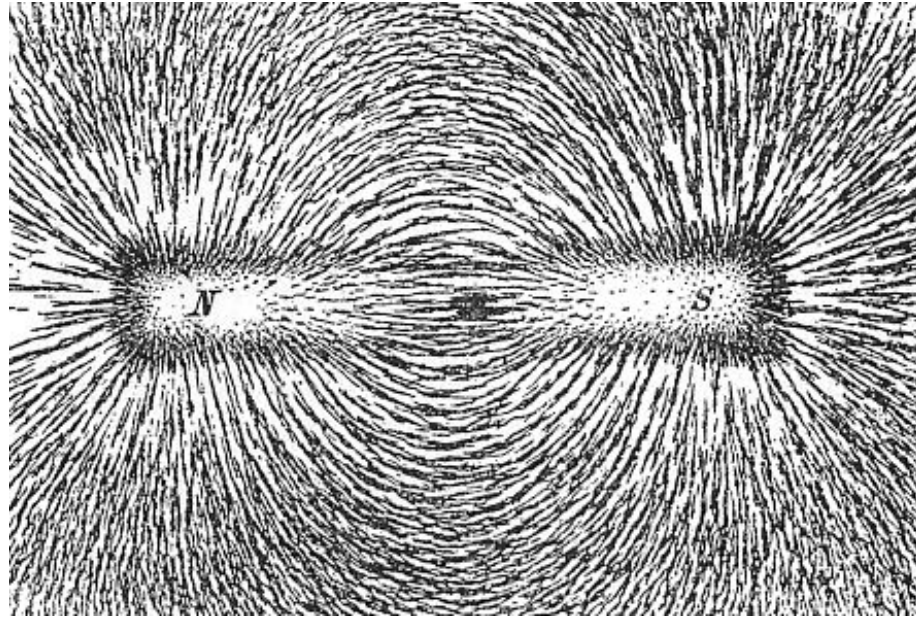
Electric field lines were used to show how electric charges would exert forces on other charges. A similar concept will be used in Magnetism.



What's nice about Magnetic field lines is that they are more easily "seen." The above is a picture of iron filings sprinkled on a paper on top of a bar magnet.

Magnetic Fields

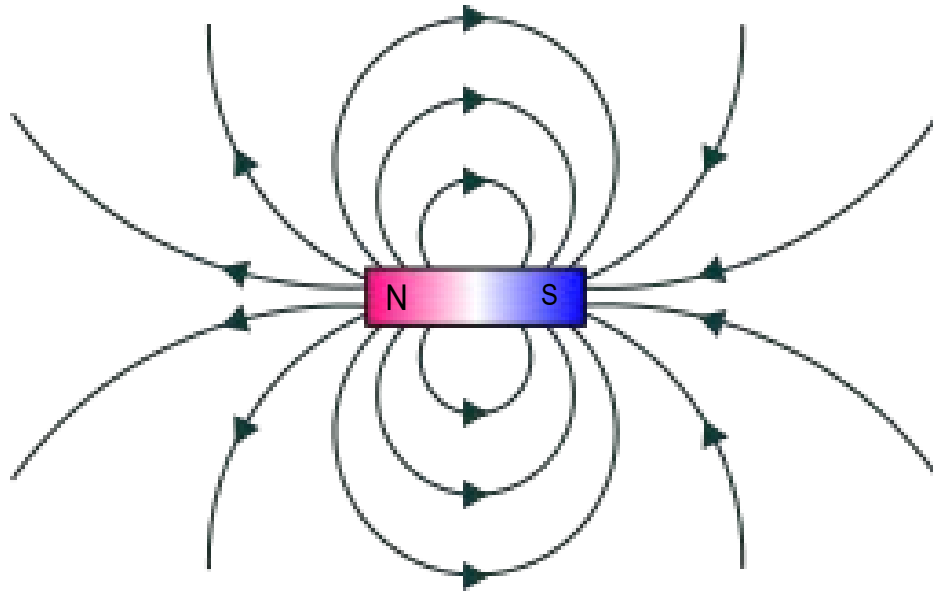
The iron filings act like little bar magnets, and align with the magnetic field of the large magnet.



The field exits one end of the magnet and returns to the other end. Note also, that the field lines extend through the magnet, making a complete loop (unlike Electric Field Lines).

Magnetic Fields

Arbitrarily, magnetic field lines are defined as leaving the north pole of the magnet and reentering at the south pole as seen below. The lines specify the direction that the north pole of a magnet will point to.

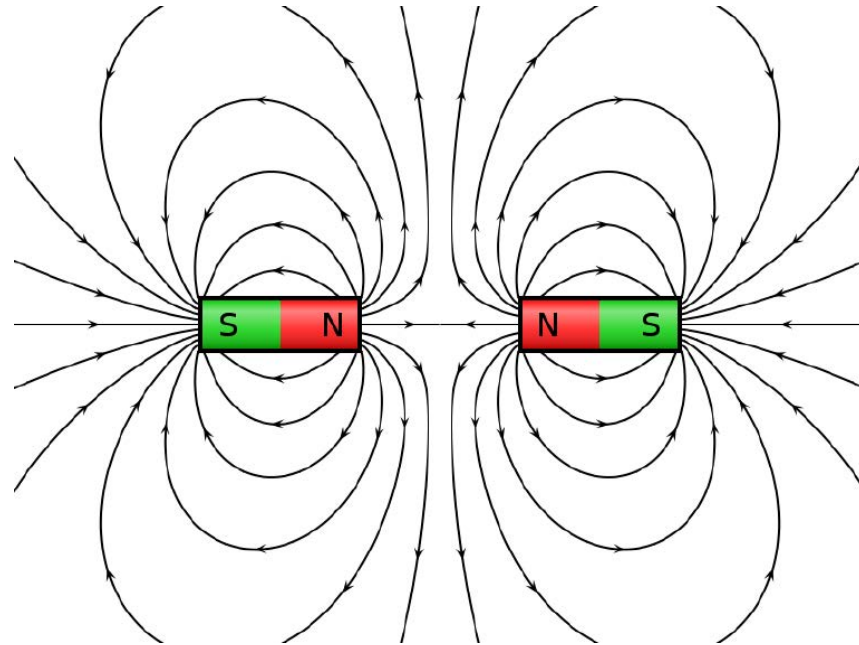


The more lines per unit area, the stronger the field.

The lines that seem not to be in loops are - we just ran out of room on the slide. All magnetic field lines form complete loops.

Magnetic Fields

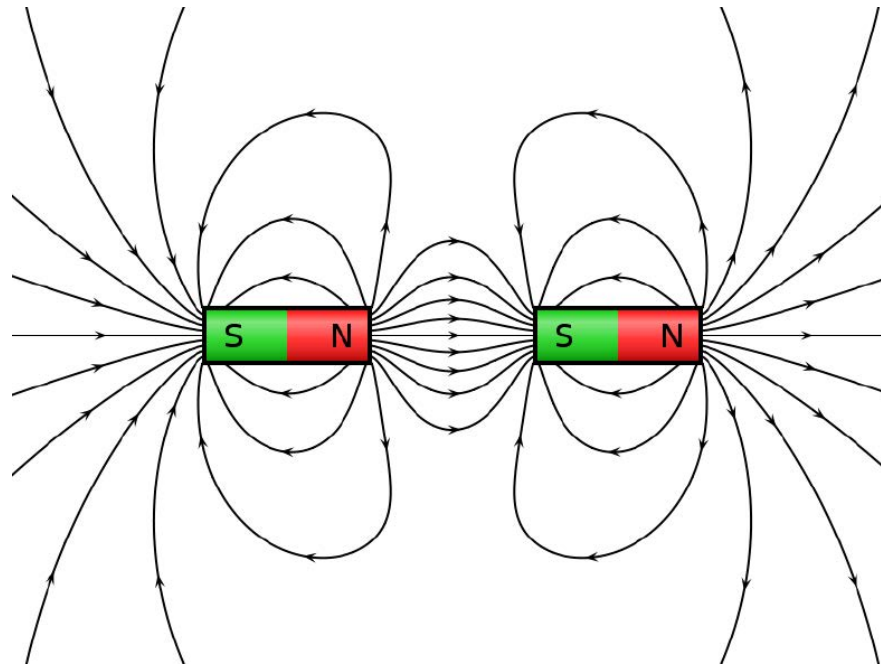
Like Electric Fields, different configurations of magnets will produce interesting Magnetic Fields.



Here are two magnets with their north poles next to each other - these magnets are repelling each other.

Magnetic Fields

Like Electric Fields, different configurations of magnets will produce interesting Magnetic Fields.



Here are two magnets with their opposite poles next to each other - these magnets are attracting each other.

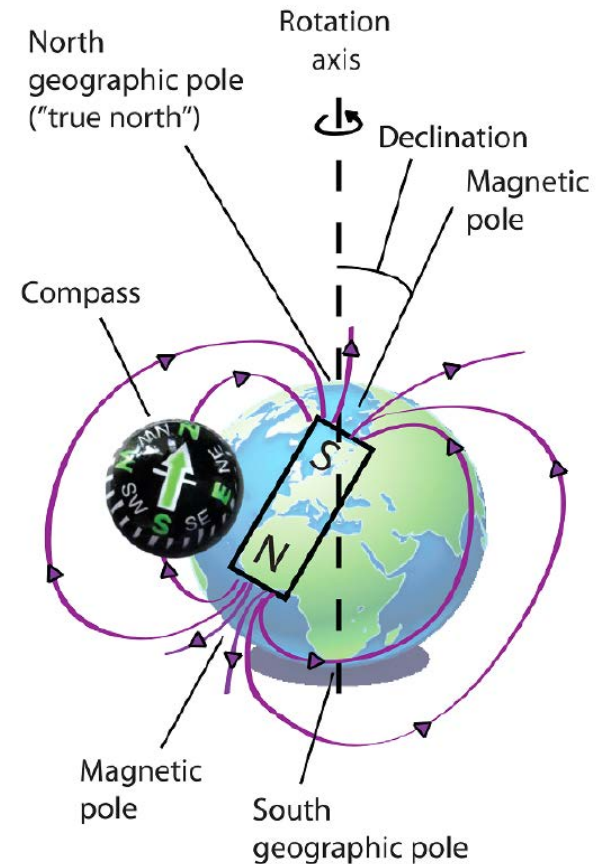
Earth's Magnetic Field

The Earth's magnetic field is similar to that of a bar magnet.

It is caused by the circulation of molten iron alloys in the earth's outer core.

The Earth's "North Pole" is really a south magnetic pole as the north ends of magnets are attracted to it.

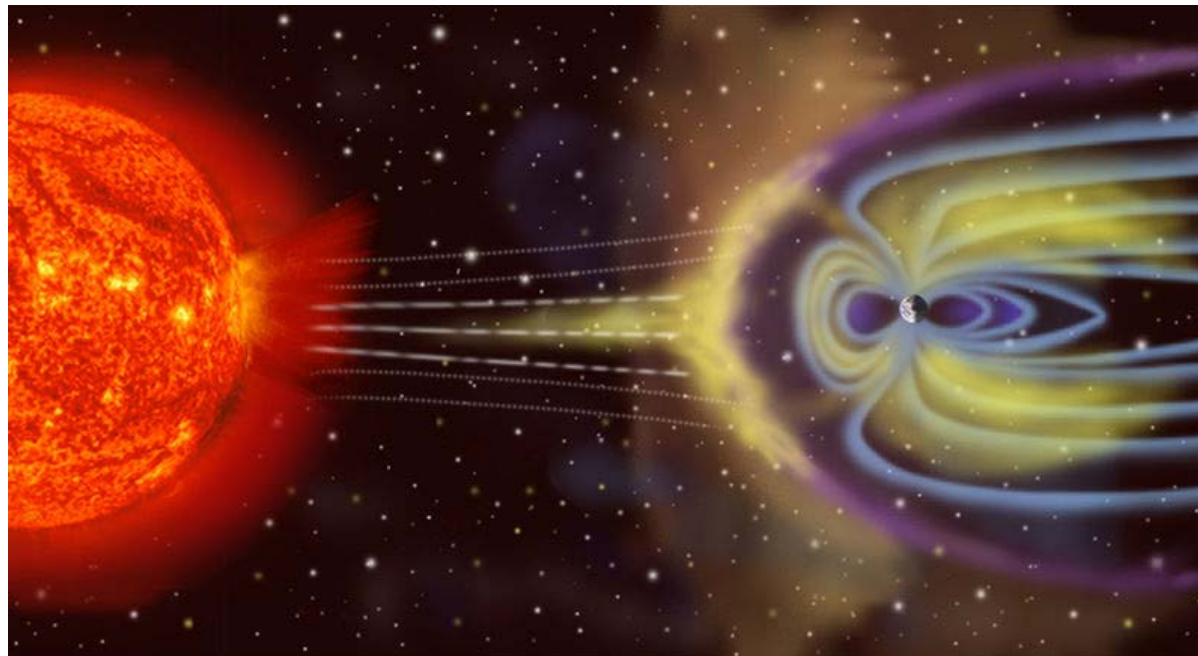
The magnetic poles are not located along the earth's axis of rotation.



Earth's Magnetic Field

The Magnetic Field extends from the core to the outer limits of the atmosphere (magnetosphere).

This picture shows the interaction of the solar wind (ions and electrons) with the magnetosphere.



Earth's Magnetic Field

This interaction also produces the Aurora Borealis and Aurora Australis.



Magnetic Field Units

The symbol for the Magnetic Field is B . The field is a vector and has both magnitude and direction.

The unit of B is the Tesla, T , where $1T = 1 \frac{N}{Amp - m}$

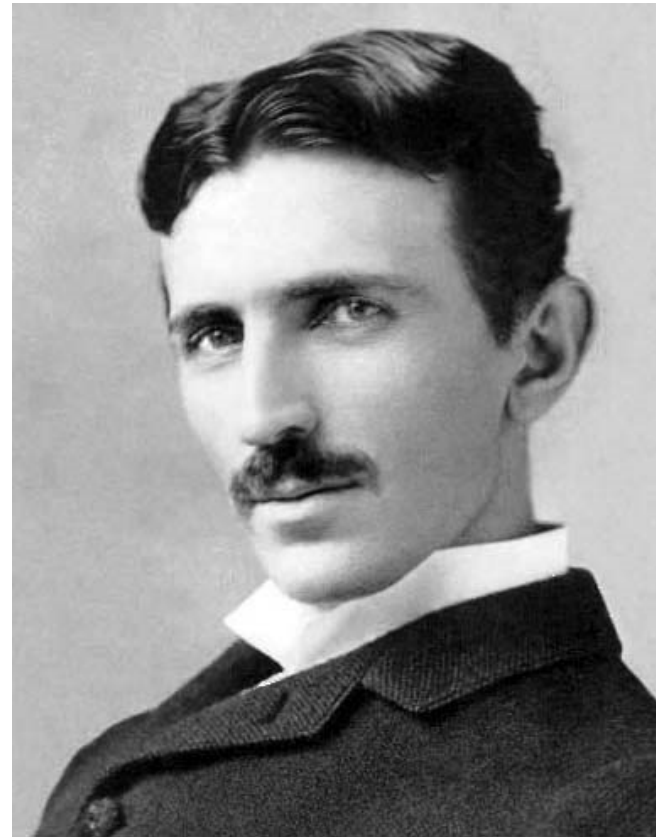
Because the Tesla is such a large magnitude, another unit is frequently used, the Gauss, G , where $1G = 10^{-4}T$

To gain perspective, the magnetic field of the Earth at its surface is around $0.5 \times 10^{-4}T$ or simply $0.5 G$.

Magnetic Field Units



Carl Friedrich Gauss
1777-1855 - Mathematician and
Physicist.



Nikola Tesla
1856-1943, Inventor, Engineer,
Physicist.

Origin and Direction of Magnetic Fields



<https://www.njctl.org/video/?v=M2u3Uj53A3E>



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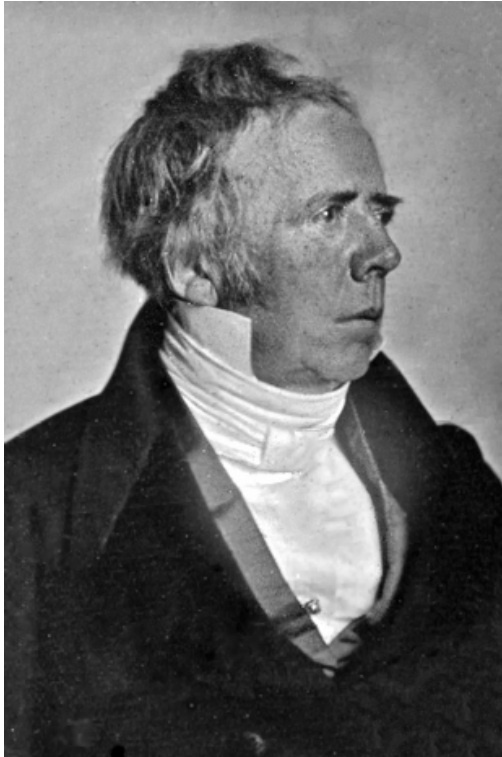
Electric Currents Produce Magnetic Fields

In 1820, while searching for a relationship between electricity and magnetism, Hans Christian Oersted noticed that a compass needle would be deflected away from pointing towards the north pole when he connected a wire to a battery, and would return to pointing north when the circuit was disconnected.

Oersted deduced that an electric current produced a magnetic field that affected the compass needle more strongly than the earth's magnetic field.

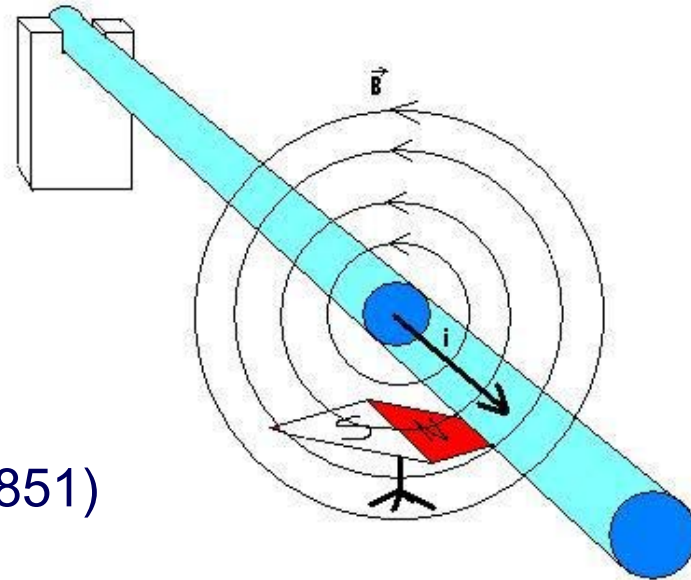
In addition to this first experimental evidence that electric and magnetic fields are related, Oersted produced Aluminum for the first time (which was later used to carry current).

Electric Currents Produce Magnetic Fields



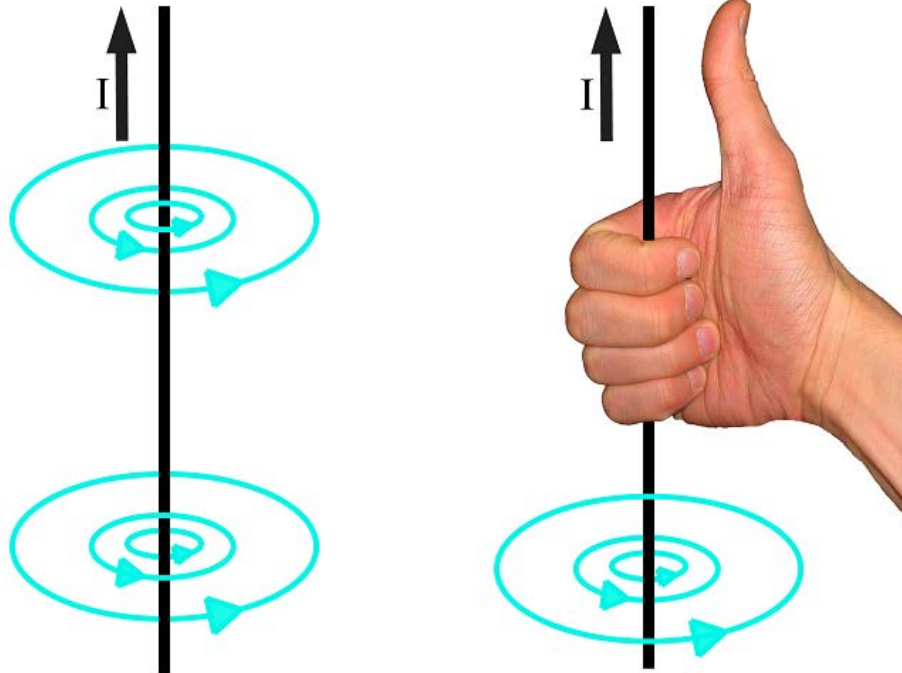
Hans Christian Oersted (1777-1851)
Physicist and Chemist

Current carrying wire generating a magnetic field that deflects a compass needle.



Electric Currents Produce Magnetic Fields

It has been experimentally observed that the direction of the magnetic field depends on the direction of the electric current.



The direction of the field is given by the right-hand rule (actually through the use of vector calculus, but the right-hand rule gives the correct result).

Orient your right hand thumb in the direction of the current.

The B field follows the path followed by your curled fingers.

Electric Currents Produce Magnetic Fields

When you have a current circulating around an iron core, a magnetic field is created and the device is called an electromagnet.

This is an industrial electromagnet that when the current is turned on, it picks up metallic objects.

Metal scrap is being attracted from the ground to the electromagnet.



Quelle: Deutsche Fotothek

Electric Currents Produce Magnetic Fields

Earlier, it was stated that when a magnet is cut in half, and those pieces are cut in half and this is continued all the way down to the atomic level, then each piece would still have a north and south pole.

This is because the movement of the electrons in the nucleus can be viewed as tiny electric currents. And as shown by Oersted, changing electric currents generate magnetic fields.

So each atom is acting as a magnet with a north and south pole.

Direction of Magnetic Fields

Another difference between electric fields and magnetic fields, is that we can normally understand an electric field very easily on two dimensional paper (the electric field is, of course, three dimensional, but is easily represented in two dimensions).

But, as you just saw with Oersted's experiment, the magnetic field is looping around the wire so magnetic fields need to be shown as three dimensional to be understood. Somehow, we need to show this third dimension on our paper.

We have left / right: 

Up / down: 

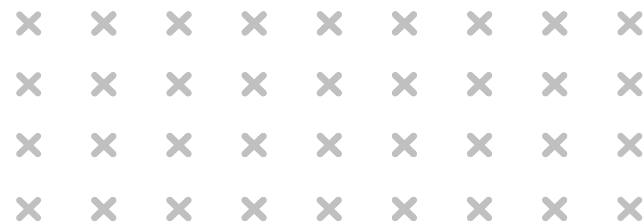
How do we represent the third dimension on a page of paper?

Magnetic Fields

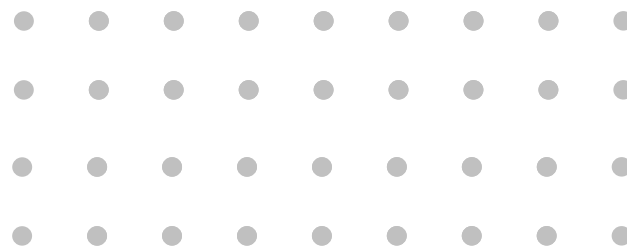
Picture the field line (which is a vector with magnitude and direction) like an arrow. The head of the arrow is the direction of the field.



If the magnetic field is into the page, you will see the tail of the arrow:



If the magnetic field is out of the page, you will see the front of the arrow:

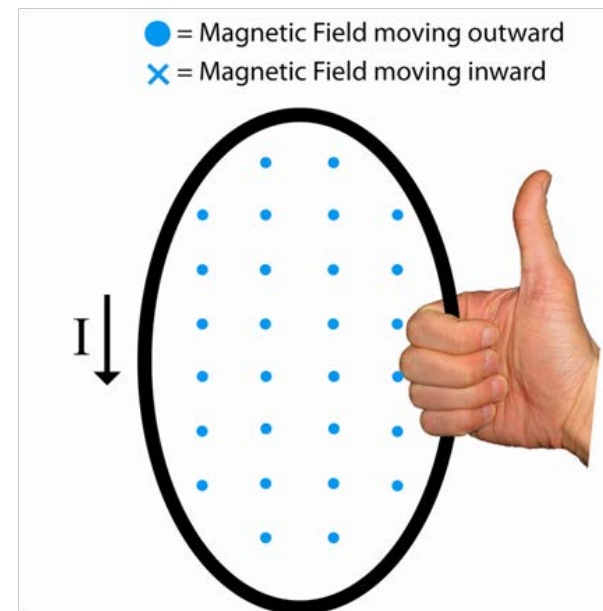


Electric Currents Produce Magnetic Fields

Here's how the magnetic field would look inside a current carrying loop.

