I'm not robot

reCAPTCHA

Continue

Magnetic force of wire

The magnetic field of an infinitely long straight wire can be obtained by applying Ampere's law. The expression for the magnetic field is Show Once the magnetic field has been calculated, the magnetic force expression can be used to calculate the force. The direction is obtained from the right hand rule. Note that two wires carrying current in the same direction attract each other, and they repel if the currents are opposite in direction. The calculation below applies only to long straight wires, but is at least useful for estimating forces in the ordinary circumstances of short wires. Once you have calculated the force on wire 2, of course the force on wire 1 must be exactly the same magnitude and in the opposite direction according to Newton's third law. The earth's magnetic field is about 0.5 gauss. The magnetic force on a current-carrying wire is perpendicular to both the wire and the magnetic field with direction given by the right hand rule. If the current is perpendicular to the magnetic field then the force is given by the simple product: Data may be entered in any of the fields. Whey you have finished entering data, click on the quantity you wish to calculate in the active formula above. The quantities will not be forced to be consistent until you click on a choice. Default values will be entered for unspecified parameters, but all values may be changed. Magnetic interactions with charge Magnetic force applications Experiments show that when a wire carrying a current immersed in a uniform magnetic field, a deflecting force applied to it. But what is the physical origin of this force? Recall that, once a moving charge encounters a magnetic field, a side-way force exert on it. A wire carrying current is made up of a very large number of such moving charges. Let's go and see what happens inside a wire. Current in a wire is due to the movement of the conduction electrons (by convention, their movement is in the opposite direction of current). Suppose these electrons move toward the right with a drift velocity v_d. From the magnetic field, a force $\vec{F}_B$ of magnitude $ev_d B$ exerted on each such conduction electrons. The right-hand rule tells us that the direction of the force must be upward. Thus, we can conclude an upward force is applied to the wire due to an upward force exerted on each conduction electrons inside it. The above consequence is in full agreement with the experiment mentioned earlier. Now, with this physics in mind, we want to derive the equation of force on a wire carrying current in a magnetic field as below. Consider a length L of the wire immersed in a magnetic field directed out of the plane of page and conduction electrons travel to the right. Those electrons with drift velocity v_d takes time $t=\frac{L}{v_d}$ to traverse the length L. Thus, in that time a net charge of $q=it=\frac{iL}{v_d}$ passes through the end of the length. The magnetic force on this moving charge is \begin{align*} F_B&=q v_d B \sin \theta \\ \\ &=\Big(\frac{iL}{v_d}\Big)v_d B \sin 90^\circ\\ \\ &= iLB\end{align*} in above, $\theta = 90^\circ$ substituted, since electrons moves at right angle with the magnetic field. Therefore, the force on a straight wire carrying current i and immersed in a uniform magnetic field B that is perpendicular to the wire is determined as $F_B=i L B$. We can generalize the above formula, to include the case in which the magnetic field is not perpendicular to the wire as \[\vec{F}_B = i\vec{L}\times \vec{B} \] In this cross product, $\vec{L}$ is the length vector with a magnitude of length of that segment of the wire inserted into the magnetic field. The direction of this vector is directed along the direction of the current. The magnitude of the force is also given as $F_B= i LB \sin \theta$, where θ is the angle between $\vec{L}$ and $\vec{B}$. The direction of the $\vec{F}_B$ is perpendicular to the plane of $\vec{L}$ and $\vec{B}$ and is determined using the right-hand rule. Put your right fingers along the current direction such that your palm directed toward the magnetic field direction, your thumb shows the direction of the magnetic force. Example problem (1): A current i passing through a wire and immersed in a uniform magnetic field B so that a maximum force applying on it as shown in the figure below. Find the direction of the magnetic field. Solution: Method (I) using the right-hand rule Put your right fingers in direction of current i such that the thumb points to the magnetic force. In this setup, your palm which is directed to the negative of the z-axis shows the direction of the magnetic field. Method (II) using cross-product algebra The equation of the force on a wire carrying current i is $\vec{F}_B=i \vec{L}\times \vec{B}$. In this example, the length vector $\vec{L}$ is toward the negative of y-axis that is $\vec{L}=L\,(-\hat{j})$ and force is to the x-axis , $\vec{F}_B=F_B\,(\hat{i})$. Substituting these vectors in above formula, we have \begin{align*} \vec{F}_B &= i\vec{L}\times \vec{B} \\ F_B\,(\hat{i}) &= L\,(-\hat{j}) \times \vec{B}\end{align*} Thus, $\vec{B}$ must be directed to $-\hat{k}$ or $\hat{k}$ (since maximum force is obtained when force is perpendicular to both L and B). From the cross product algebra, one can deduce B must be to $-\hat{k}$ to produces a vector along the x-axis. Example (2): A wire is extended horizontally and a constant current passes through it toward the east. The Earth's magnetic field is from south to north. What is the direction of the force applied to it from the earth's magnetic field? Solution: first realize that, in a plane, directions are as follows: east is to the right, west to the left, north into the page, south out of the page, and up and down is trivial (see figure below). Thus, using the right-hand rule, the force on the wire is in the up direction. Example (3): In the figure below, there is a magnetic field of magnitude 500 Gauss that extends horizontally from west to east. A straight wire of length L = 80 cm carrying current i = 25 A in the direction shown and placed at an angle of θ = 37° with horizontal into that magnetic field. What is the magnitude and direction of the magnetic force on this portion of the wire? Solution: put the given data into the equation of force on a current carrying wire $F_B= i L B \sin \theta$ as follows \begin{align*} F_B &= i L B \sin \theta \\ &= 25\times 0.8 \times (500\times 10^{-4}) \times \sin 37^\circ \\ &= 0.6\quad {\rm N}\end{align*} Note that the SI unit of magnetic field is Tesla and recall that ${\rm 1\, T= 10^{-4}\, G}$. Use the right-hand rule to find the direction of the force. Put your right fingers in the direction of the current and through the smaller angle curl them toward the magnetic field. The thumb points to the force direction. Here, the force is into the page as $\otimes$. Example Problem (4): A long and straight wire carrying a current i = 5 A is immersed in the magnetic field $\vec{B}=0.18\,\hat{i}+0.24\,\hat{j} \quad {\rm T}$. Find the maximum magnetic force on each meter of this wire. Solution: The magnitude of the force exerted on a wire by a magnetic field is maximum when the direction of the wire is perpendicular to the field. Thus, the magnitude of the maximum force $F_{max} = i \ell B $ obtained as \begin{align*}F_{max} &= i \ell B \\ &=5\times 1\times 0.3 \\&= 1.5\quad {\rm N}\end{align*} where in above the magnitude of magnetic field vector is determined as below \begin{align*} B&=\sqrt{B_x^2+B_y^2}\\&=\sqrt{(0.18)^2+(0.24)^2}\\&=0.3\quad {\rm T}\end{align*} Example (5): A straight wire of length $\ell=5\pi$ is formed into a semi-circle as shown in the figure below and placed in an external magnetic field of $B = 25\,{\rm G}$. If a current of $i=2\,{\rm A}$ passes through it, find the magnetic force on the wire due to the external magnetic field. Solution: Recall that in the equation of magnetic force on a wire carrying current, $\vec{F}_B=i\vec{L} \times \vec{B}$, $\vec{L}$ was the length vector (or displacement vector) which extends from the initial point to the final point on the wire. Here, the length vector $\vec{L}$ extends from left to right in the direction of x-axis i.e. $\vec{L}=L\,\hat{i}$ where L is equal to the diameter of the semi-circle and its magnitude is calculated as \begin{align*} \text{length of wire} &= \text{circumference of semi-circle} \\ 5\pi &= \pi \, r\\ \Rightarrow r&= 5\,{\rm cm} \end{align*} Thus, the diameter is $L=2r=10\,{\rm cm}$. Now, we can find the magnitude of the force as \begin{align*} F &= i L B \sin \theta \\ &=2\times (5\times 10^{-2})\times (25\times 10^{-4})\times \sin 90^\circ \\ &= 5\times 10^{-3}\quad {\rm N}\end{align*} Example Problem (6): In the figure shown, find the direction of the magnetic force on the segment of the wire inside the