

Magnetic field due to a long straight wire

SP212 - General Physics II



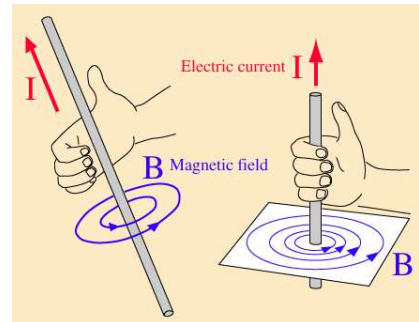
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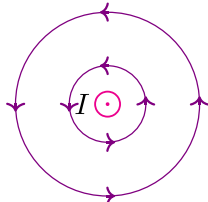
$$B_{\text{wire}} = \frac{\mu_0 I}{2\pi r}$$

Magnetic field due to a long straight wire

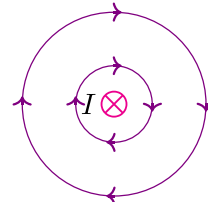
- B_{wire} is the magnetic field strength [units are tesla, T]
- I is the current flowing through the wire [units are amperes, A]
- r is the radial distance from the wire to the point in space where we are finding the magnetic field [units are meters, m]

The direction of the field can be determined by use of the *right hand rule*. Point the thumb of your right hand in the direction of the current. Your fingers will curl in the direction of the magnetic field created by this current.

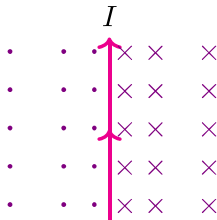




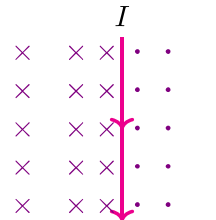
A current out of the page creates counter-clockwise magnetic field lines.



A current into the page creates clockwise magnetic field lines.



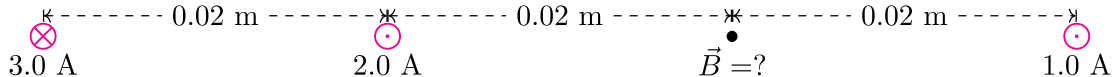
A current going up the page creates a magnetic field that is into the page to its right and out of the page to its left.



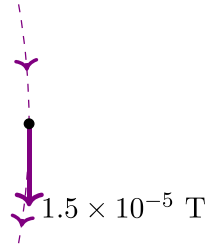
A current going down the page creates a magnetic field that is out of page to its right and in to the page to its left.

Example:

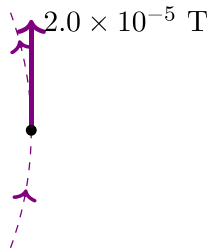
Three very long, straight wires are shown below. What is the net magnetic field at the indicated point due to these three wires?



3.0 A



The wire at the far left carries a 3.0 A current into the page. It is located 0.04 m from the position of interest. The strength of the magnetic field at this position due to this wire is $\frac{\mu_0(3.0 \text{ A})}{2\pi(0.04 \text{ m})} = 1.50 \times 10^{-5} \text{ T}$. A wire carrying a current into the page creates a clockwise magnetic field. The position we are interested in is to the right of this wire (the 3 o'clock position) so a clockwise magnetic field will point down at this position.



The second wire from the left carries a 2.0 A current out of the page. It is located 0.02 m from the position of interest. The strength of the magnetic field at this position due to this wire is $\frac{\mu_0(2.0 \text{ A})}{2\pi(0.02 \text{ m})} = 2.00 \times 10^{-5} \text{ T}$. A wire carrying a current out of the page creates a counter-clockwise magnetic field. The position we are interested in is to the right of this wire (the 3 o'clock position) so a counter-clockwise magnetic field will point up at this position.



The wire at the right carries a 1.0 A current out of the page. It is located 0.02 m from the position of interest. The strength of the magnetic field at this position due to this wire is $\frac{\mu_0(1.0 \text{ A})}{2\pi(0.02 \text{ m})} = 1.00 \times 10^{-5} \text{ T}$. A wire carrying a current out of the page creates a counter-clockwise magnetic field. The position we are interested in is to the left of this wire (the 9 o'clock position) so a counter-clockwise magnetic field will point down at this position.