Your thumb points in the direction of the current, and your fingers curl around and show the magnetic field coming out of the board within the loop.

What direction is the magnetic field outside the loop? That's right - into the board, as your fingers continue curling.

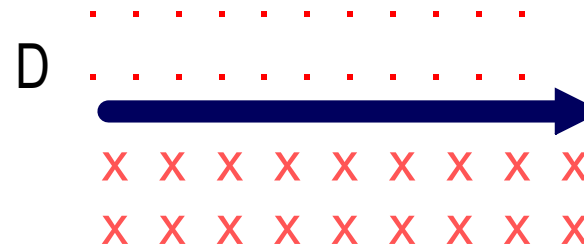
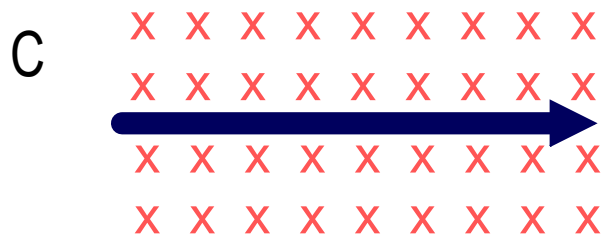
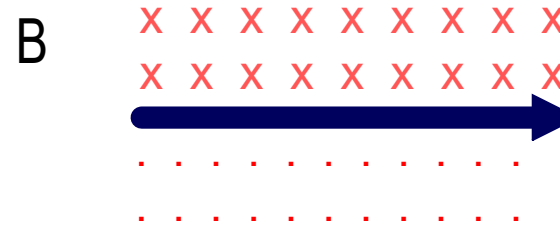
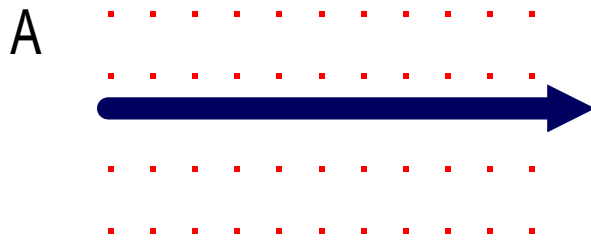


Right-hand-rule:

Right thumb points in the direction of the current

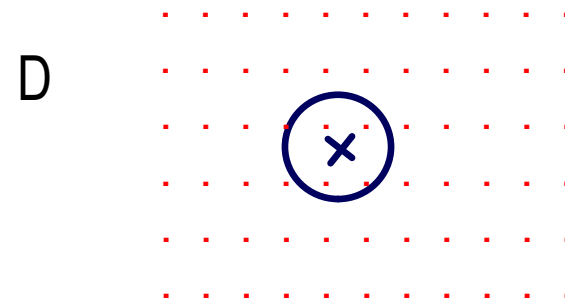
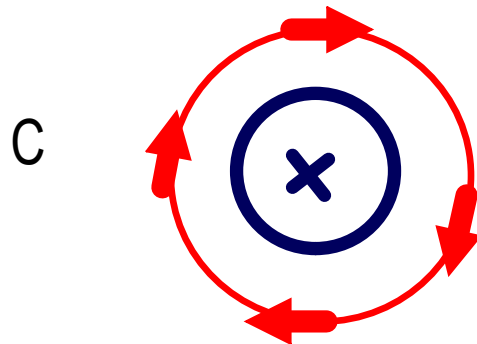
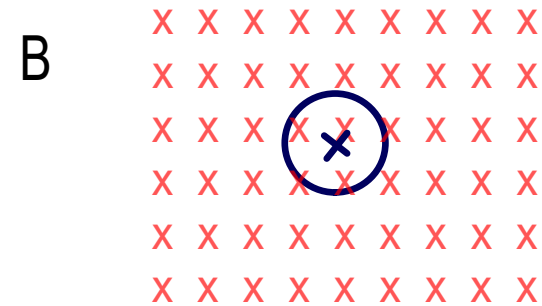
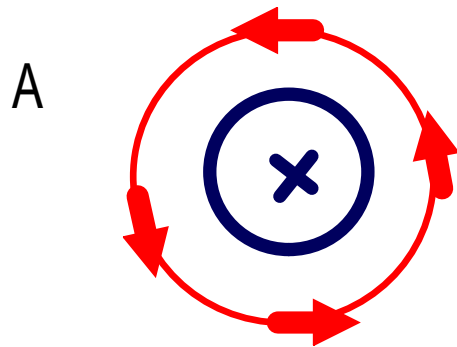
Right fingers point in the direction of the magnetic field.

4 Which diagram shows the magnetic field (red) around a current carrying wire (blue?)



Answer

5 Which diagram shows the magnetic field (red) around a current carrying wire (blue)?



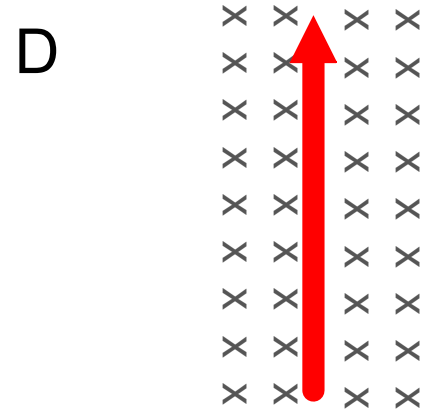
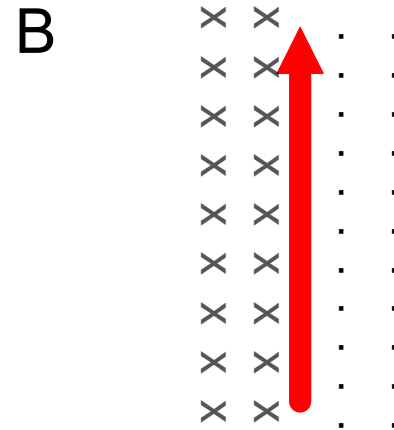
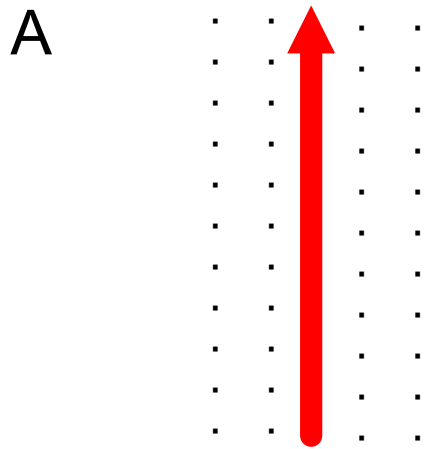
Answer



<https://www.njctl.org/video/?v=WX-2wnm9bVs>



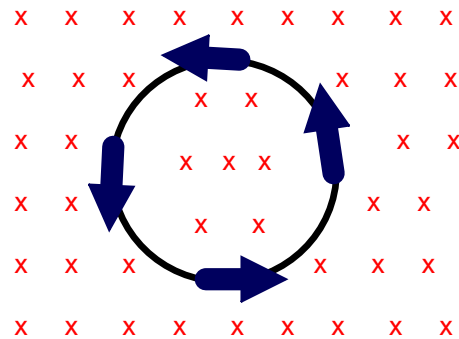
6 Which diagram shows the magnetic field (black) around a current carrying wire (red)?



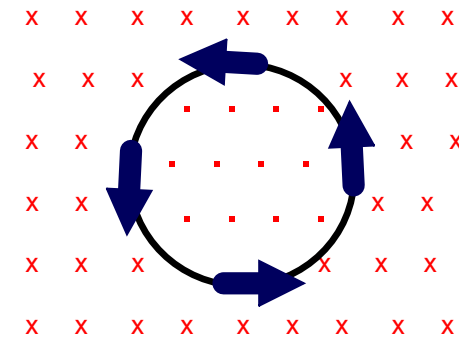
Answer

7 Which diagram shows the magnetic field inside and outside a current carrying loop of wire?

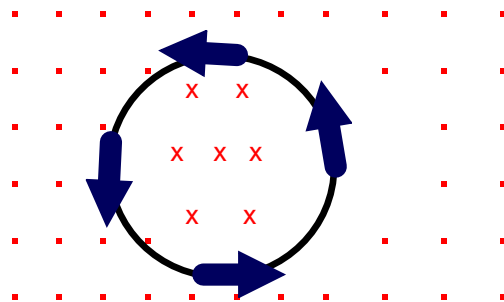
A



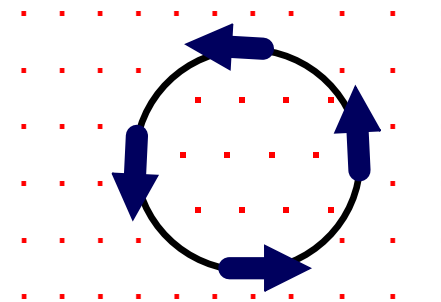
B



C



D



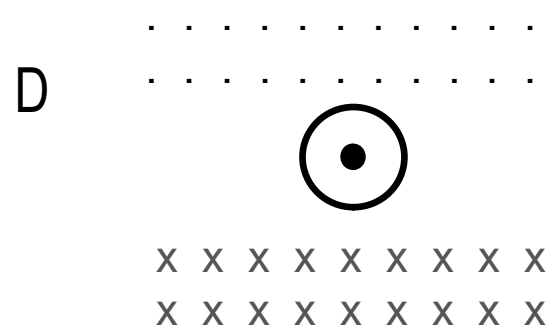
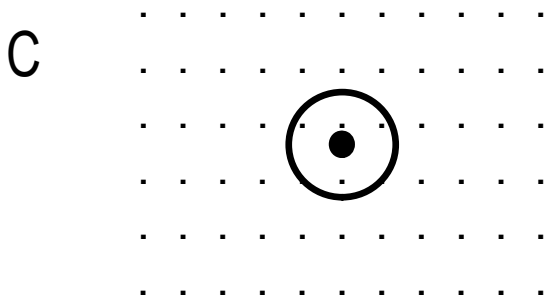
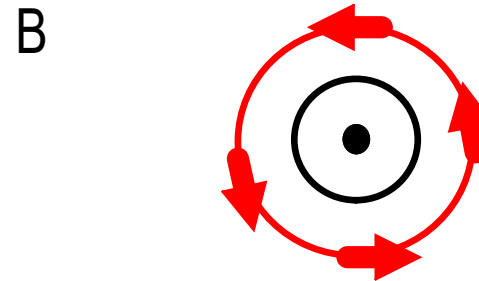
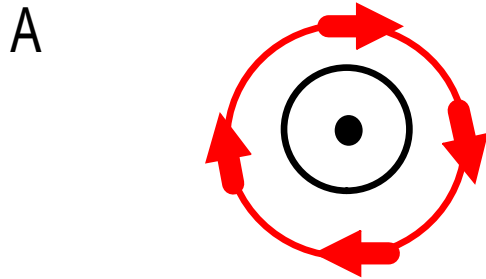
Answer



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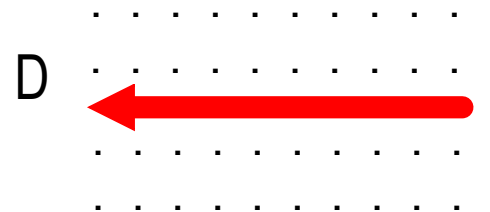
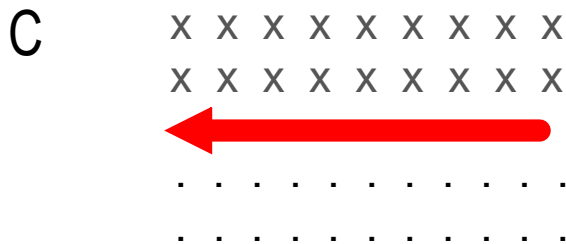
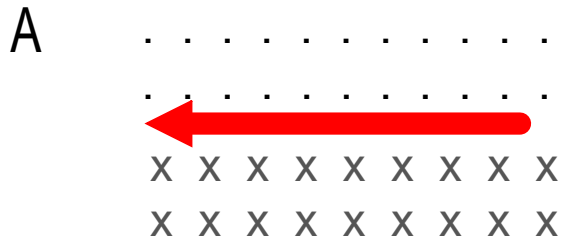


8 Which diagram shows the magnetic field around a current carrying wire?



Answer

9 Which diagram shows the magnetic field around a current carrying wire?



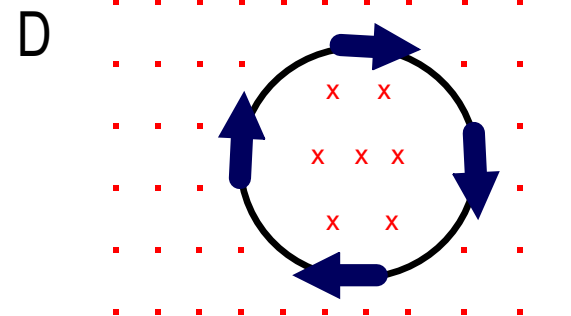
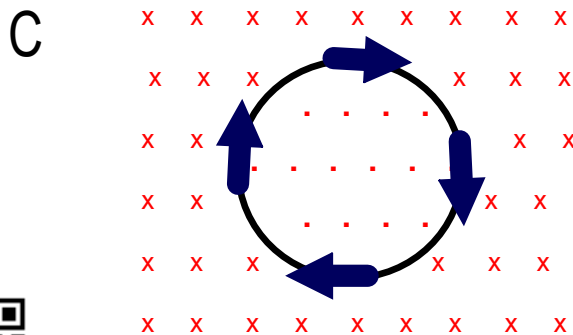
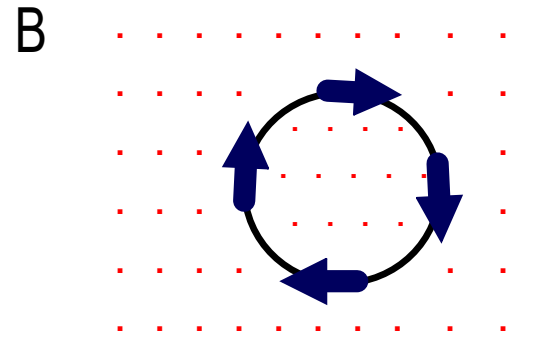
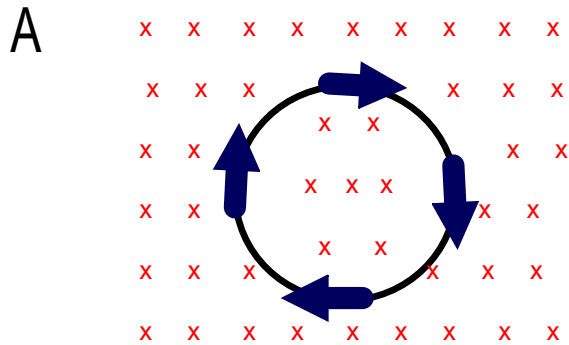
Answer



<https://www.njctl.org/video/?v=epk5ptbYSpQ>



10 Which diagram shows the magnetic field inside and outside a current carrying loop of wire?



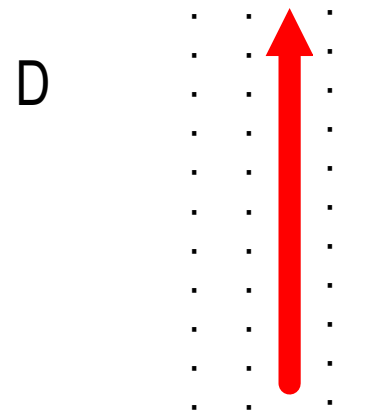
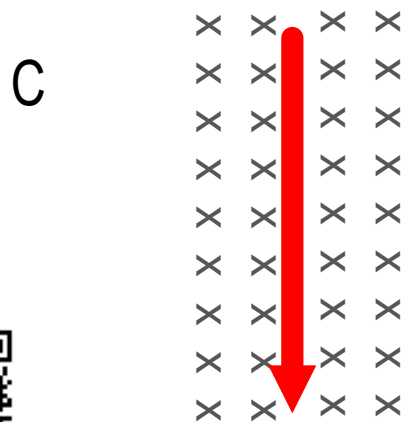
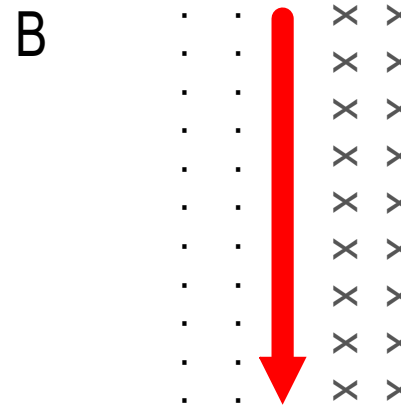
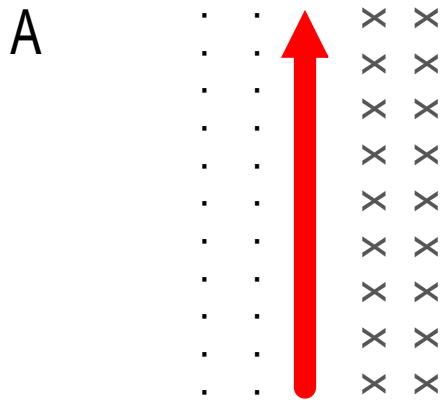
Answer



https://www.njctl.org/video/?v=l_JKvXis3Fs



11 Which diagram shows the magnetic field around a current carrying wire?



<https://www.njctl.org/video/?v=FnEyGxt1ImA>



Answer

Magnetic Field & Force on a Moving Charge



<https://www.njctl.org/video/?v=P6w2kcjPuKY>

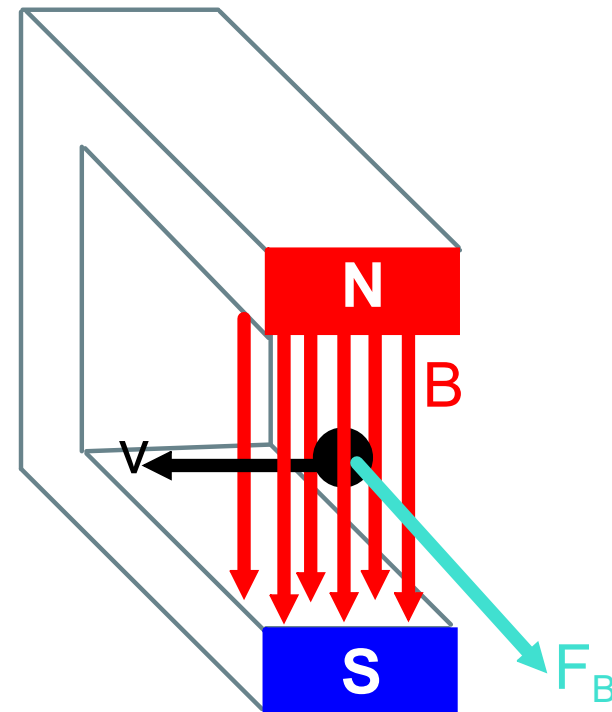


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Magnetic Field & Force on a Moving Charge

Magnetic fields are observed to exert a force on a moving charge but only if the charge is moving and the direction of its velocity is perpendicular to the direction of the magnetic field.

The horseshoe magnet has a uniform magnetic field directed south, a positive charge is moving through it to the left and a magnetic force is exerted perpendicular to both the direction of the charge and the field.



Magnetic Field & Force on a Moving Charge

The direction of the force on a positive charge is perpendicular to both the charge's velocity and the magnetic field.

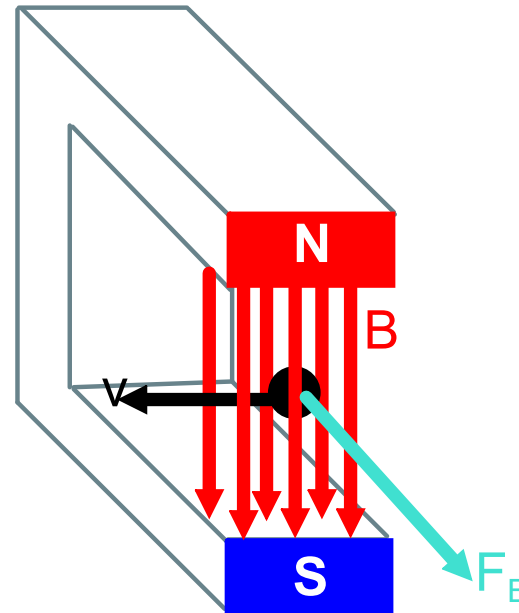
The "right-arm-rule" is a handy way to determine the direction of the magnetic force.

Using the right arm:

arm points in the direction of the moving positive charge

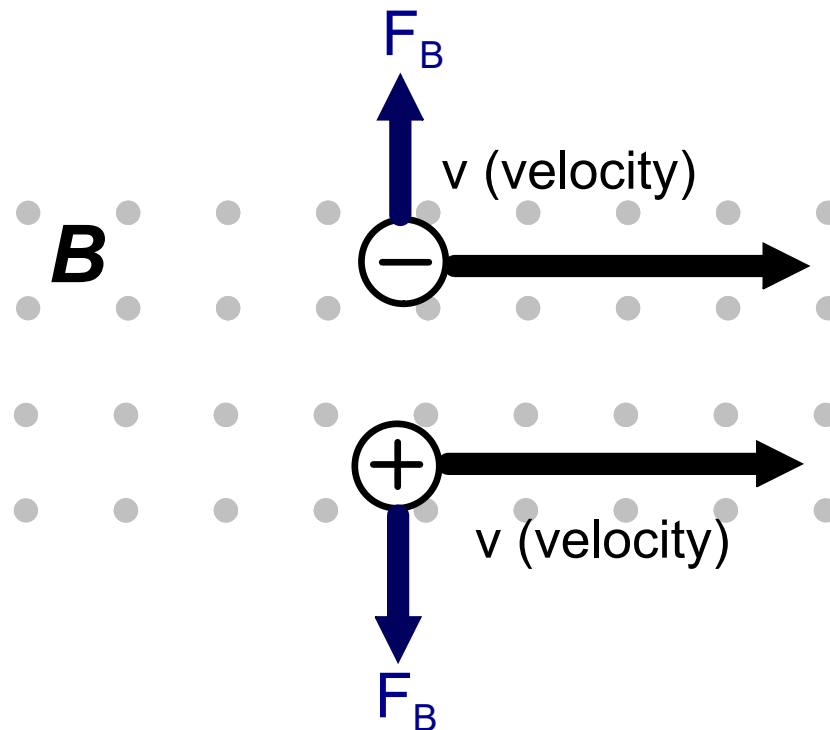
fingers point in the direction of the magnetic field

thumb points in the direction of the magnetic force

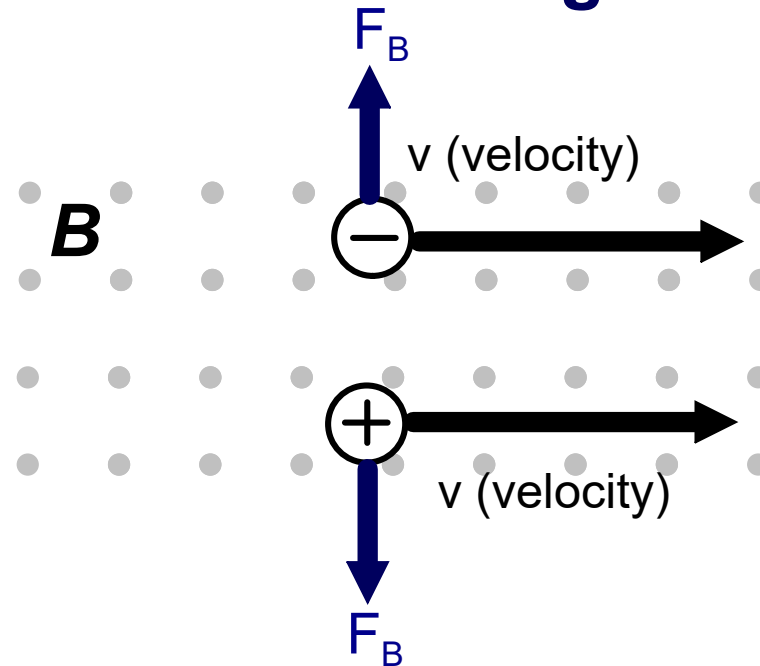


Force on a Moving Charge

Here, we have the case of a negative charge and a positive charge moving to the right in a uniform magnetic field that is pointed out of the page.



Force on a Moving Charge

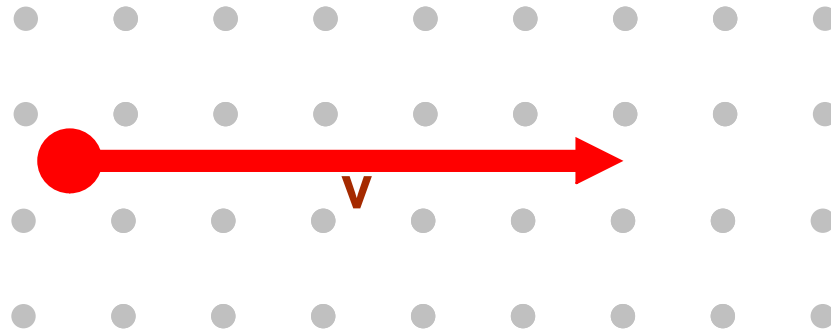


Notice, the force on the negative charge in the same field is acting in the opposite direction.

Use the right-arm-rule to find the force on the positive charge.

Use the same method for the negative charge, but then flip the direction of the resultant force, or use your left arm for negative charges.

12 What is the direction of the force on a proton moving to the right, with speed v , as shown below?



A 

B 

C 

D 

E zero

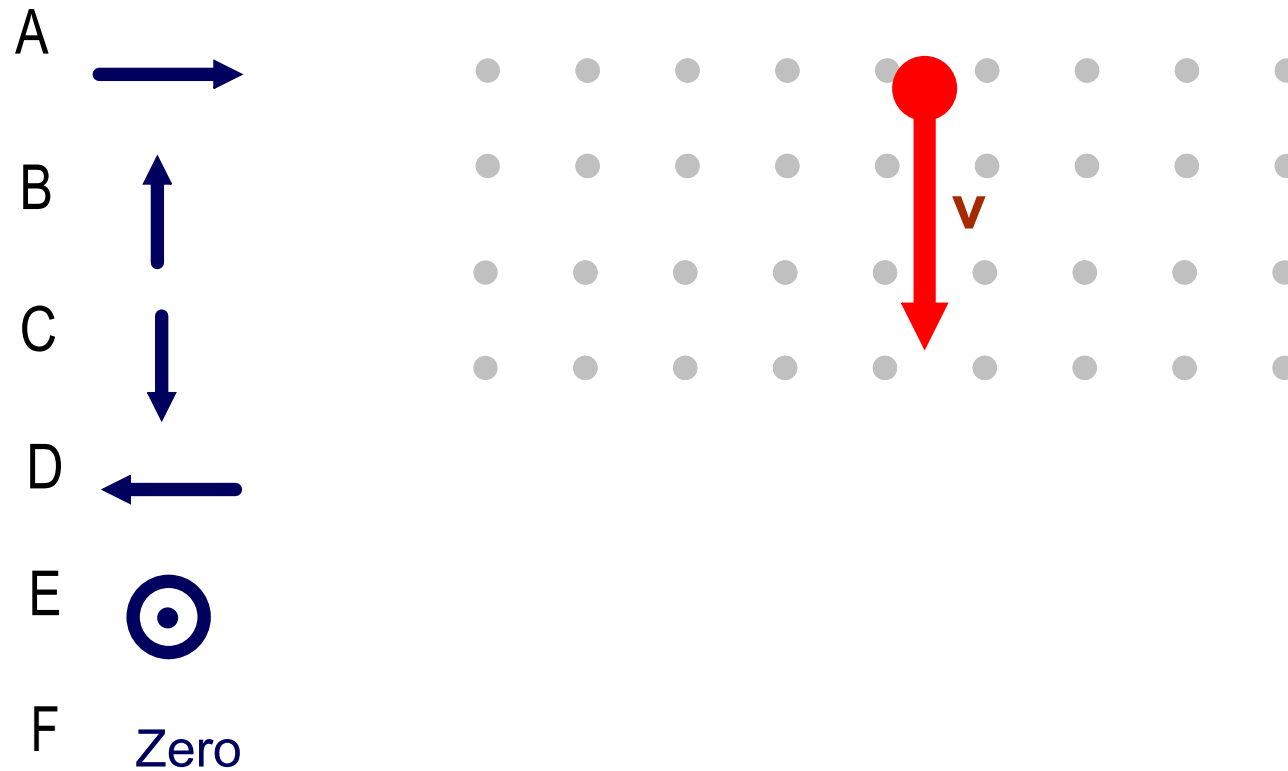
Answer



<https://www.njctl.org/video/?v=MZmDiBwHvpE>



13 What is the direction of the magnetic force on the proton below?



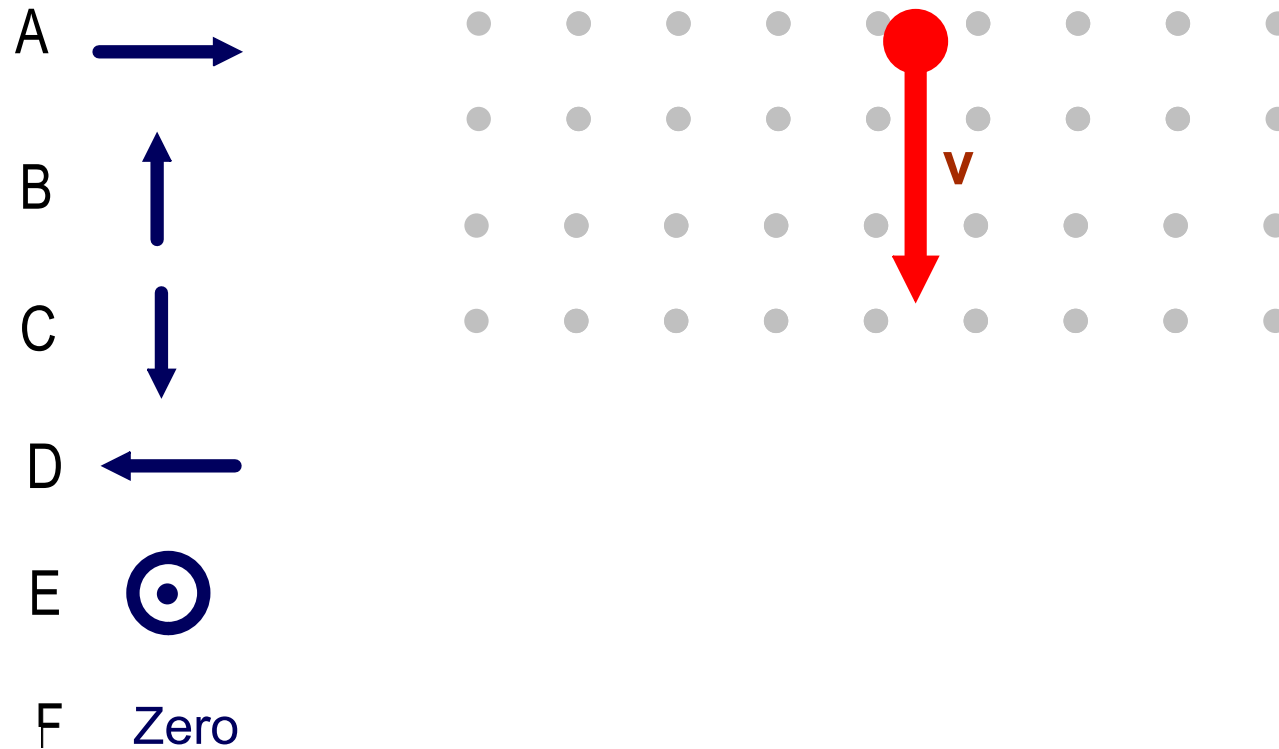
Answer



<https://www.njctl.org/video/?v=NVNSELBbfhA>



14 What is the direction of the magnetic force on the electron below?



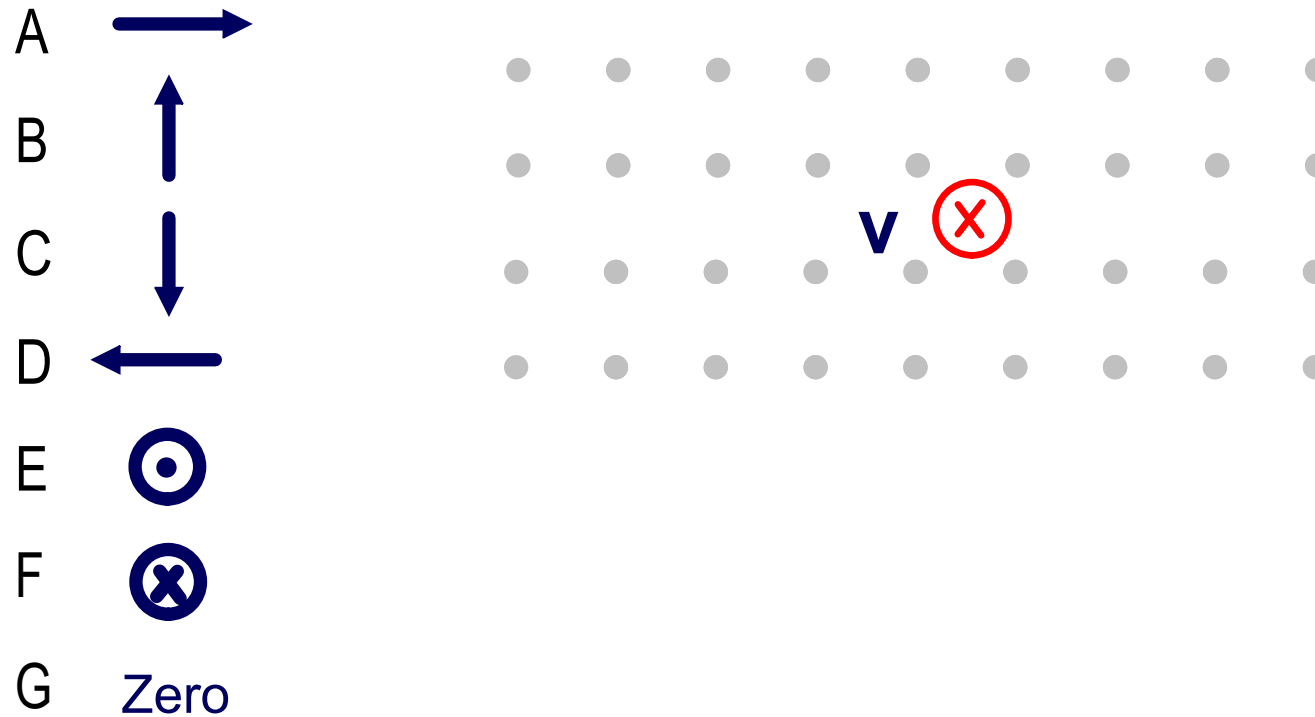
Answer



https://www.njctl.org/video/?v=Q_2mbnfGLso









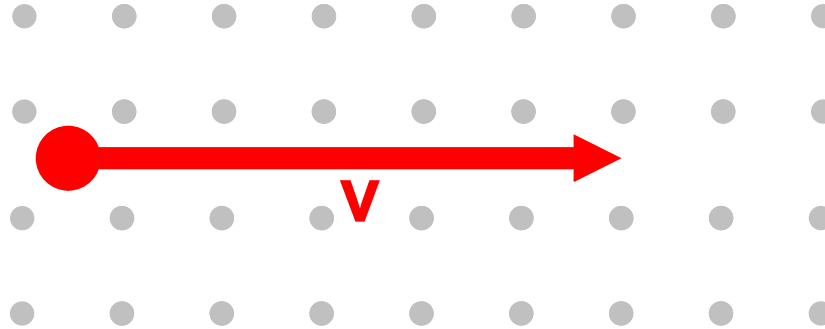
15 What is the direction of the magnetic force on the electron below?



Answer

16 What is the direction of the magnetic force on the electron below?

- A 
- B 
- C 
- D 
- E 
- F 
- G Zero









Answer

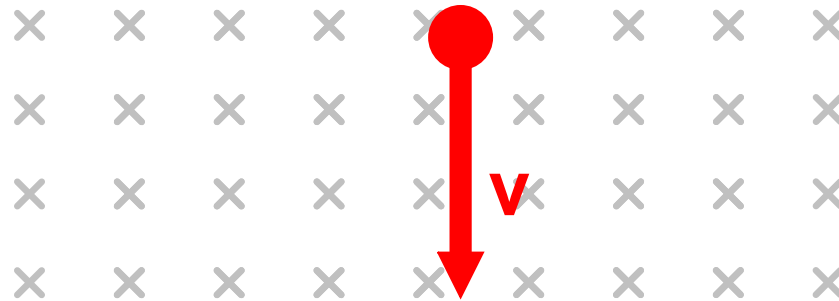


<https://www.njctl.org/video/?v=1pE15pUwsZE>



17 What is the direction of the magnetic force on the proton below?

- A 
- B 
- C 
- D 
- E 
- F 
- G Zero



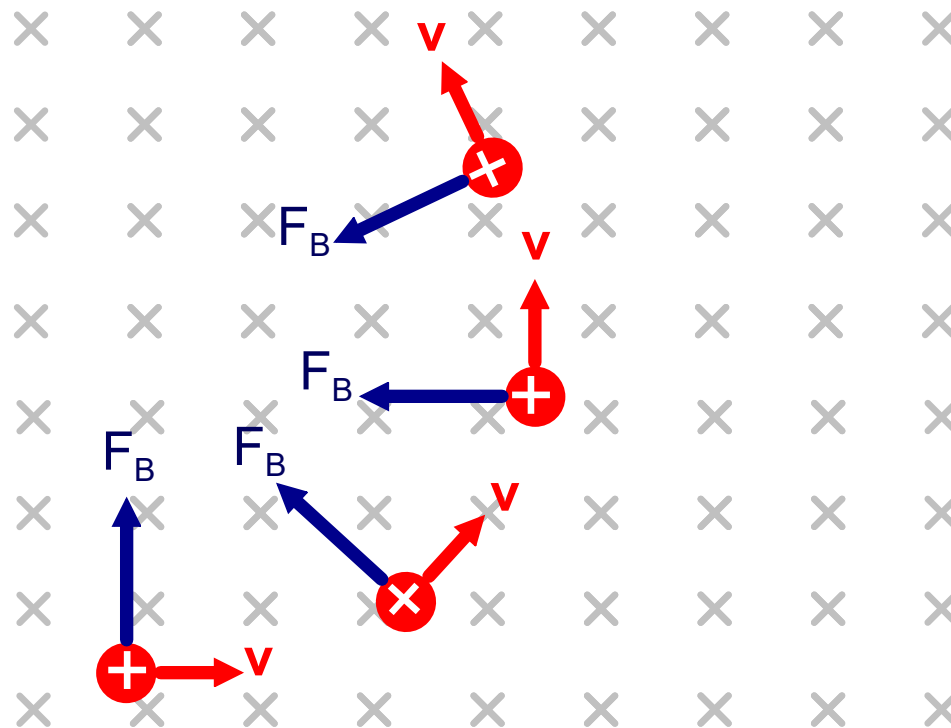
Answer



Magnetic Field & Force on a Moving Charge

When a charge enters a uniform magnetic field it experiences a force perpendicular to its velocity.

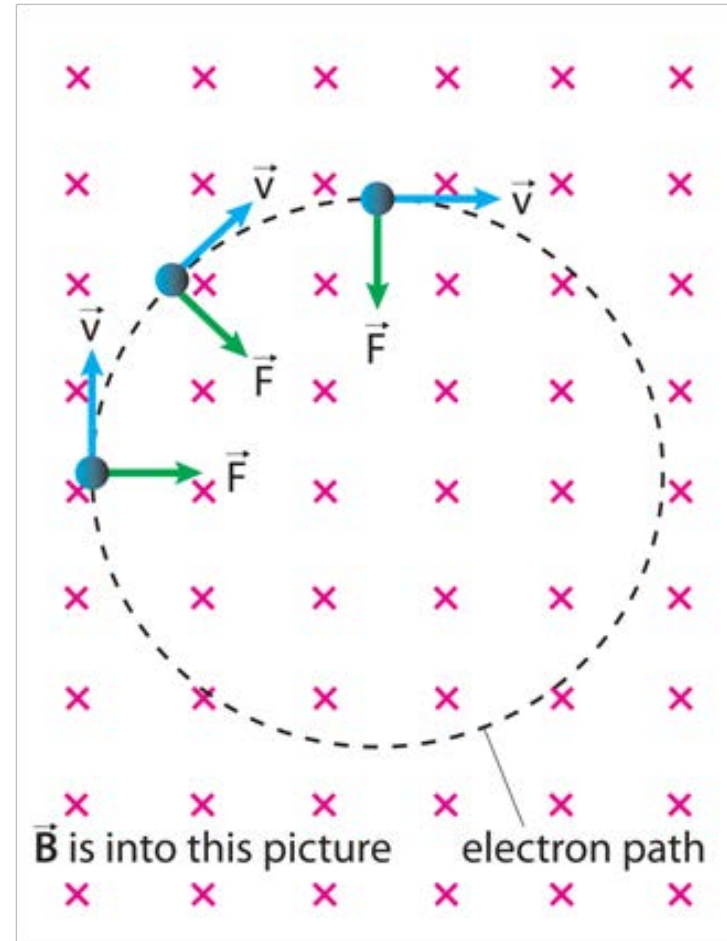
As this force is exerted on the charge, what will be the direction of the charge's acceleration?



Magnetic Field & Force on a Moving Charge

Since the magnetic force is perpendicular to the charge's velocity, we have a "center seeking" force, which results in centripetal motion - the charge moves in a circle.

An electron injected with velocity, v , into the magnetic field on the right will have a magnetic force directed to the right at all times (towards the middle of a circle). A positive particle will move in a counter clockwise path.



Magnetic Field & Force on a Moving Charge

Not only do magnetic poles exert a force on each other, but a magnetic field will exert a force on a moving charge. If the charge is not moving - it does not feel the force. This is a very unique concept and phenomenon in the universe.

The force on a moving charge is related to the magnitude of its charge, velocity and strength of the magnetic field - but only the portion of the magnetic field that is perpendicular to the charge's motion. This will become clearer in AP Physics, but for now, here's the equation:

$$F = qvB_{\text{perpendicular}}$$

18 A proton moving at a speed of 75,000 m/s horizontally to the right enters a uniform magnetic field of 0.050 T which is directed vertically downward. Find the direction and magnitude of the magnetic force on the proton.

Answer



<https://www.njctl.org/video/?v=cOiXV1p8j0M>



19 An electron experiences an upward force of 2.8×10^{-12} N when it is moving at a speed of 5.1×10^6 m/s towards the north. What is the direction and magnitude of the magnetic field?

Answer



<https://www.njctl.org/video/?v=-LqnDSpWfPA>



Magnetic Field & Force on a Current-Carrying Wire



<https://www.njctl.org/video/?v=MPmTZZQCnWY>

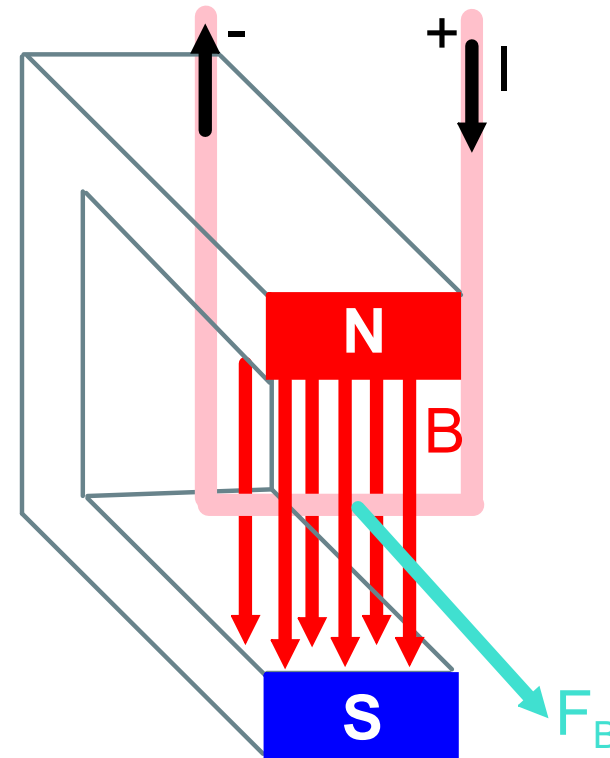


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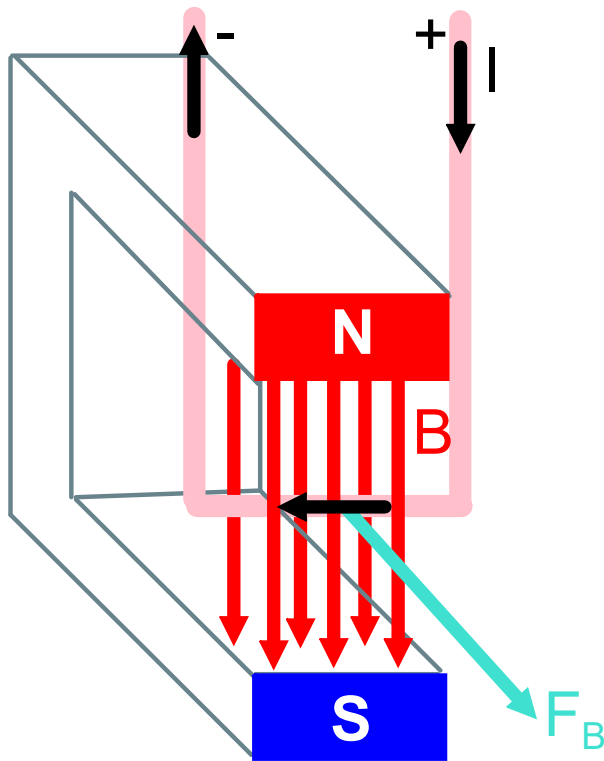
Magnetic Field & Force on a Current-Carrying Wire

A magnet also exerts a force on a current-carrying wire, when current flow is perpendicular to the direction of the magnetic field.

The direction of the force can be found using the right-arm-rule again, but this time place your arm in the direction of the conventional current.



Magnetic Field & Force on a Current-Carrying Wire

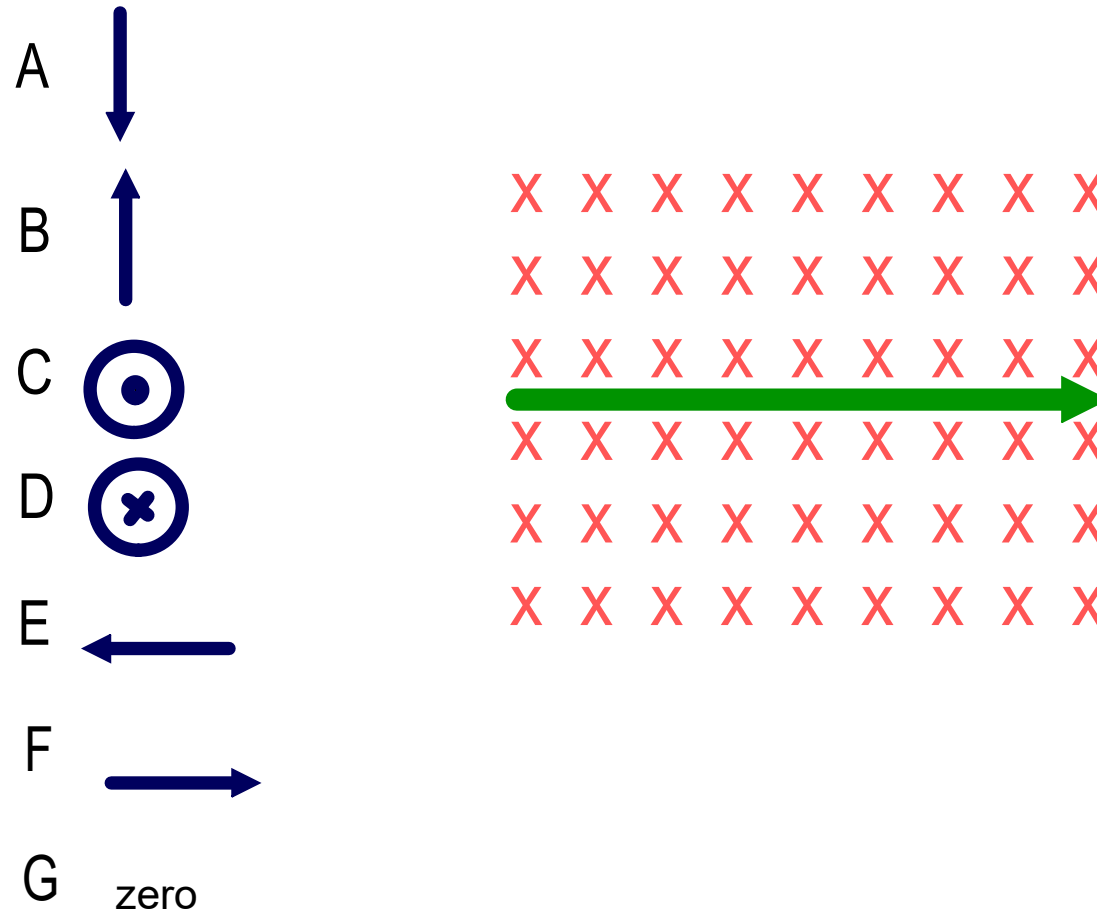


Current flows toward the left in the field, so right arm points left.