Finally, we add these three magnetic fields (15 μT pointing down, 20 μT pointing up, and 10 μT pointing down) together as vectors. We find that the net magnetic field at the indicated point is 5.00 μT pointing down.

The net magnetic field at the indicated point is 5.00 μT or 5.00×10^{-6} T pointing down.

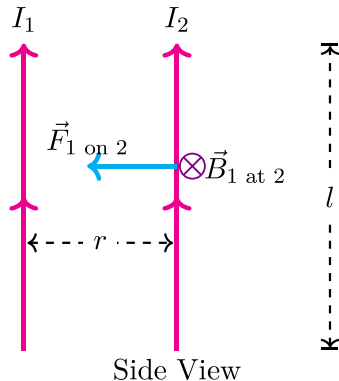
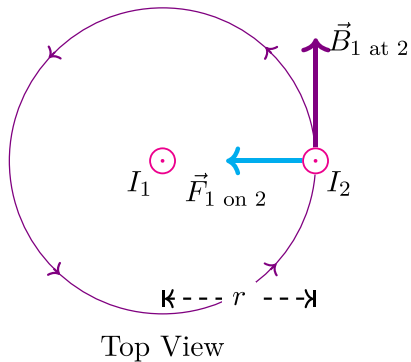
Magnetic force between long straight wires

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Two infinitely long, straight wires that are parallel to each other and separated by distance r .



$$B_1 \text{ at } 2 = \frac{\mu_0 I_1}{2\pi r}$$

$$F_{1 \text{ on } 2} = I_2 l B_1 \text{ at } 2 \sin 90^\circ = \frac{\mu_0 I_1 I_2}{2\pi r} l$$

$$F_{1 \text{ on } 2} = \frac{\mu_0 I_1 I_2 l}{2\pi r}$$

Magnetic force between two long, straight, parallel wires.

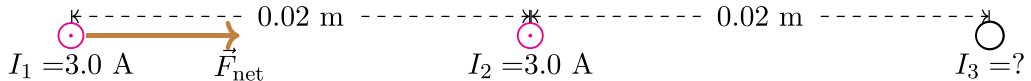
- $F_{1 \text{ on } 2}$ is the size of the magnetic force on a section of wire [units are newtons, N]
- I_1 and I_2 are the currents in the two wires [units are amperes, A]
- r is the distance between the wires [units are meters, m]
- l is the length of the section of wire* [units are meters, m]

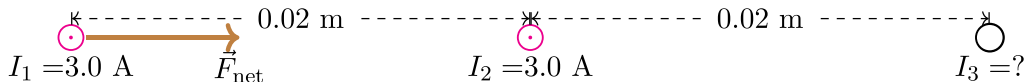
* This equation is exact only when the wires are infinitely long, so we use this only to find the force on a section of wire that is l long. It is fairly accurate for finding the total force on the wire as long as $l \gg r$.

- Wires that carry currents in the same direction will attract each other.
- Wires that carry currents in opposite directions will repel each other.

Example:

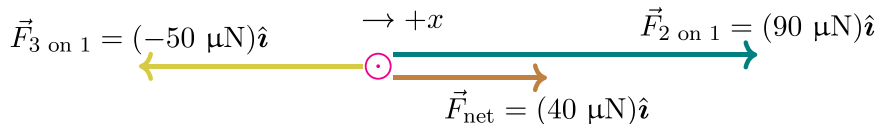
There are three long, straight, parallel wires that are separated by 0.02 m each. The left wire and the middle wire each carry 3.0 A out of the page. The net force on a 1.0 m section of the left-most wire due to the other two wires is 4.00×10^{-5} N to the right. What is the current in the right-most wire?





Solution:

$F_{2 \text{ on } 1} = \frac{\mu_0(3.0 \text{ A})(3.0 \text{ A})}{2\pi(0.02 \text{ m})}(1.0 \text{ m}) = 9.00 \times 10^{-5} \text{ N}$. These two wires carry currents in the same direction, so they attract.



The force between wires 1 and three is repulsive (which means that I_3 must be into the page) and has size $50 \mu\text{N}$.

$$F_{3 \text{ on } 1} = \frac{\mu_0(3.0 \text{ A})I_3}{2\pi(0.04 \text{ m})}(1.0 \text{ m}) = 5.00 \times 10^{-5} \text{ N. This gives } I_3 = 3.33 \text{ A.}$$

The current in the right wire is 3.33 A into the page.