The magnetic field points south, so right fingers point south.

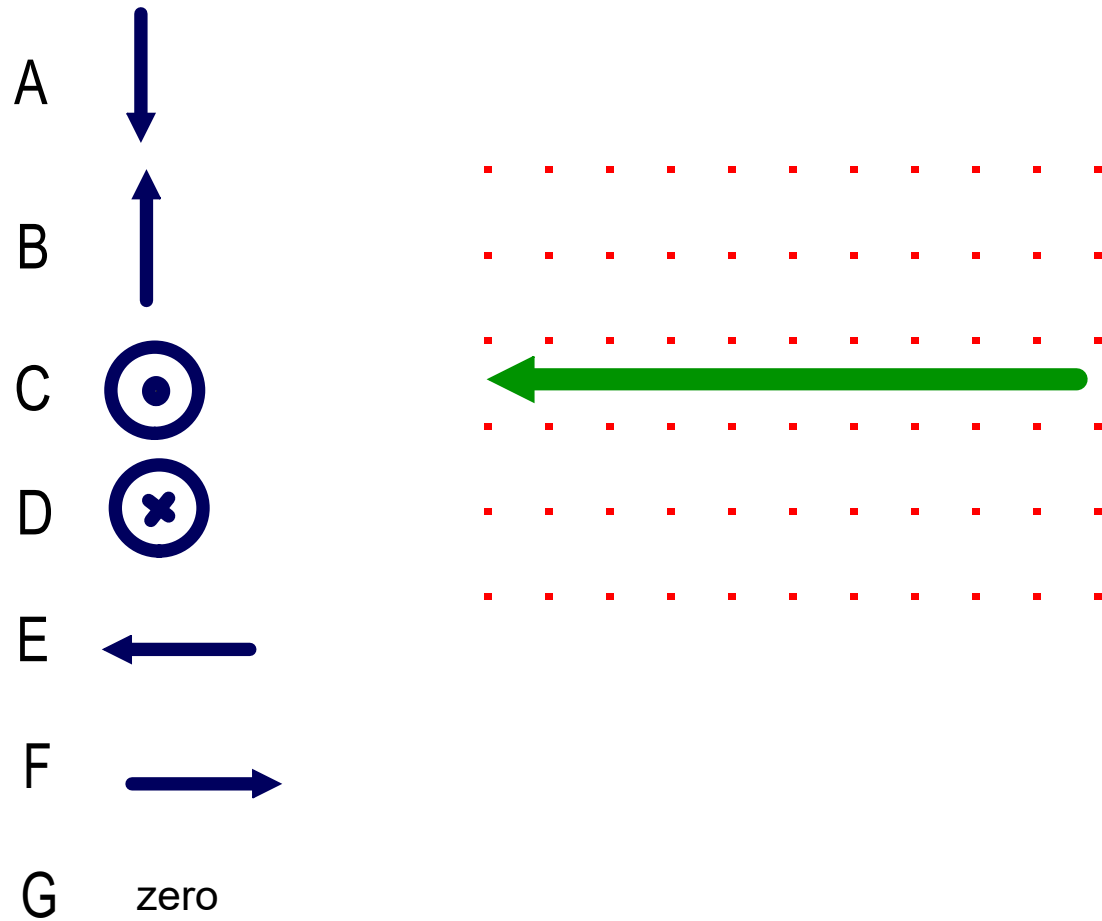
Right thumb points out of the page in the direction of the magnetic force.

20 What is the direction of the magnetic force on the current carrying wire (green) in the magnetic field (red)?



Answer

21 What is the direction of the magnetic force on the current carrying wire (green) in the magnetic field (red)?



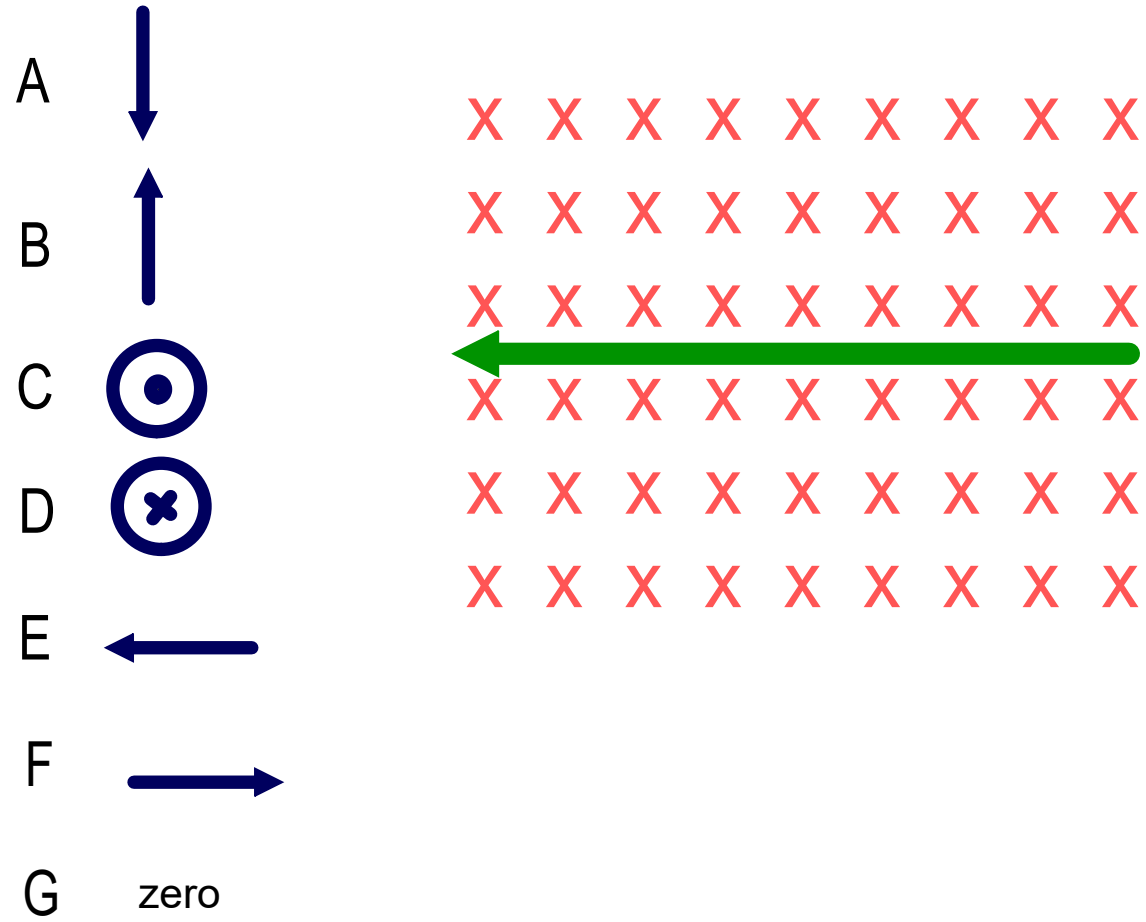
Answer



<https://www.njctl.org/video/?v=GcKlJSHDqKE>



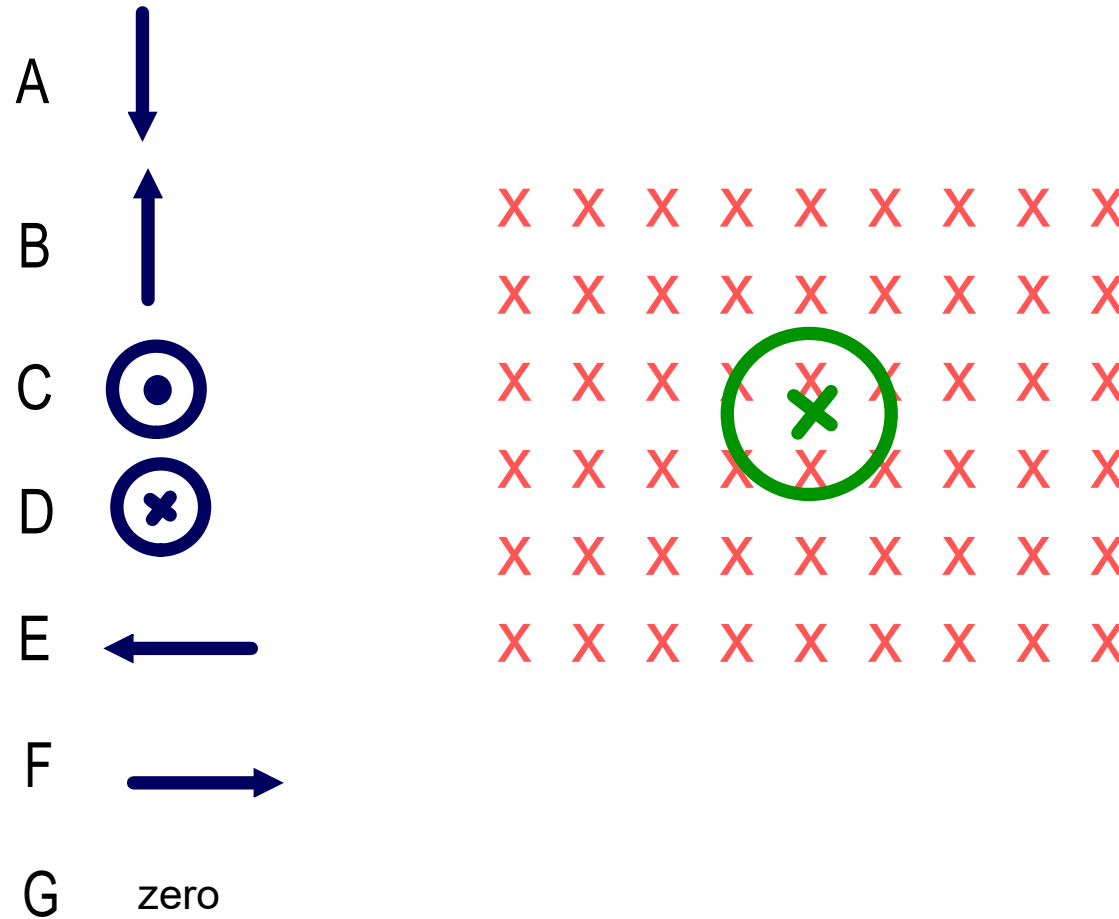
22 What is the direction of the magnetic force on the current carrying wire (green) in the magnetic field (red)?



Answer



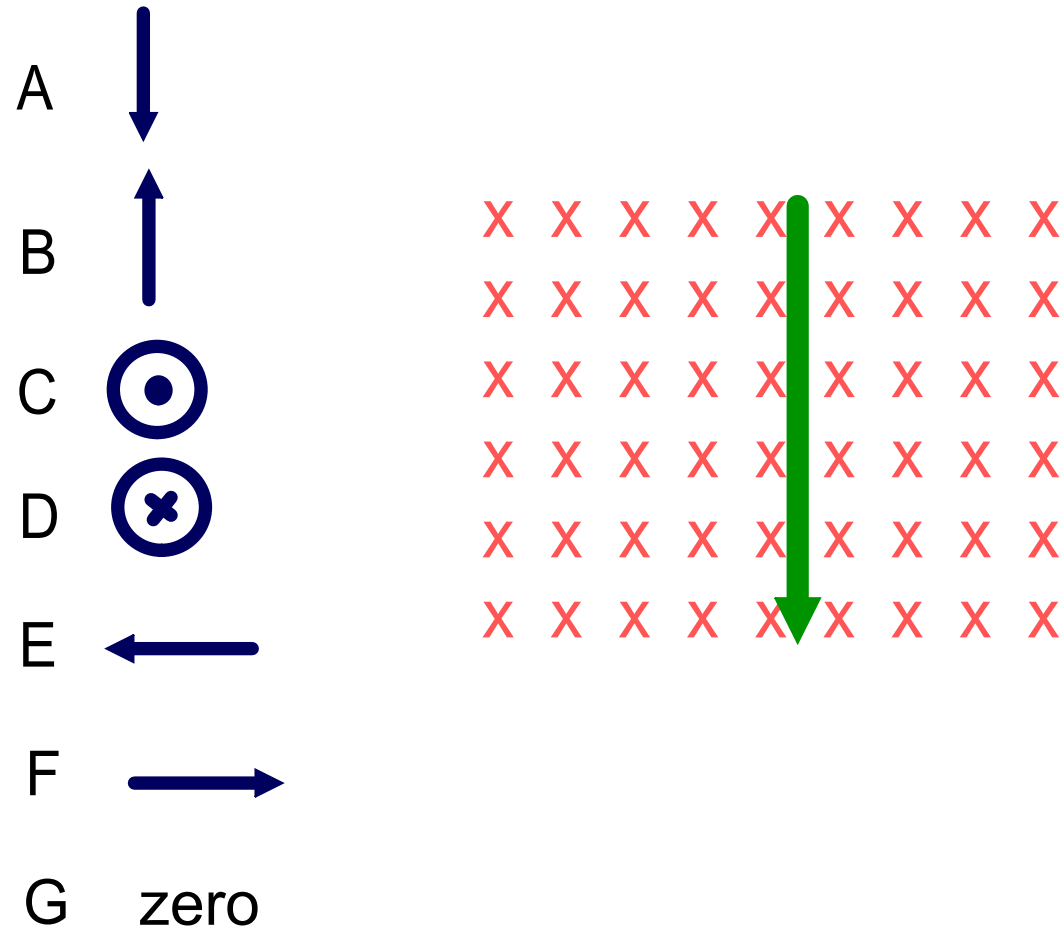
23 What is the direction of the magnetic force on the current carrying wire (green) in the magnetic field (red)?



Answer



24 What is the direction of the magnetic force on the current carrying wire (green) in the magnetic field (red)?



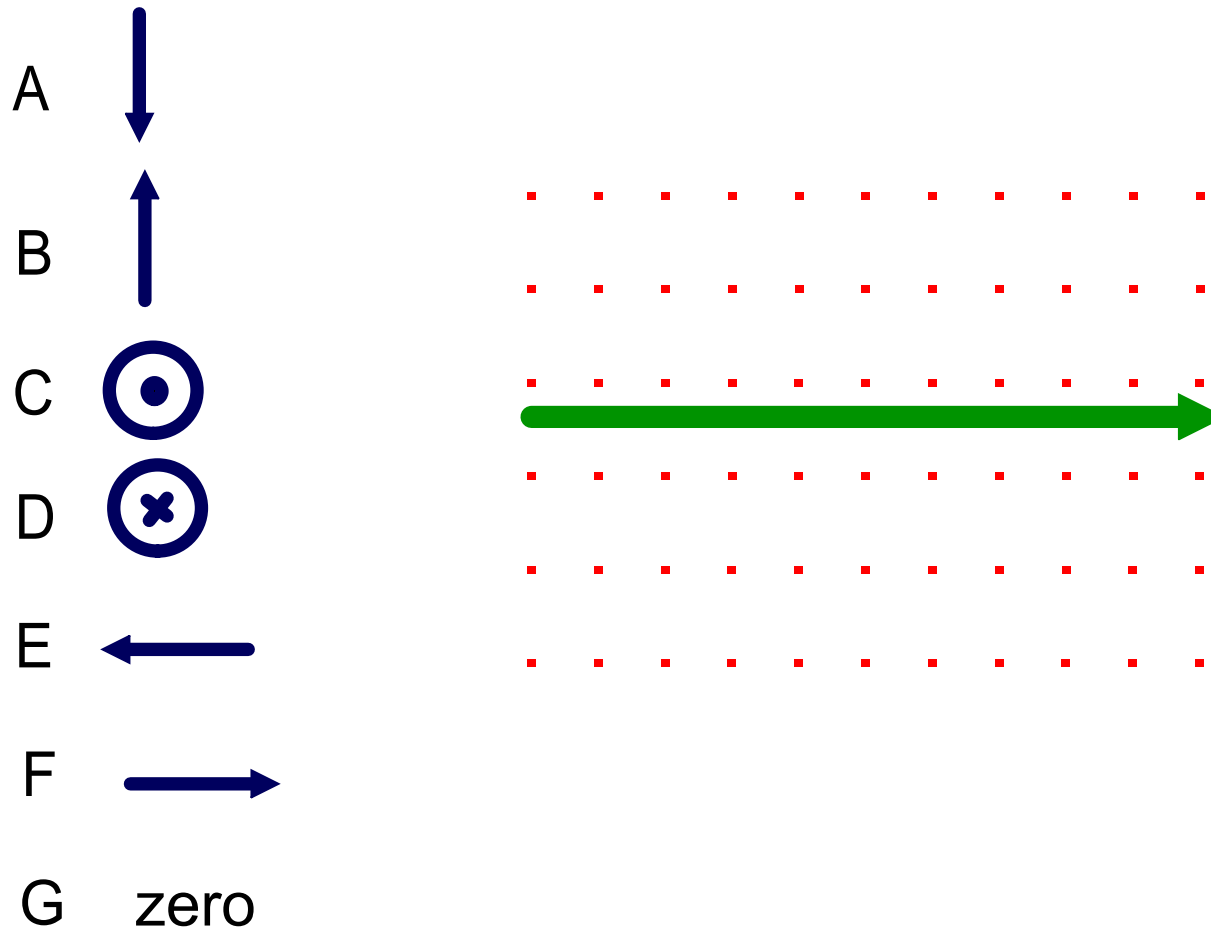
Answer



<https://www.njctl.org/video/?v=AX2qEWZQcpc>









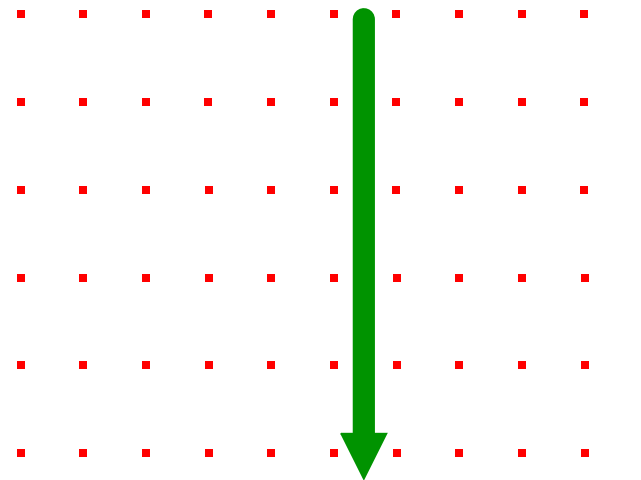
25 What is the direction of the magnetic force on the current carrying wire (green) in the magnetic field (red)?



Answer







26 What is the direction of the magnetic force on the current carrying wire (green) in the magnetic field (red)?

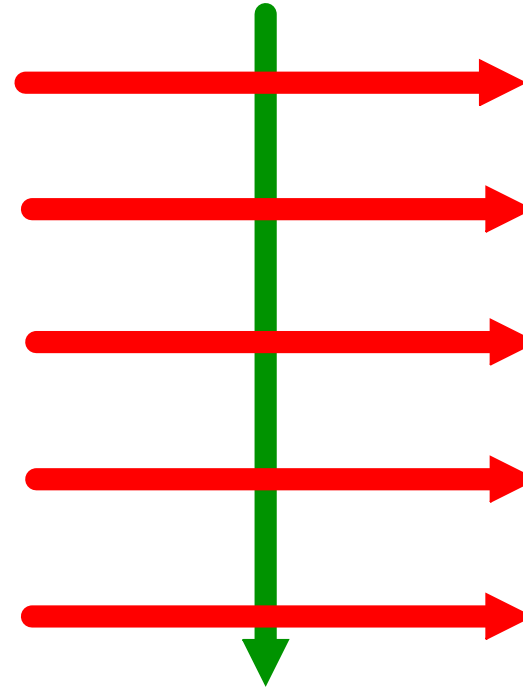
- A 
- B 
- C 
- D 
- E 
- F 
- G zero



Answer







27 What is the direction of the magnetic force on the current carrying wire (green) in the magnetic field (red)?

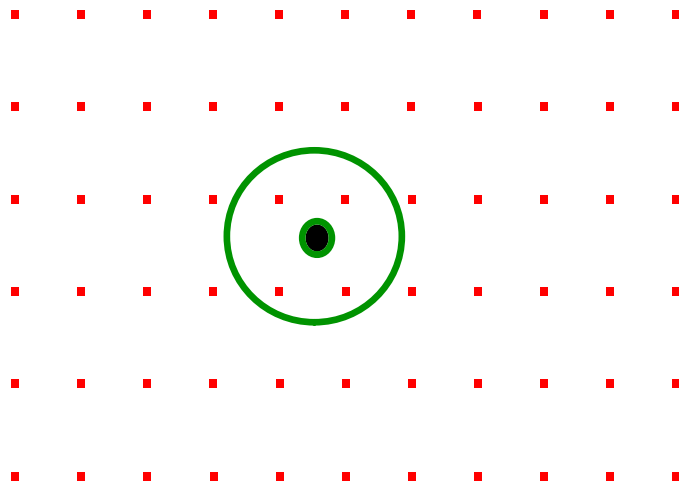
- A 
- B 
- C 
- D 
- E 
- F 
- G zero



Answer

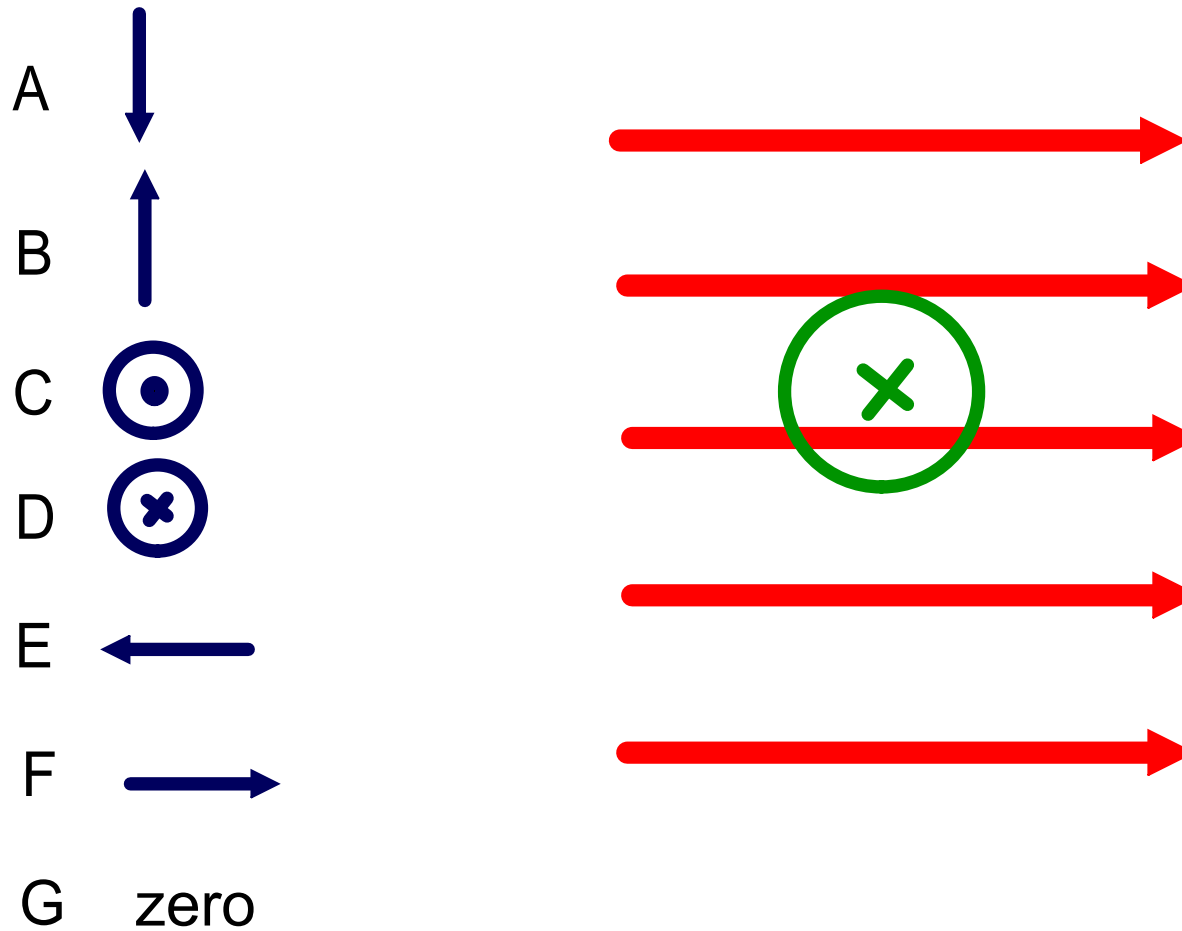
28 What is the direction of the magnetic force on the current carrying wire (green) in the magnetic field (red)?

- A 
- B 
- C 
- D 
- E 
- F 
- G zero









Answer

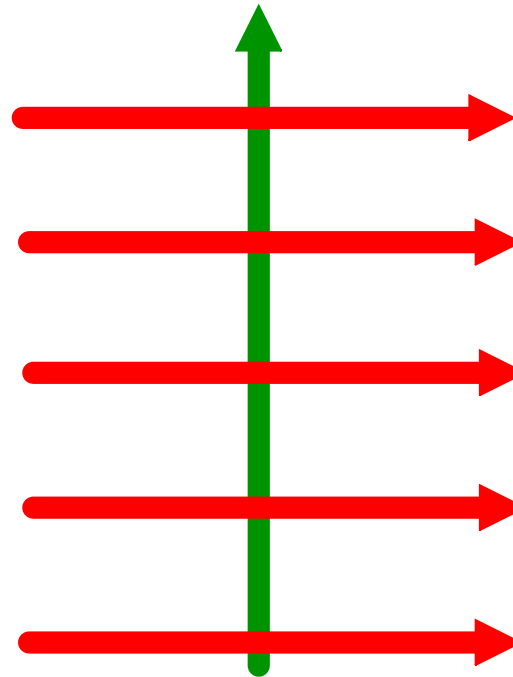
29 What is the direction of the magnetic force on the current carrying wire (green) in the magnetic field (red)?



Answer

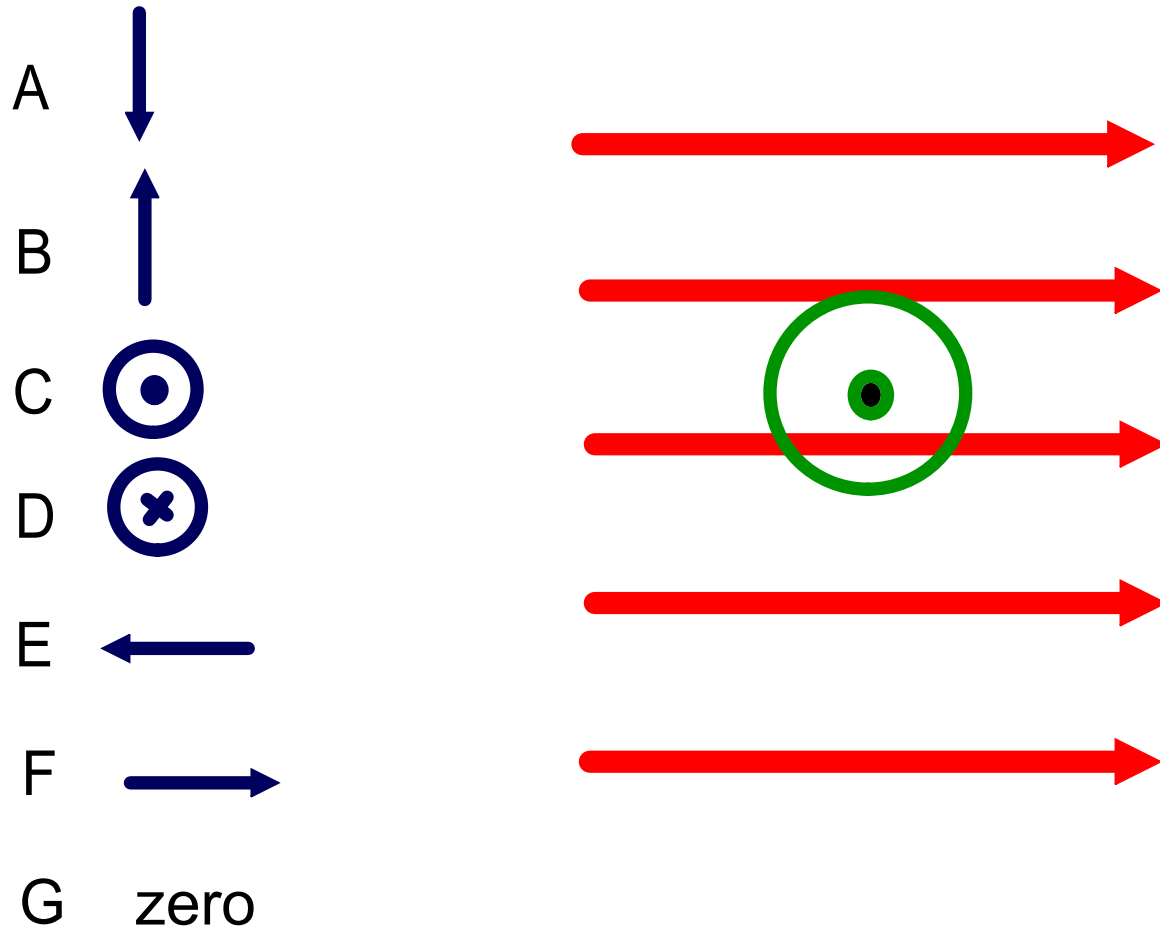
30 What is the direction of the magnetic force on the current carrying wire (green) in the magnetic field (red)?

- A 
- B 
- C 
- D 
- E 
- F 
- G zero









Answer

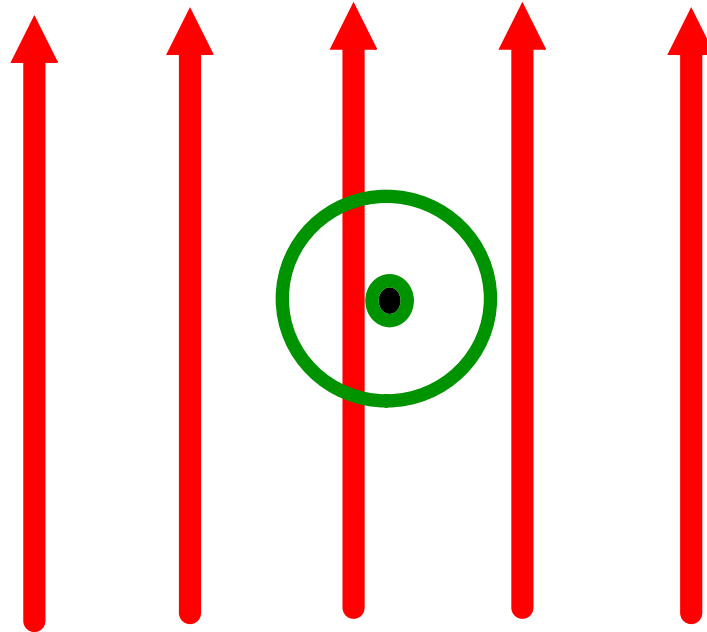
31 What is the direction of the magnetic force on the current carrying wire (green) in the magnetic field (red)?



Answer

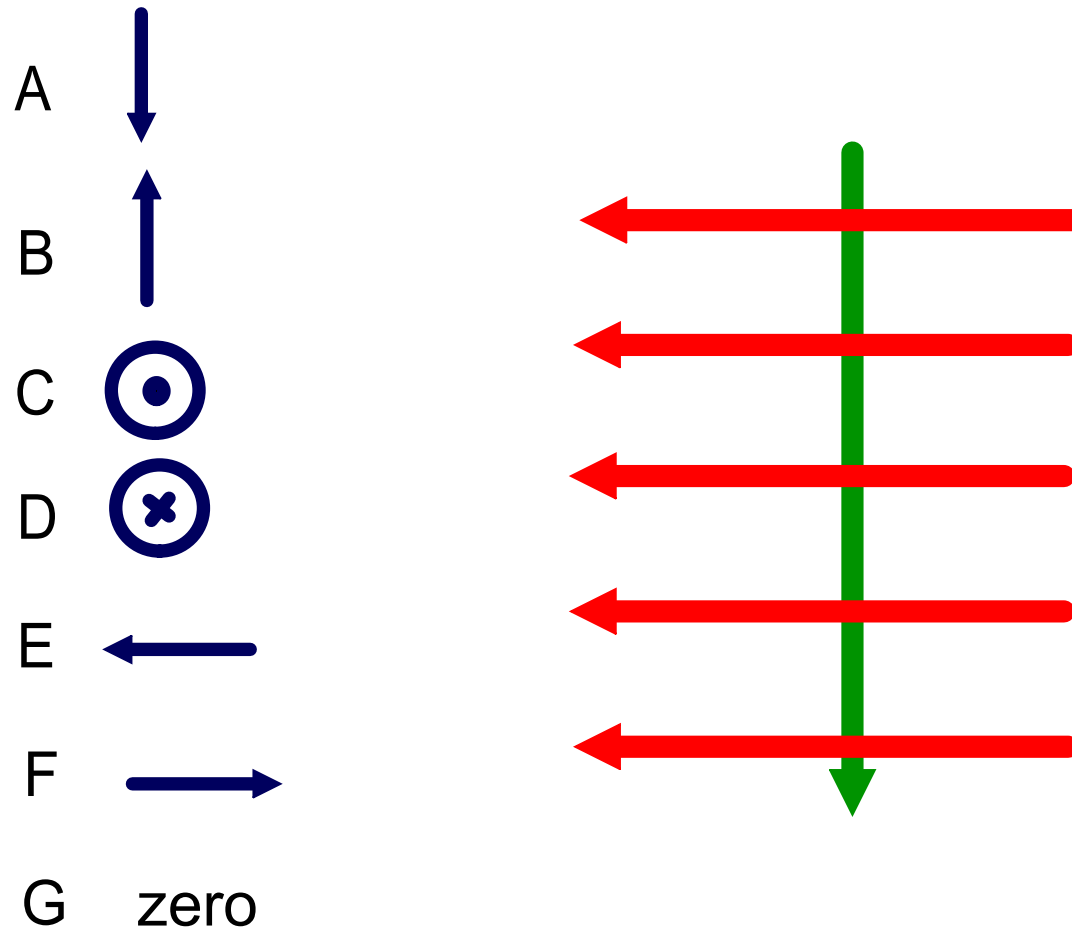
32 What is the direction of the magnetic force on the current carrying wire (green) in the magnetic field (red)?

- A 
- B 
- C 
- D 
- E 
- F 
- G zero









Answer

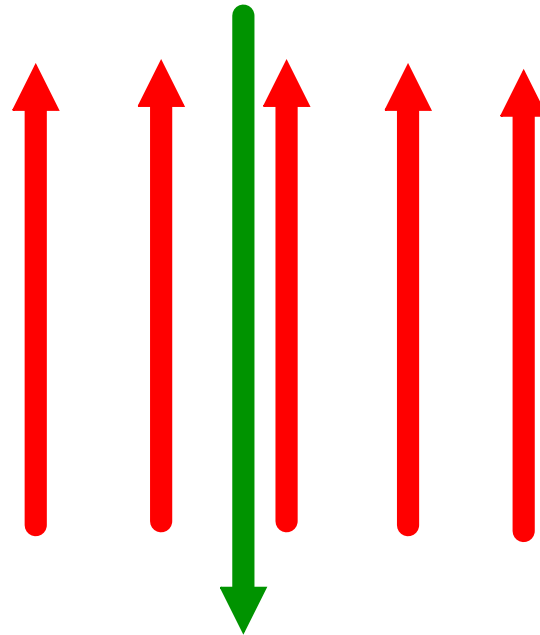
33 What is the direction of the magnetic force on the current carrying wire (green) in the magnetic field (red)?



Answer







34 What is the direction of the magnetic force on the current carrying wire (green) in the magnetic field (red)?

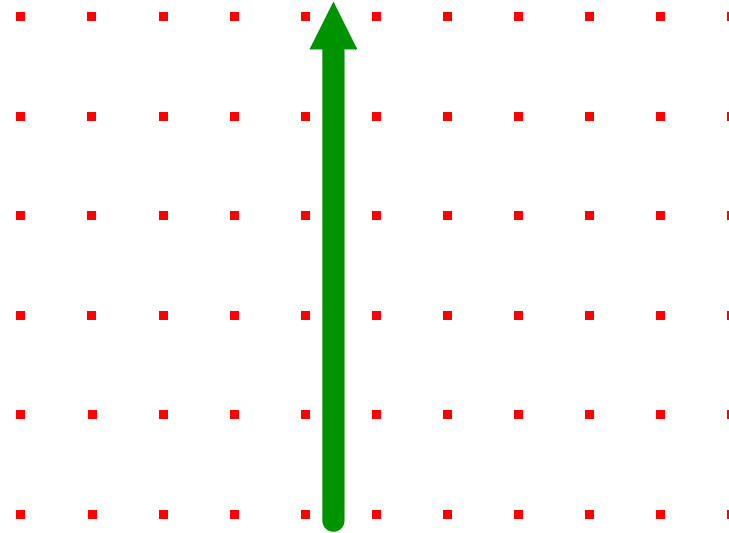
- A 
- B 
- C 
- D 
- E 
- F 
- G zero



Answer







35 What is the direction of the magnetic force on the current carrying wire (green) in the magnetic field (red)?

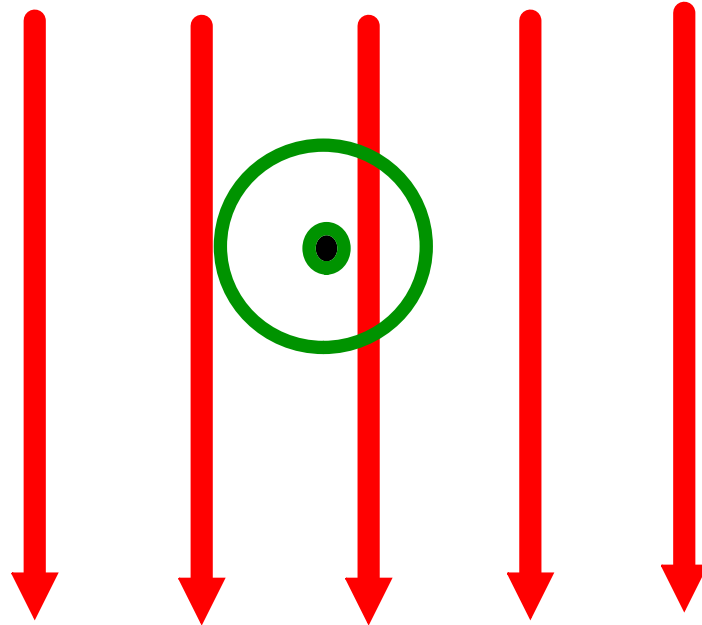
- A 
- B 
- C 
- D 
- E 
- F 
- G zero



Answer

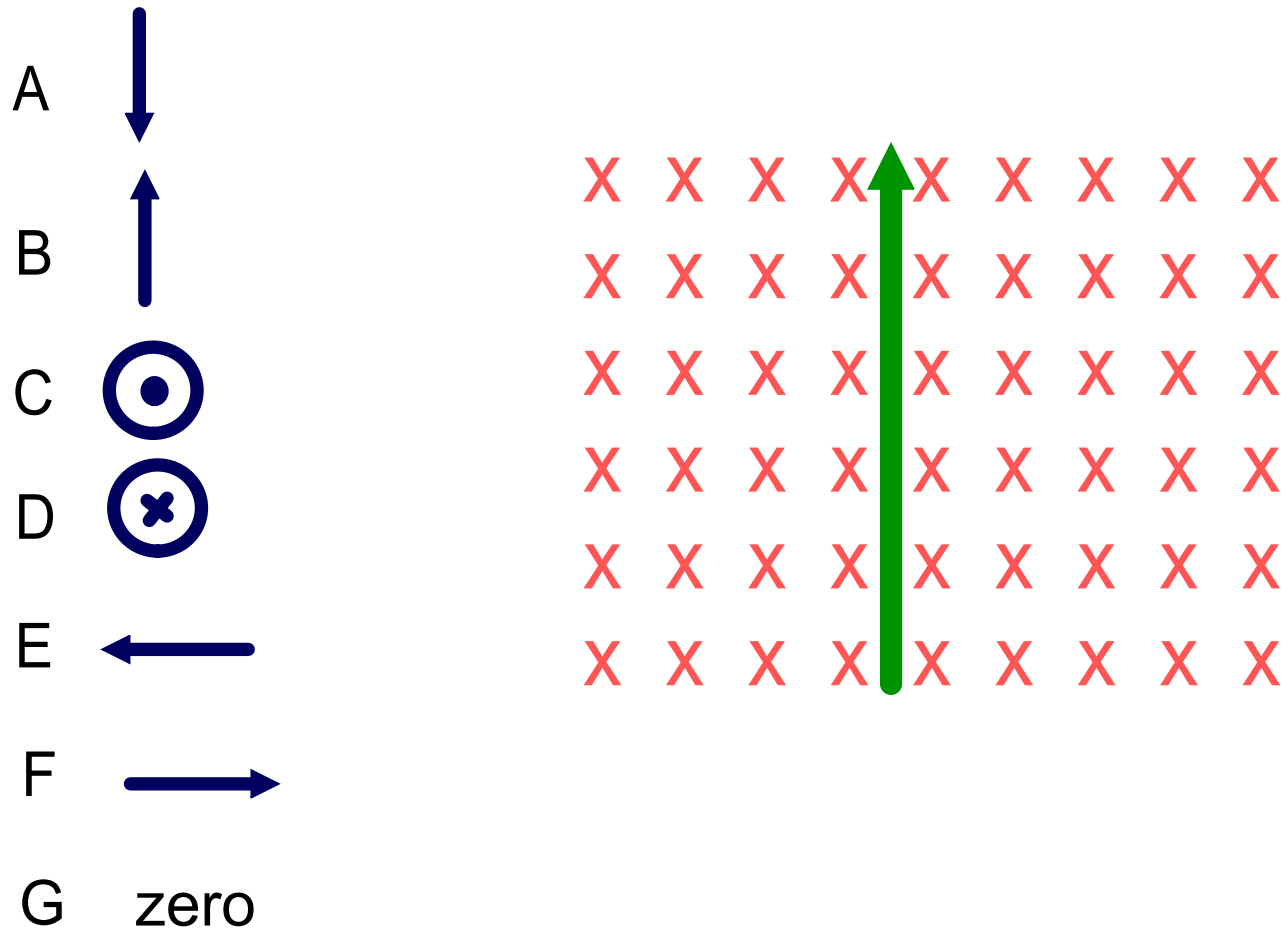
36 What is the direction of the magnetic force on the current carrying wire (green) in the magnetic field (red)?

- A 
- B 
- C 
- D 
- E 
- F 
- G zero



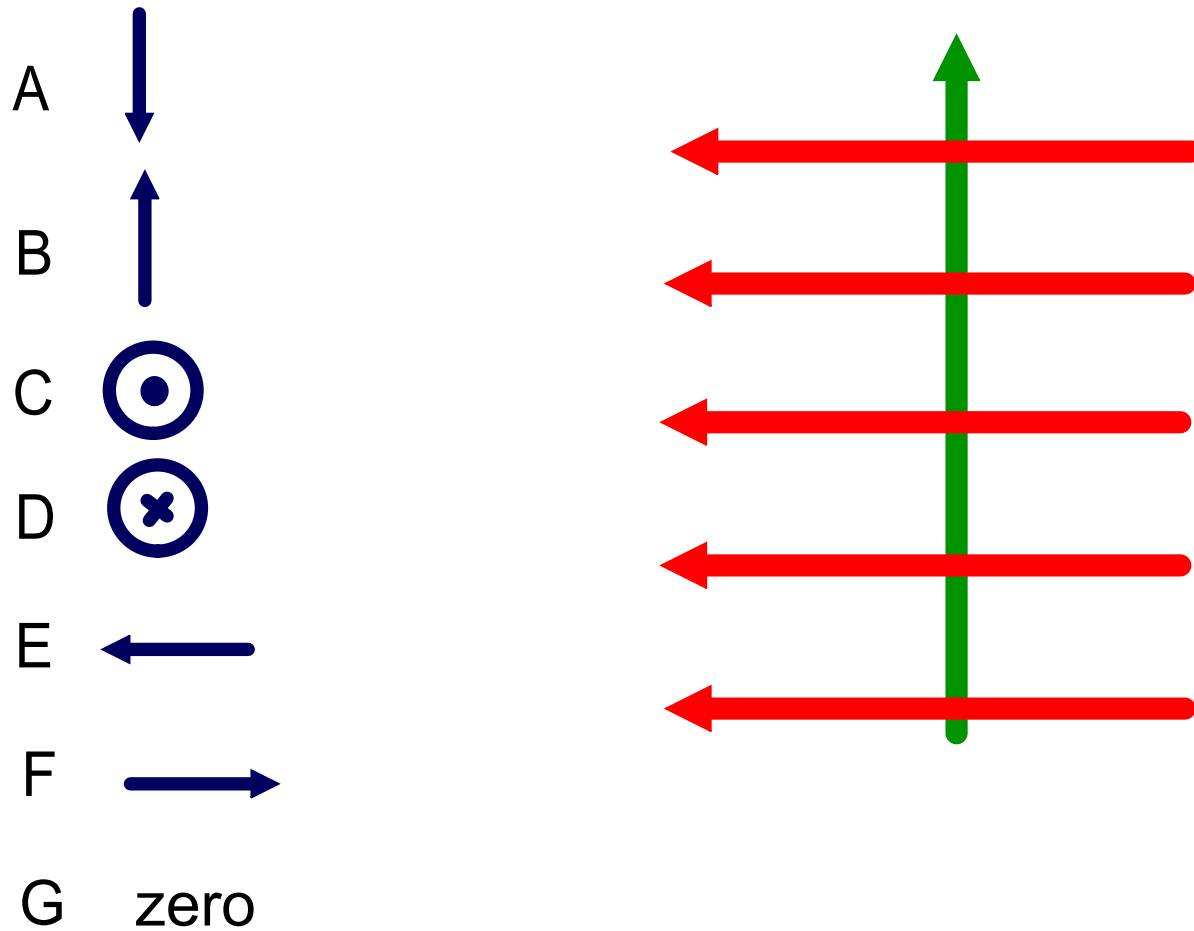
Answer

37 What is the direction of the magnetic force on the current carrying wire (green) in the magnetic field (red)?



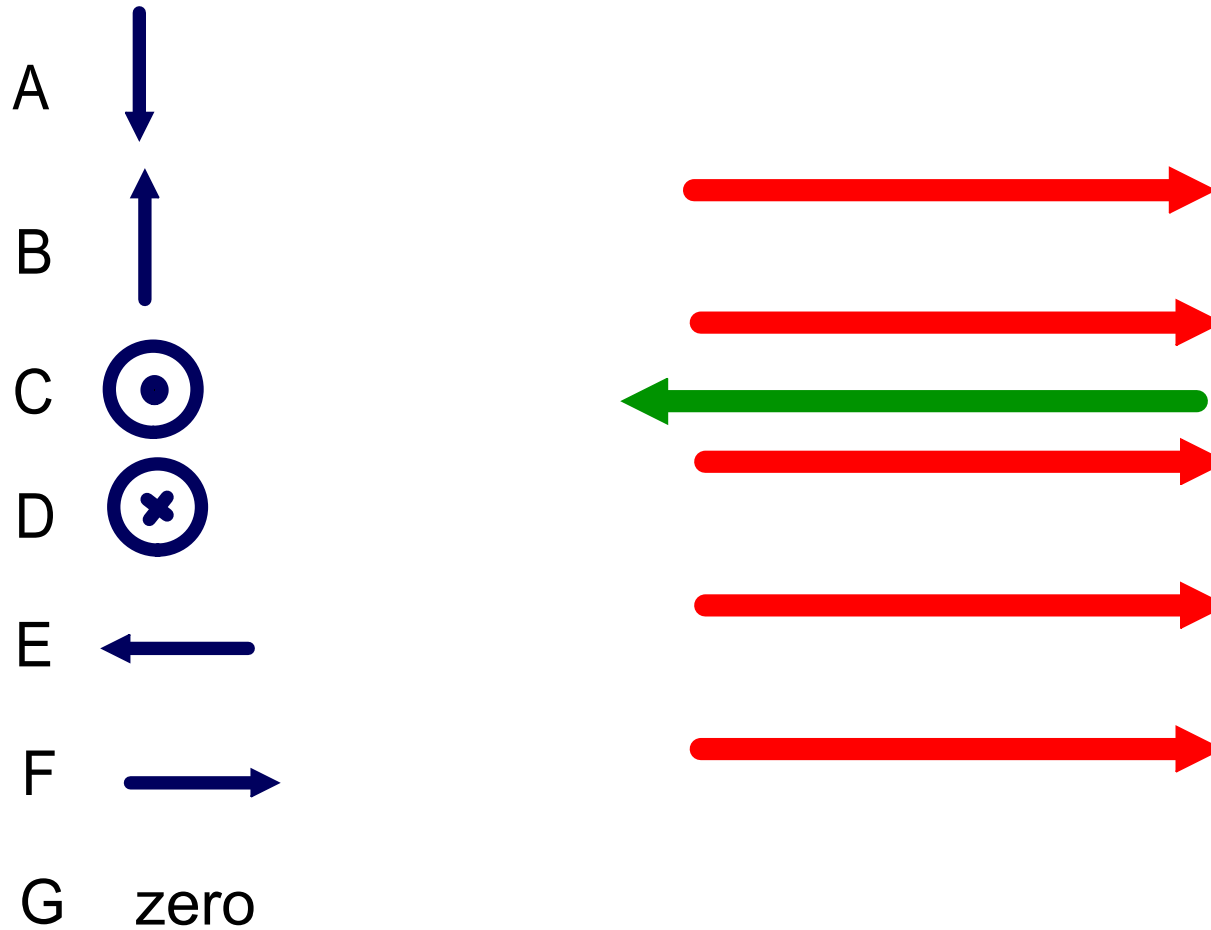
Answer

38 What is the direction of the magnetic force on the current carrying wire (green) in the magnetic field (red)?



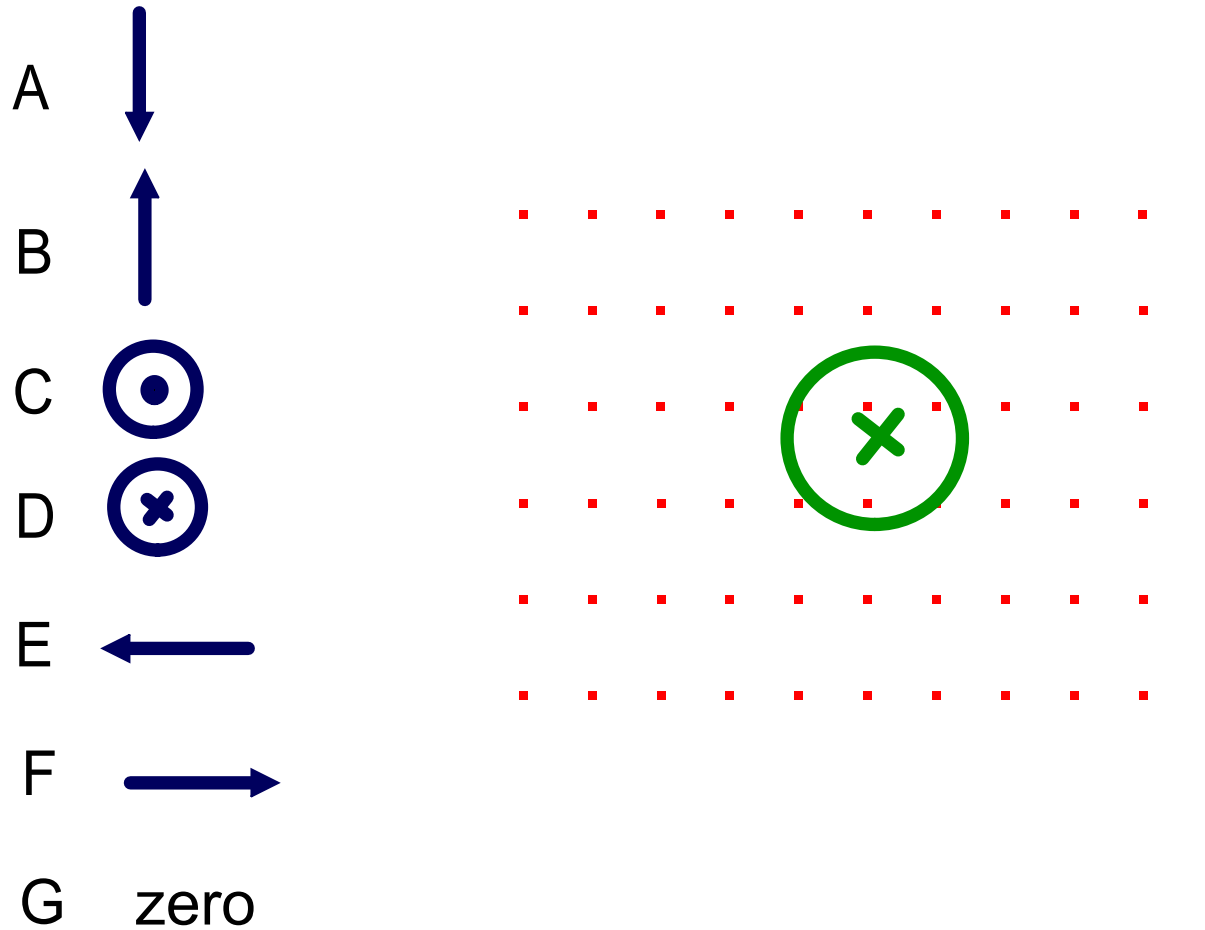
Answer

39 What is the direction of the magnetic force on the current carrying wire (green) in the magnetic field (red)?









Answer

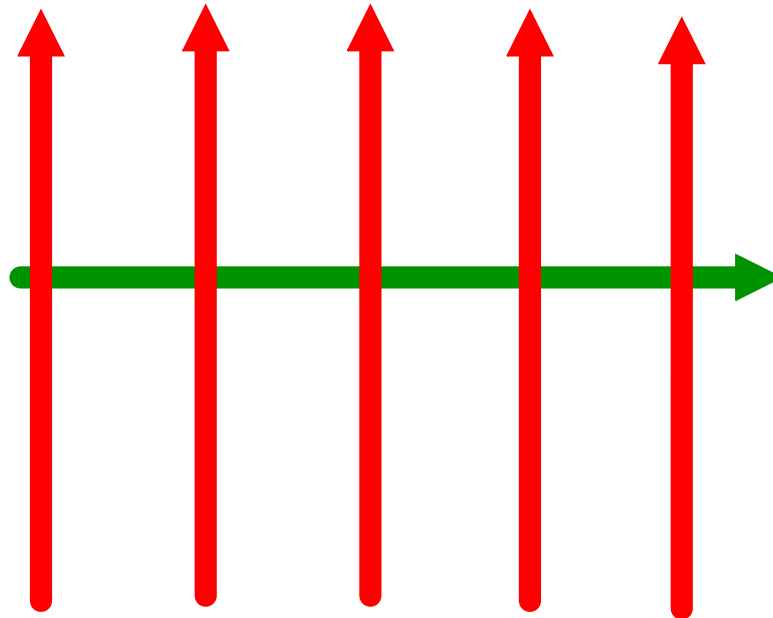
40 What is the direction of the magnetic force on the current carrying wire (green) in the magnetic field (red)?



Answer

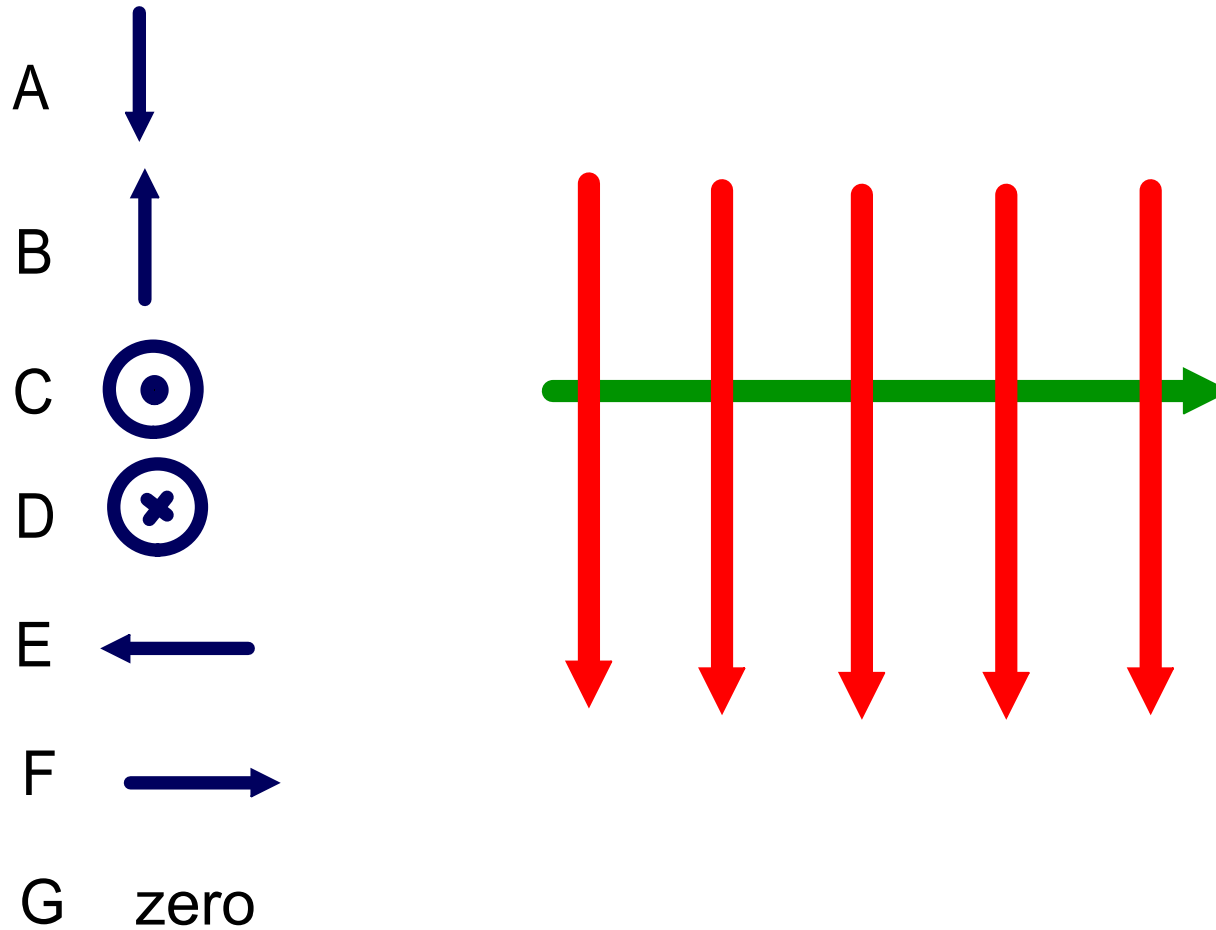
41 What is the direction of the magnetic force on the current carrying wire (green) in the magnetic field (red)?

- A 
- B 
- C 
- D 
- E 
- F 
- G zero



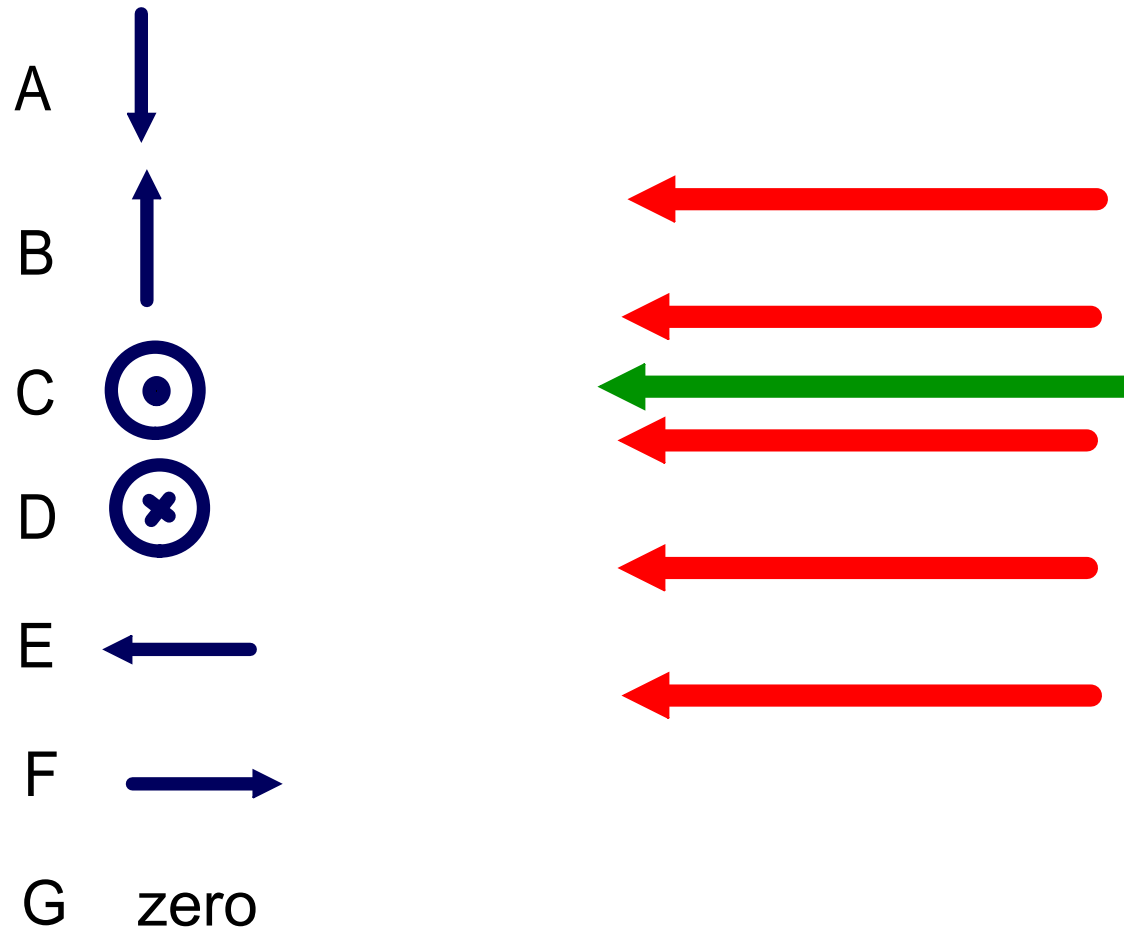
Answer

42 What is the direction of the magnetic force on the current carrying wire (green) in the magnetic field (red)?



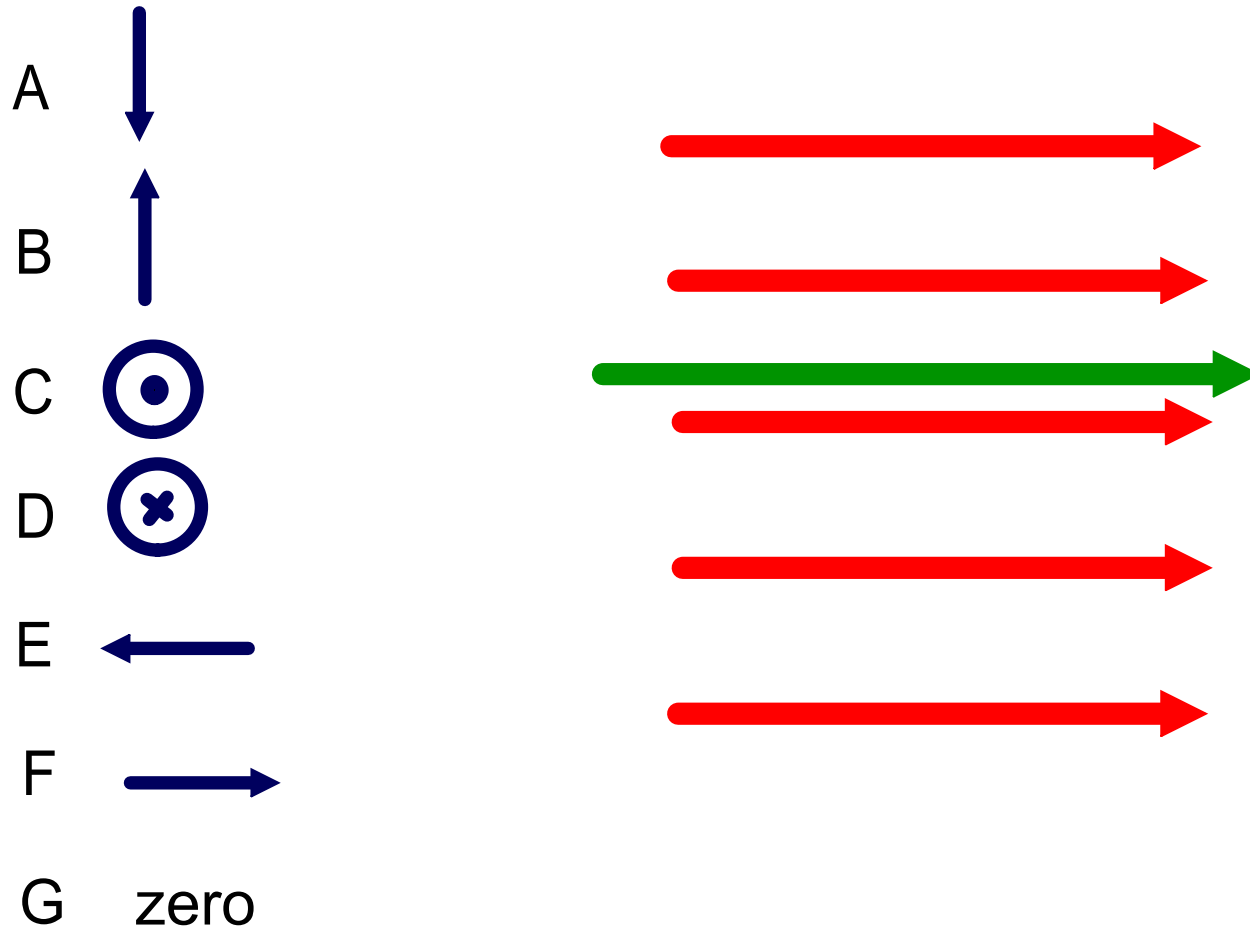
Answer

43 What is the direction of the magnetic force on the current carrying wire (green) in the magnetic field (red)?









Answer

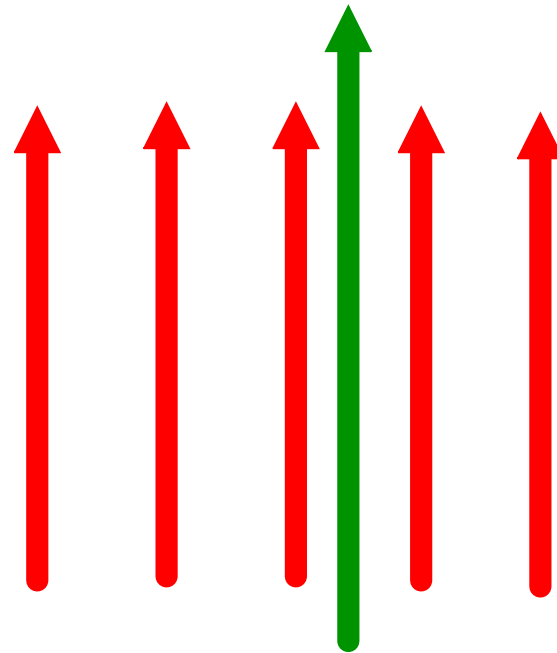
44 What is the direction of the magnetic force on the current carrying wire (green) in the magnetic field (red)?



Answer

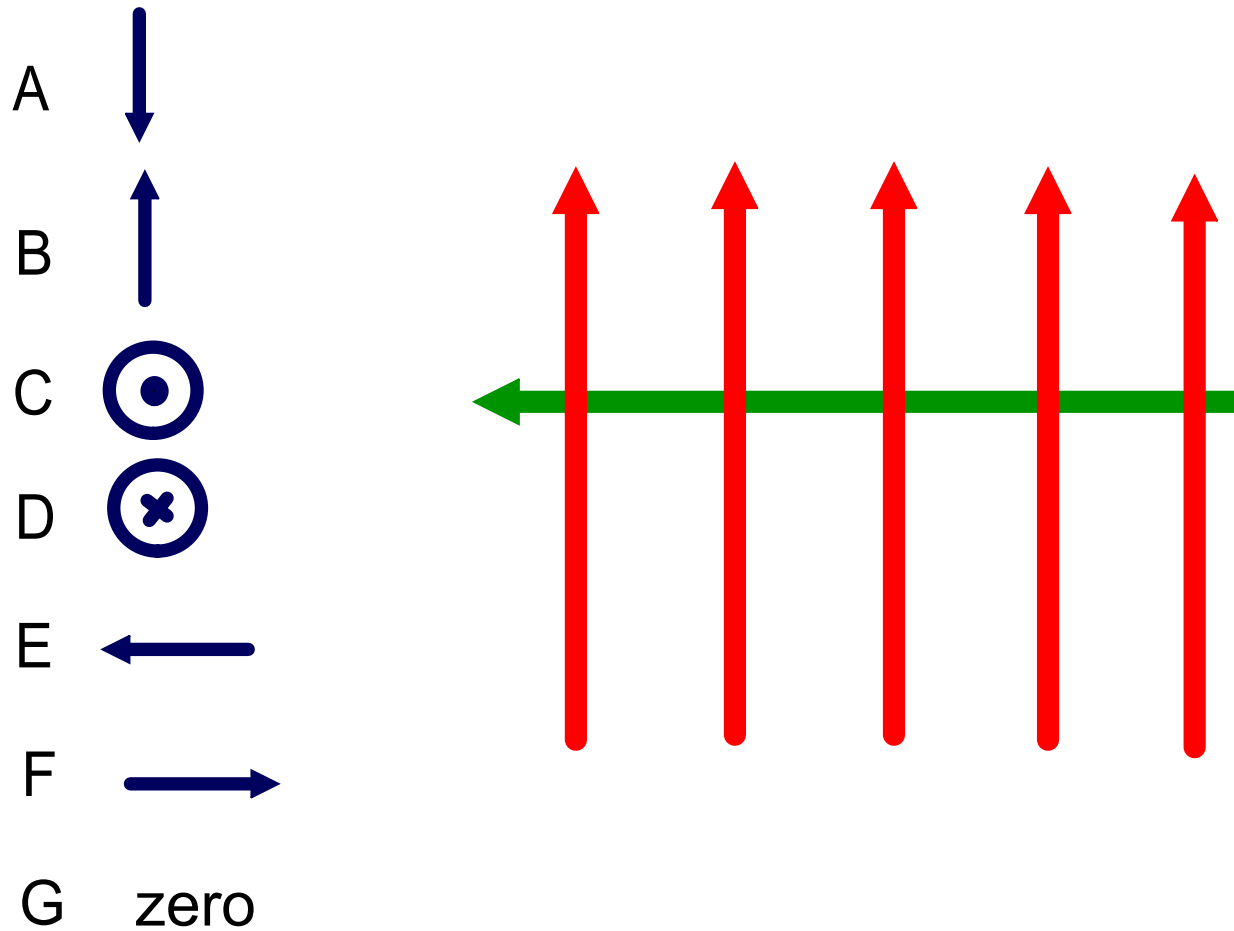
45 What is the direction of the magnetic force on the current carrying wire (green) in the magnetic field (red)?

- A 
- B 
- C 
- D 
- E 
- F 
- G zero



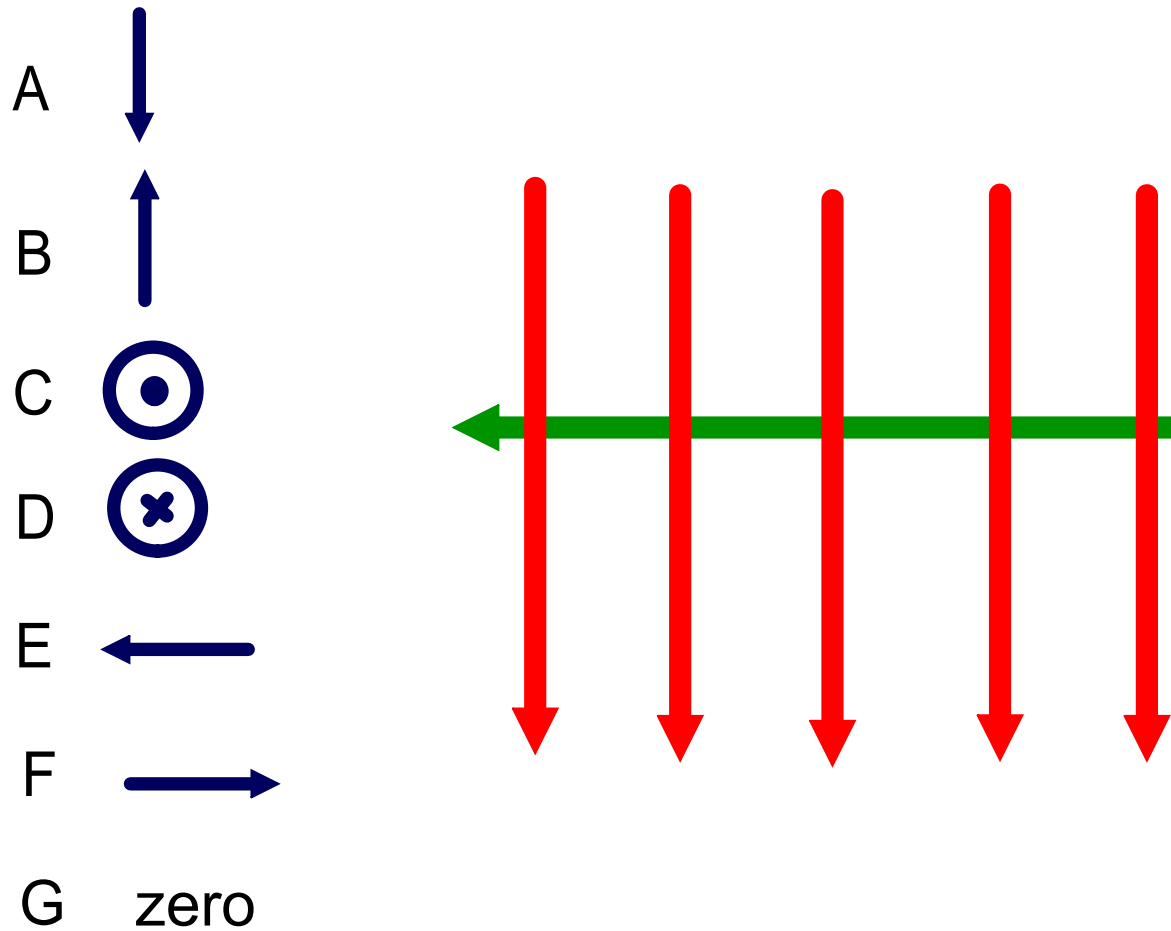
Answer

46 What is the direction of the magnetic force on the current carrying wire (green) in the magnetic field (red)?



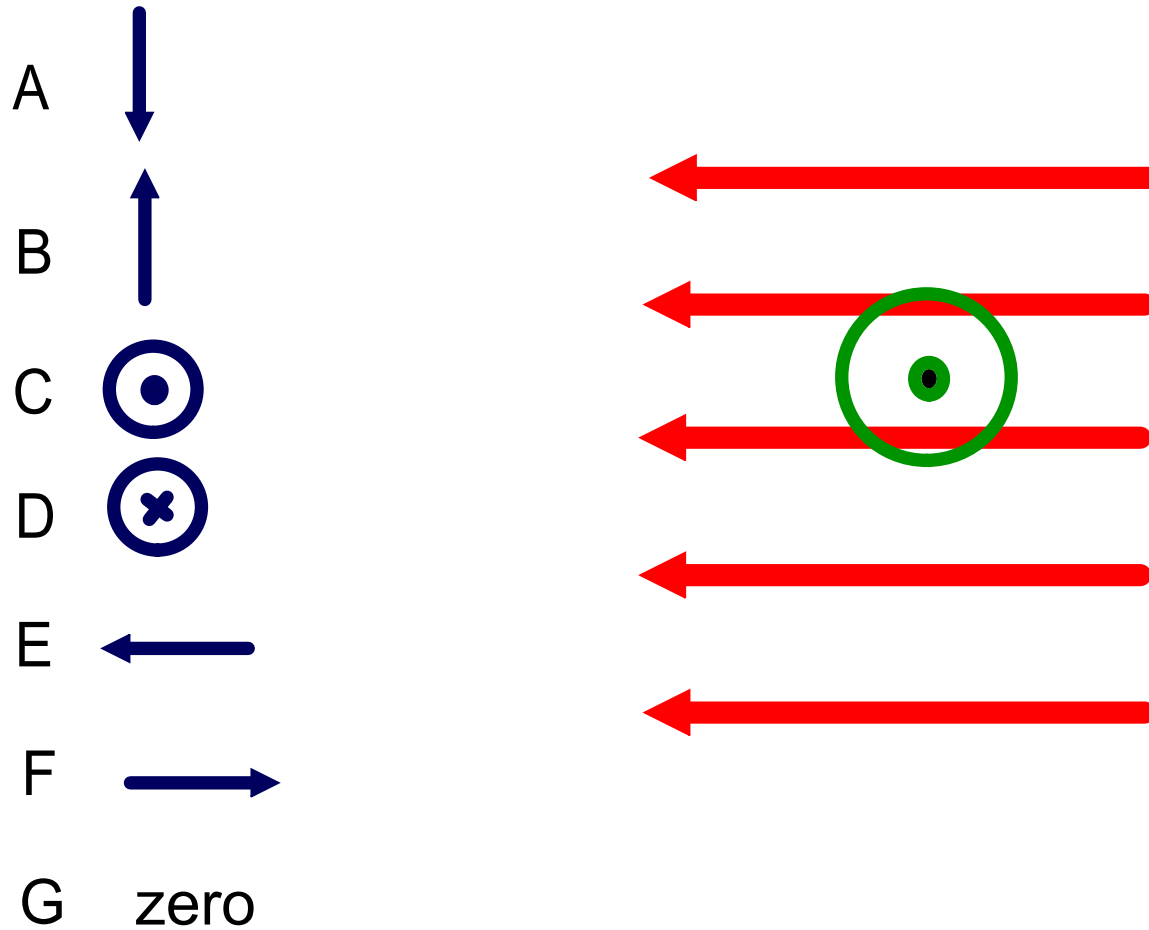
Answer

47 What is the direction of the magnetic force on the current carrying wire (green) in the magnetic field (red)?









Answer

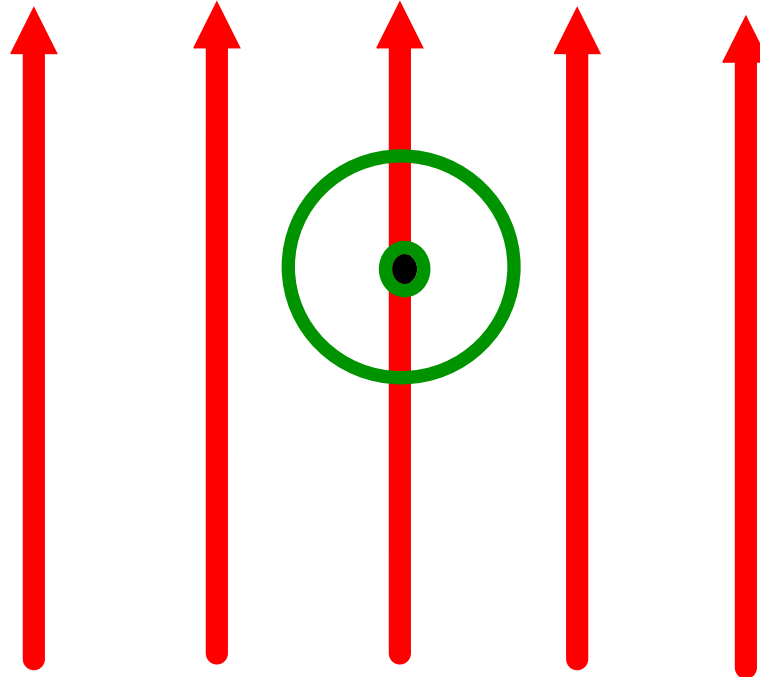
48 What is the direction of the magnetic force on the current carrying wire (green) in the magnetic field (red)?



Answer

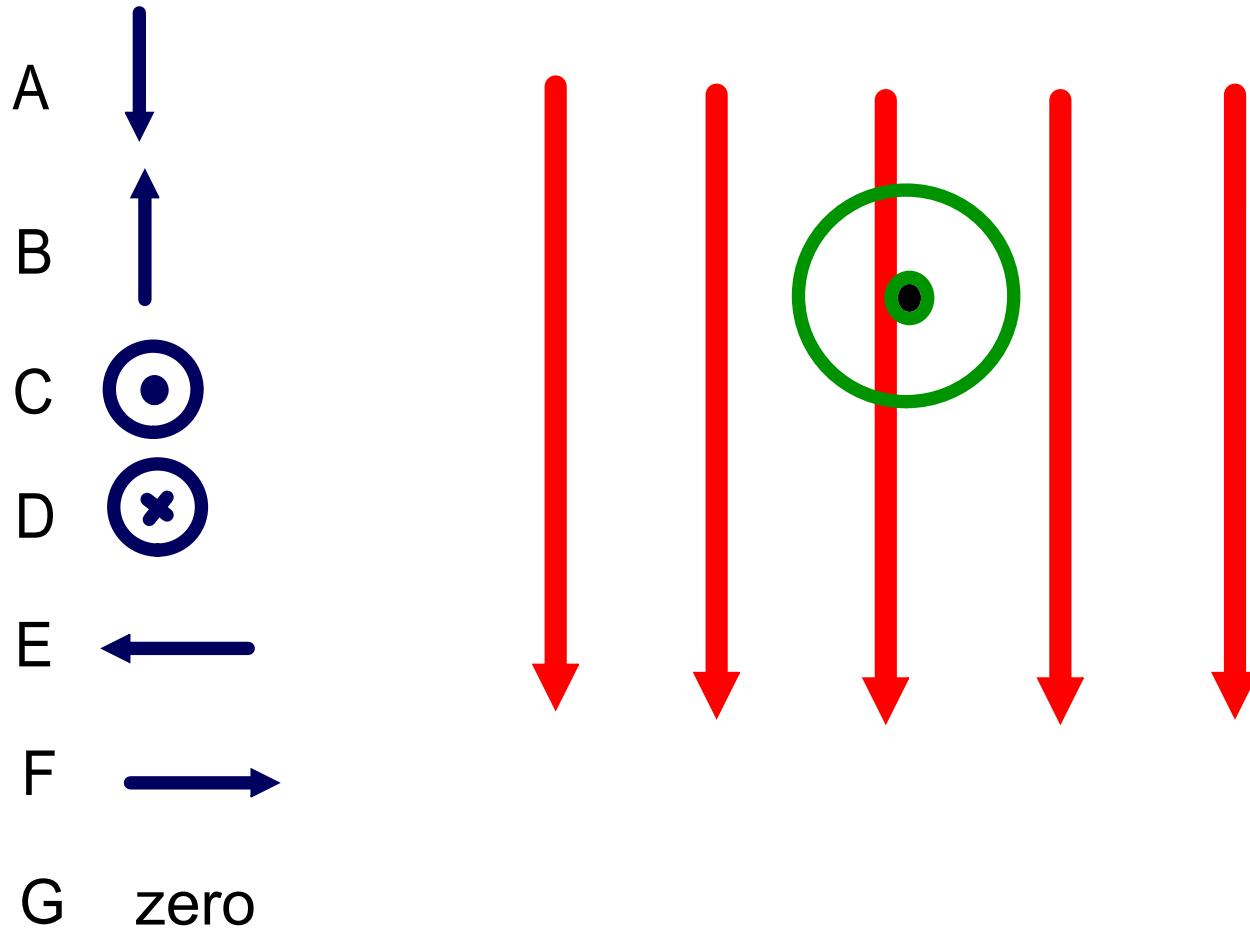
49 What is the direction of the magnetic force on the current carrying wire (green) in the magnetic field (red)?

- A 
- B 
- C 
- D 
- E 
- F 
- G zero



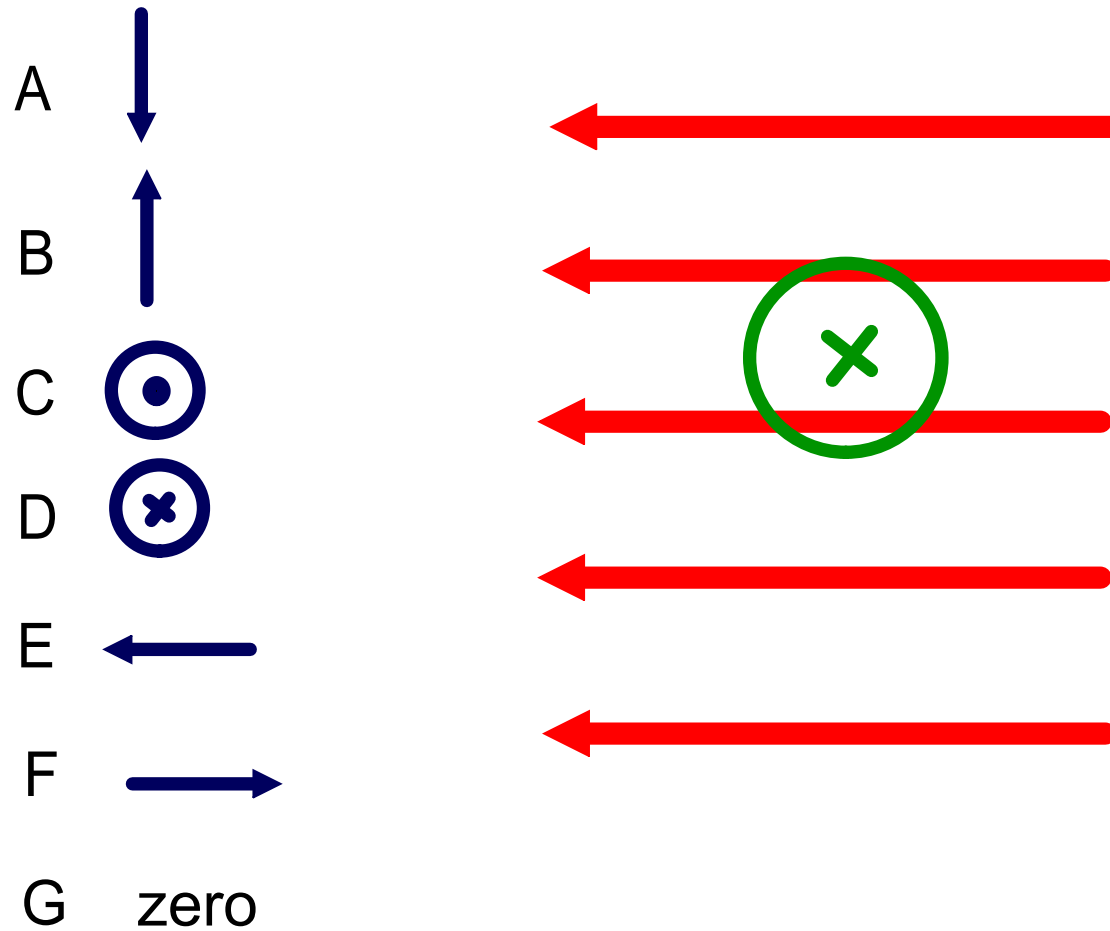
Answer

50 What is the direction of the magnetic force on the current carrying wire (green) in the magnetic field (red)?



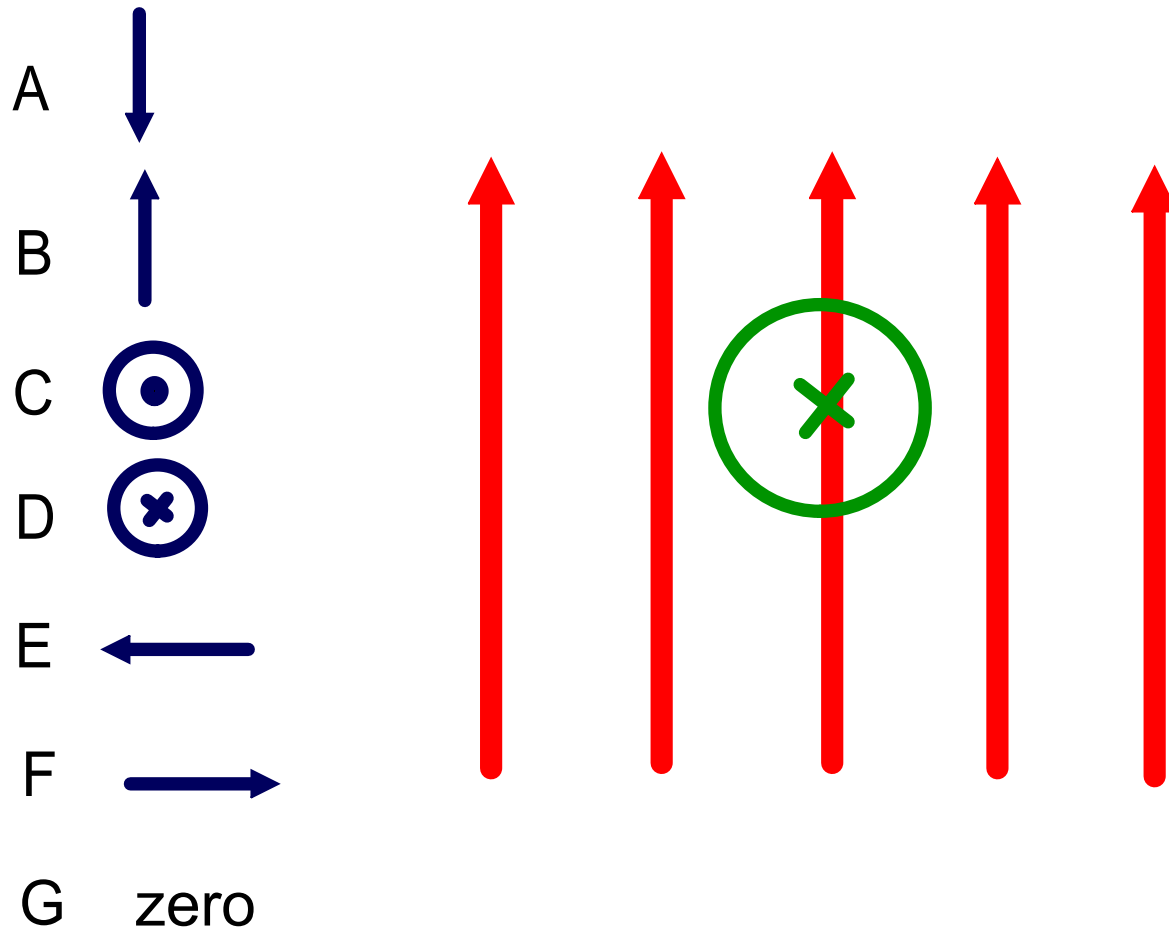
Answer

51 What is the direction of the magnetic force on the current carrying wire (green) in the magnetic field (red)?









Answer

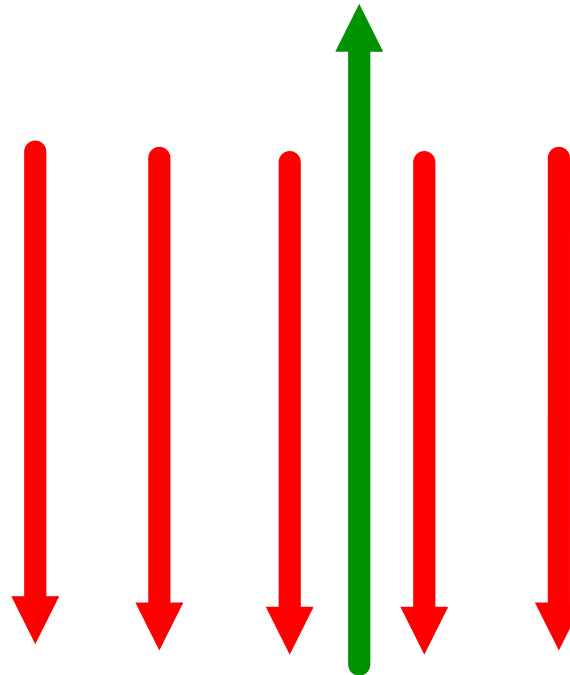
52 What is the direction of the magnetic force on the current carrying wire (green) in the magnetic field (red)?



Answer

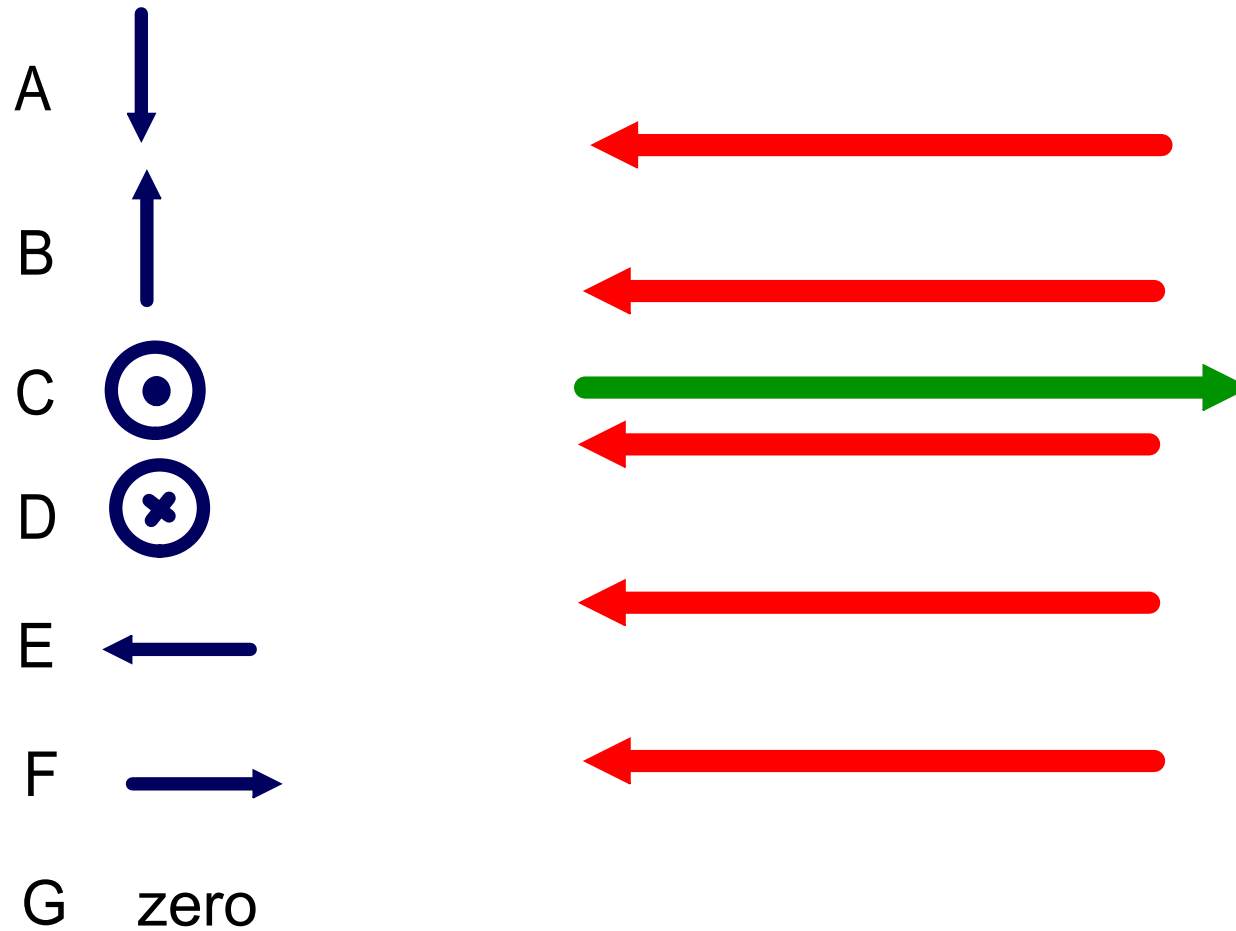
53 What is the direction of the magnetic force on the current carrying wire (green) in the magnetic field (red)?

- A 
- B 
- C 
- D 
- E 
- F 
- G zero









Answer

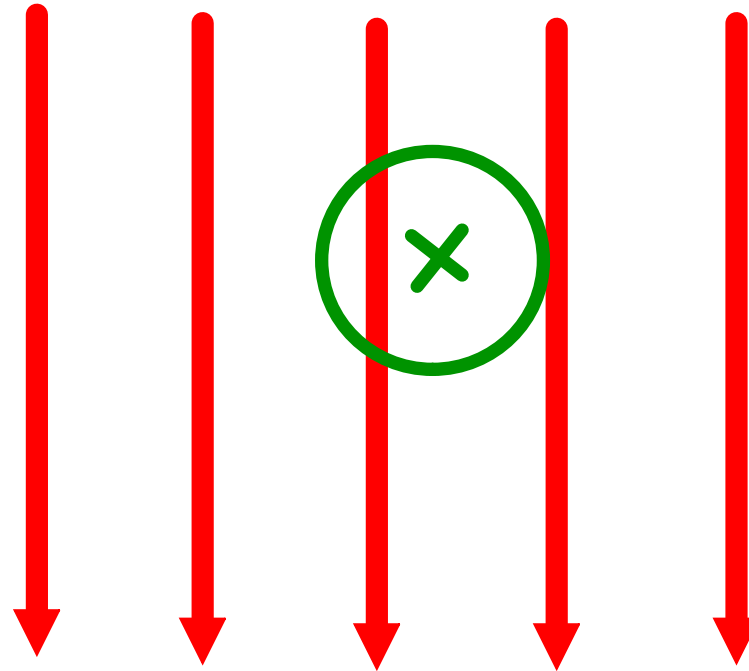
54 What is the direction of the magnetic force on the current carrying wire (green) in the magnetic field (red)?



Answer

55 What is the direction of the magnetic force on the current carrying wire (green) in the magnetic field (red)?

- A 
- B 
- C 
- D 
- E 
- F 
- G zero



Answer

Magnetic Field & Force on a Current-Carrying Wire

The force on the wire depends on the current, the length of the wire, the magnetic field, and its orientation.

$$F = ILB_{\text{perpendicular}}$$

I is the current

L is the length of wire

B is the magnetic field (perpendicular to both the force and current)

56 A 0.5 m long wire carries a current of 2.0 A in a direction perpendicular to a 0.3 T magnetic field. What is the magnitude of the magnetic force acting on the wire?

Answer



<https://www.njctl.org/video/?v=iQFjAgXJHFY>



57 A uniform magnetic field exerts a maximum force of 20 mN on a 0.25 m long wire carrying a current of 2.0 A. What is the strength of the magnetic field?

Answer



<https://www.njctl.org/video/?v=RrssfOtHxrk>



58 A 0.050N force acts on a 10.0 cm wire that is perpendicular to a 0.30 T magnetic field. What is the magnitude of the electric current through the wire?

Answer

Magnetic Field Due to a Long, Straight Current-Carrying Wire



https://www.njctl.org/video/?v=7400VR_lbz4



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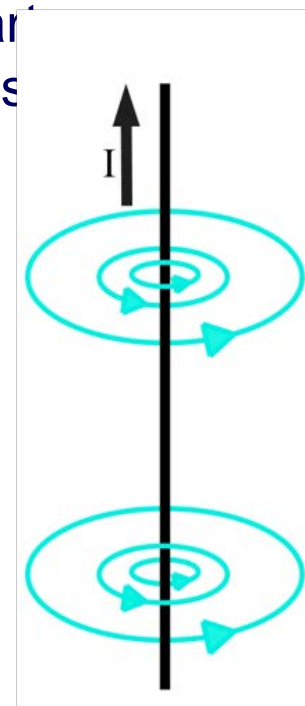
Magnetic Field Due to a Long Straight Wire

It was determined experimentally by Oersted, Ampere and others that the magnetic field decreases as the distance, r , increases away from the wire. The Biot-Savart Law and Ampere's Law (which will be done in AP Physics) both calculate this value:

$$B = \frac{\mu_0 I}{2\pi r}$$

The constant μ_0 is called the permeability of free space, and has the value:

$$\mu_0 = 4\pi \times 10^{-7} \text{ T}\cdot\text{m}/\text{A}$$



The constant μ_0 is the magnetic equivalent of the electrical constant, ϵ_0 , which is the permittivity of free space.

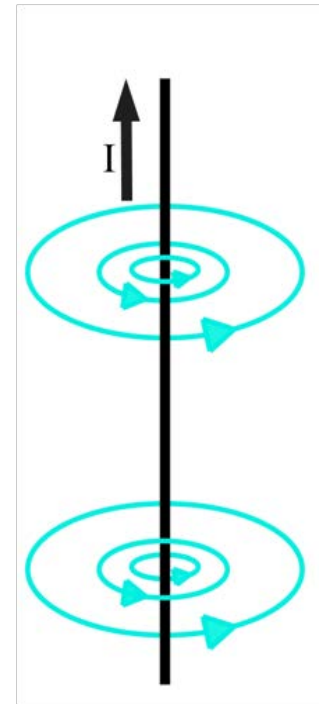
Magnetic Field Due to a Long Straight Wire

It was determined experimentally by Oersted, Ampere and others that the magnetic field decreases as the distance, r , away from the wire. The Biot-Savart Law and Ampere's Law (which will be done in AP Physics) both calculate this value:

$$B = \frac{\mu_0 I}{2\pi r}$$

The constant μ_0 is called the permeability of free space, and has the value:

$$\mu_0 = 4\pi \times 10^{-7} \text{ T}\cdot\text{m/A}$$



The constant μ_0 is the magnetic equivalent of the electrical constant, ϵ_0 , which is the permittivity of free space.

59 What is the magnetic field at a point 0.50 m away from a wire carrying 40.0 A of current?

Answer



<https://www.njctl.org/video/?v=9LLpmyEwTVk>



60 A long straight wire carries a current of 12 A towards the west (left). What is the direction and magnitude of the magnetic field 10.0 cm to the south (below) the wire?

Answer



<https://www.njctl.org/video/?v=i74cnUc5BA8>



61 A straight wire with a current of 50 A is oriented vertically. What is the magnitude of the magnetic field at a point 2 m away from the wire?

Answer



<https://www.njctl.org/video/?v=jHYr32UqSfl>



62 A long straight wire carries a current of 30.0 A towards the west (left). What is the direction and magnitude of the magnetic field 5.0 m to the north (above) the wire?

Answer



<https://www.njctl.org/video/?v=l455aqffXA>



Magnetic Field & Force between Two Current- Carrying Wires



<https://www.njctl.org/video/?v=w4CyoE6FwP4>



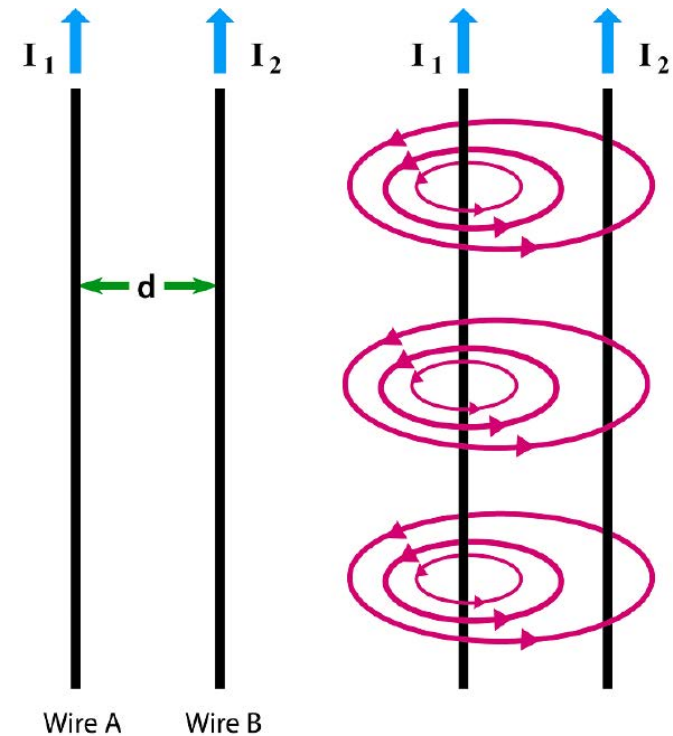
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Force between Two Parallel Wires

Set up two current carrying wires, each of length L , next to each other. Each wire will create a magnetic field that will exert a force on the other wire. Let's look at the force on Wire B due to Wire A.

Since the wires are separated by a distance d , the magnetic field generated by Wire A at Wire B's position is:

$$B_1 = \frac{\mu_0 I_1}{2\pi d}$$



Force between Two Parallel Wires

The magnetic field due to Wire A is everywhere perpendicular to the current in Wire B, so the force on Wire B due to Wire A is:

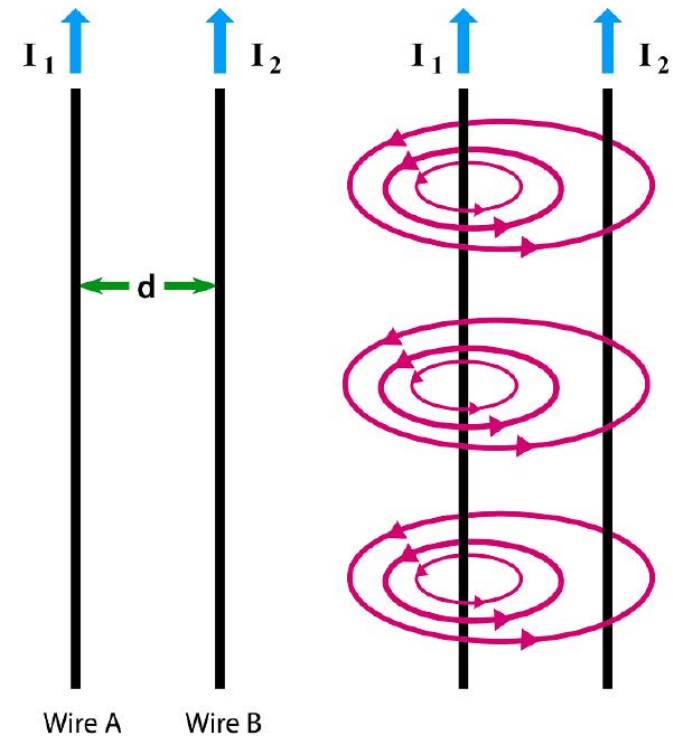
$$F_{AB} = I_2 L B_1$$

Substitute the value of B_1 found on the previous slide:

$$F_{AB} = I_2 L \frac{\mu_0 I_1}{2\pi d}$$

And rearranging:

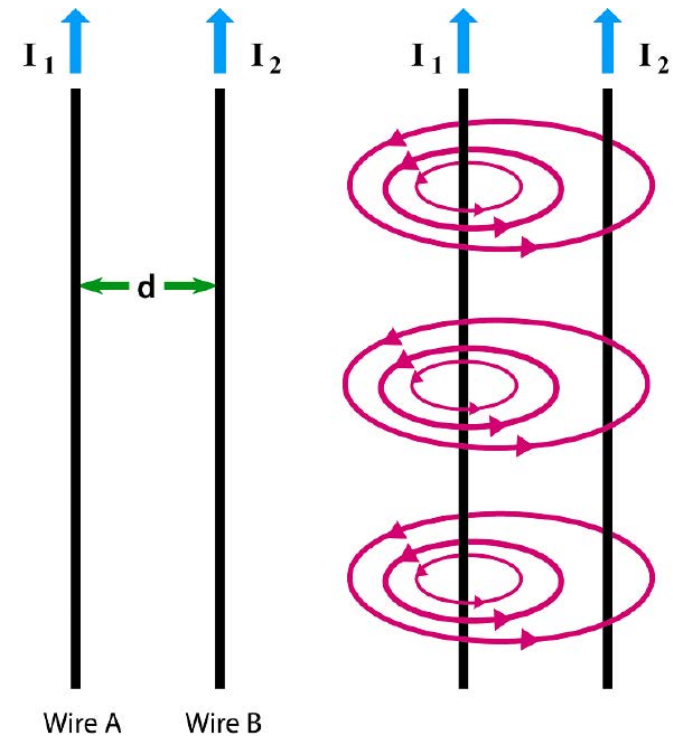
$$F_{AB} = \frac{\mu_0 I_1 I_2}{2\pi d} L$$



Force between Two Parallel Wires

We can carry out a similar analysis for the force that wire B exerts on wire A or, we could just use Newton's Third Law (it also works on magnetic and electrical forces) to state that the magnitudes of the two forces are equal.

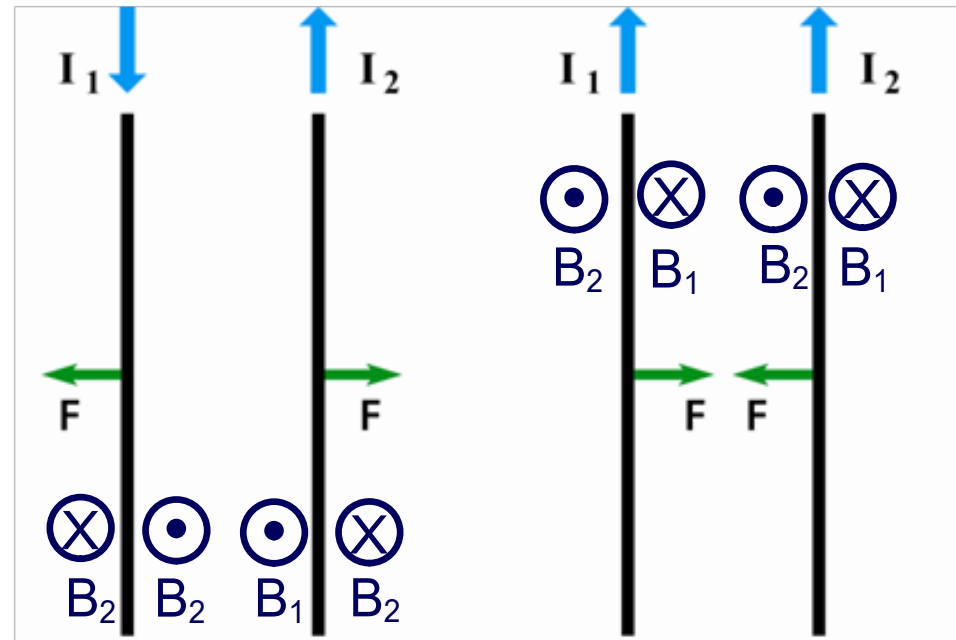
$$|F_{BA}| = |F_{AB}| = \frac{\mu_0 I_1 I_2}{2\pi d} L$$



Force between Two Parallel Wires

Using the right hand rule, the directions of B_1 and B_2 for both of the situations to the right are shown.

Then, the directions of the force on both wires are found by the right hand rule.



Parallel currents in the same direction attract.

Parallel currents in opposite directions (antiparallel) repel.

63 What is the magnitude and direction of the magnetic force between two parallel wires, 5.0 m long, 2.0 cm apart, if each carries a current of 15 A in opposite directions?

Answer



https://www.njctl.org/video/?v=EgPh_y0gNL8



64 Two parallel wires with currents flowing in opposite directions at 5.8 A and 3.2 A are separated by a distance of 12 cm. The length of the wires is 9.6m. What is the magnitude and direction of the magnetic force between the wires?

Answer



<https://www.njctl.org/video/?v=Najvgz-MqgY>



65 What is the magnitude and direction of the magnetic field force between two parallel wires 0.50 m long and 1.0 cm apart if each carries a current of 0.25 A in the same direction?

Answer



<https://www.njctl.org/video/?v=uHGIsmp9Rwk>



*Mass Spectrometer



<https://www.njctl.org/video/?v=kf5NY6VRi68>



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***Mass Spectrometer**

Now that electric and magnetic fields have both been presented, it is time to show an application that uses both types of fields.

A Mass Spectrometer is used to separate out atoms and molecules based on their mass - and is used to analyze the physical makeup of substances in terms of their relative concentrations of their constituent parts.

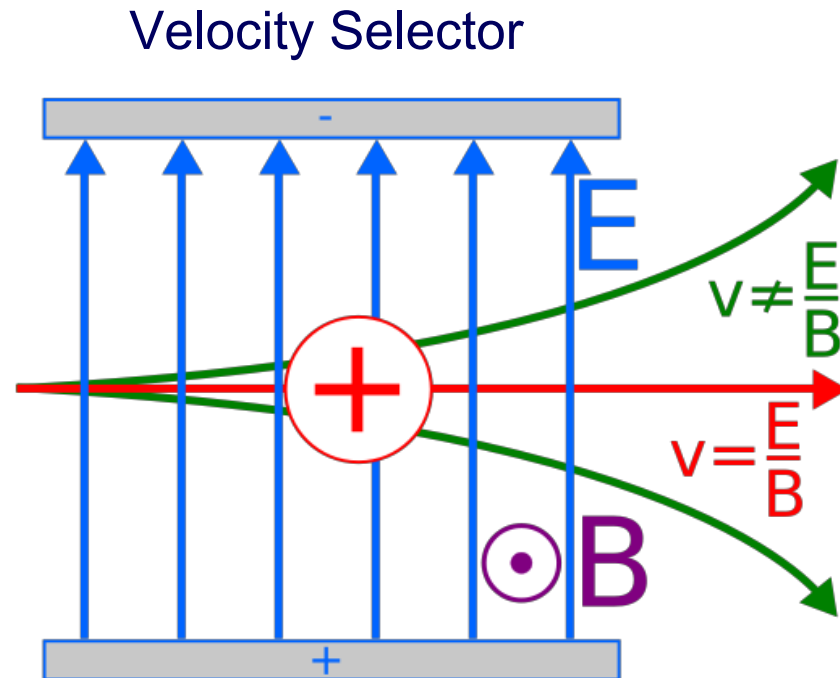
*Mass Spectrometer

This is the first part of a Mass Spectrometer - the Velocity Selector.

The substance to be analyzed is charged and injected into the left side of the Velocity Selector.

An Electric field is directed vertically up, and a Magnetic Field is perpendicular to it and directed out of the page.

There is a slit at the right side which only allows particles that are undeflected by the two fields to pass through.



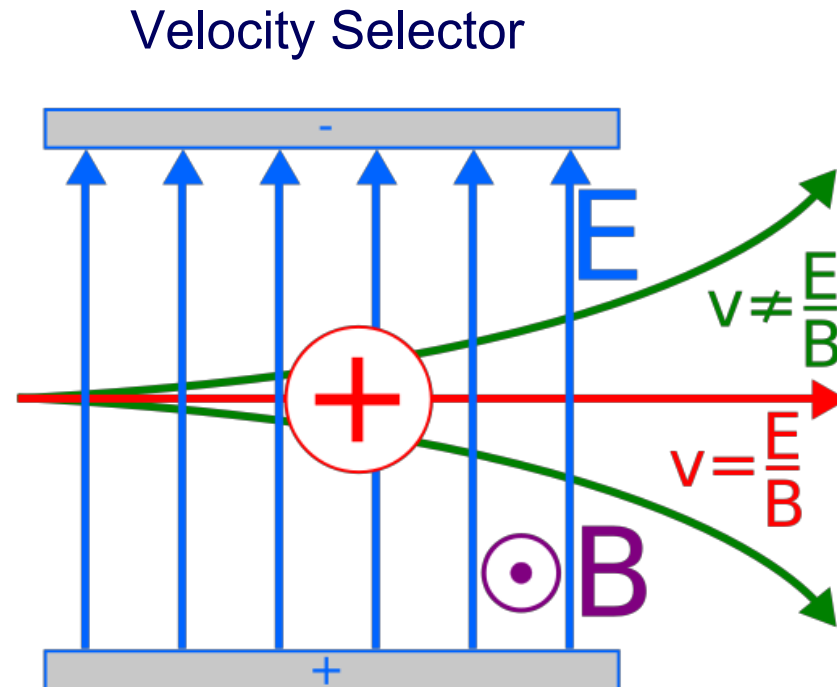
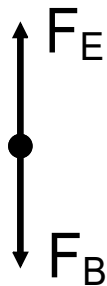
*Mass Spectrometer

Here is the free body diagram and the balanced force equation for a particle to go straight through the selector (Zero acceleration in the up/down direction).

$$F_E - F_B = 0$$

$$qE - qvB = 0$$

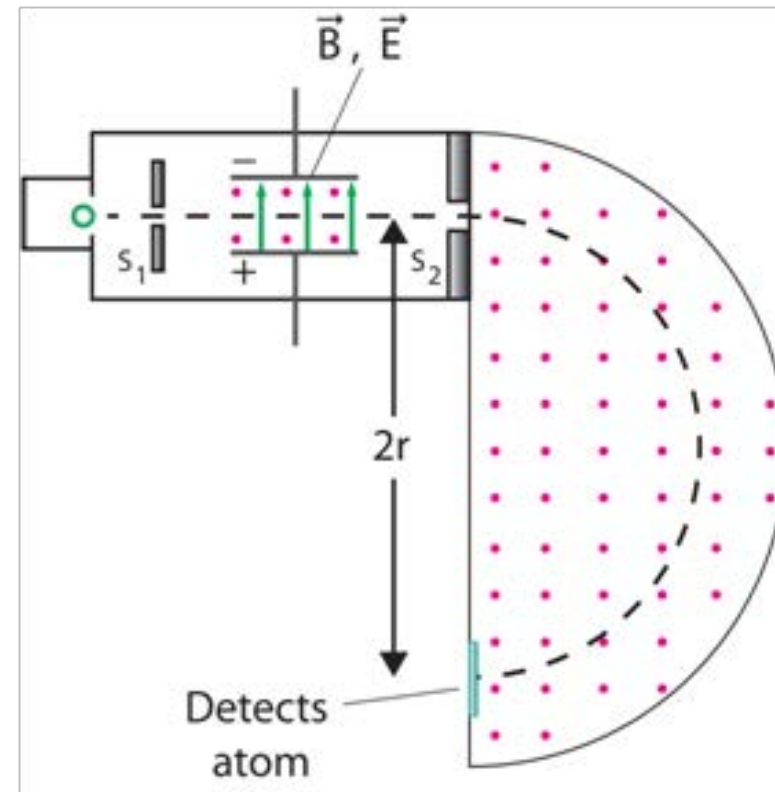
$$v = \frac{E}{B}$$



Only particles with a velocity $v = E/B$ will pass straight through - hence the name "Velocity Selector."

*Mass Spectrometer

The second part of the Mass Spectrometer is a semicircle, with a magnetic field again pointing out of the page, and of the same magnitude as the magnetic field in the velocity selector. Atoms reaching the second magnetic field will have the same speed because of the velocity selector.



*Mass Spectrometer

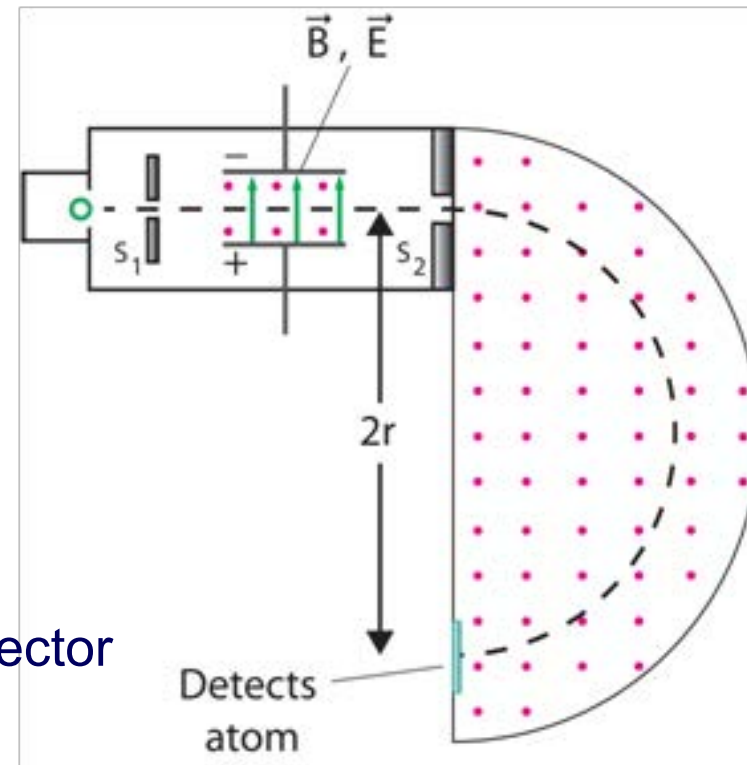
The magnetic field in stage 2 will exert a centripetal force on the charges entering it.

$$F_B = \frac{mv^2}{r} \quad \text{Newton's Second Law}$$

$$qvB = \frac{mv^2}{r} \quad \text{Magnetic Field Force}$$

$$m = \frac{qBr}{v} \quad \text{Solving for } m$$

$$m = \frac{qrB^2}{E} \quad v = E/B \text{ from velocity selector}$$



The various masses will separate out along the diameter of the semicircle and are calculated by the above equation.

Summary

- Magnets have North and South poles.
- Like poles repel, unlike poles attract each other.
- Unit of magnetic field: Tesla=10⁴ Gauss.
- Electric currents produce Magnetic fields
- A magnetic field exerts a force on a moving charge:

$$F = qvB_{\text{perpendicular}}$$

- A magnetic field exerts a force on an electric current:

$$F = ILB_{\text{perpendicular}}$$

- Magnitude of the field of a long, straight current-carrying wire:

$$B = \frac{\mu_0 I}{2\pi r}$$

- Parallel currents attract; antiparallel currents repel



<https://www.njctl.org/video/?v=KzvZzal3SO4>