magnetic field? Solution: the current flows out of the plane of the page, i.e. $\odot$, and the magnetic field is also directed from the west(left) to the east(right). Therefore, the force is exerted toward the up direction. Example Problem (7): In the figure below, a piece of ABCDE wire is immersed into a uniform magnetic field B. What current must pass through the wire to exert a net force of 2 N from the magnetic field on the wire? Solution: there are two methods to solve such problems. When a straight wire is formed into an arbitrary shape and inserted into a magnetic field, the easiest way to find the force on it is to draw the length vector $\vec{L}$ and then find the force on this vector. Here, the length vector is plotted directly from A to E. This vector has two components, one is DE and the other is AD. The former is perpendicular to B and the latter is parallel so its contribution to magnetic force is zero. Thus, the DE part only contributes to the magnetic force since the angle between it and B is 90°. Putting all these data into the equation $F_B=i\ell B \sin \theta$, we get the force on the whole ABCDE wire as below \begin{align*} F_B &=i\ell B \sin \theta \\ 2 &= i\,(0.1)\times 4\times \sin 90^\circ \\ \Rightarrow i&= 5\quad {\rm A}\end{align*} Example Problem (8): in a part of space there is a uniform magnetic field $\vec{B}=12\,\hat{i}+5\,\hat{j}$. A long and straight wire carrying current $i=3\,{\rm A}$ is placed into that area at the right angle with the field. What is the net magnetic force on each meter of the wire? Solution: first find magnitude of the magnetic field as \begin{align*} B&=\sqrt{B_x^2+B_y^2}\\&=\sqrt{12^2+5^2}\\ &=13 \quad {\rm T}\end{align*} next calculate force on the wire using the equation of maximum magnetic force on a straight wire carrying current i as \begin{align*} F_{max} &=i\ell B\\ &=3\times 13\times 1\\&=39\quad {\rm N}\end{align*} since the wire is perpendicular to the magnetic field so the force on it is maximum. Summary: The magnitude of the force on a wire carrying current i in an arbitrary magnetic field B is F = i L B sin θ, where θ is the smaller angle between the magnetic field and current. The direction of the force is determined by the right-hand rule: put your right fingers along the direction of the current such that your palm points to the magnetic field, your thumb shows the force's direction. The maximum magnetic force occurs when the angle between B and i be θ = 90°. The force on an arbitrary part of a bent wire is the same as the force on a straight wire carrying the same current and extends between the two endpoints of that section. Author: Ali Nemati Date Created: 1/18/2021 Which wire will experience the biggest force? a. 1 b. 2 c. 3 d. all wires experience the same force e. can't be determined without additional information Homework Equations F = BIL sin θ The Attempt at a Solution Can the above formula be applied to a non-straight wire? I only know that the formula is used for straight conductor. My guess: the answer is wire 2 because for wire 1 and 3, there will be vertical and horizontal components of magnetic force and some of the horizontal components will eliminate each other. The sin or cos term of the force will reduce its magnitude hence the biggest force will be experienced by wire 2. Am I correct? Thanks Answers and Replies try to divide each wire into small straight segments and analyze the force on each and add them up? Can the above formula be applied to a non-straight wire? I only know that the formula is used for straight conductor. You can still use it for each small segment of wire. Replace L with dL. As bigerst suggested, analyze the force on each segment and add them up. My guess: the answer is wire 2 because for wire 1 and 3, there will be vertical and horizontal components of magnetic force and some of the horizontal components will eliminate each other. The sin or cos term of the force will reduce its magnitude hence the biggest force will be experienced by wire 2. If you look at all the segments of the wire, it is true that they will have various vertical and horizontal components. But exactly which components add and which cancel? Think it over again. You can still use it for each small segment of wire. Replace L with dL. As bigerst suggested, analyze the force on each segment and add them up. So I cannot just change the "L" with length of the circular wire, which is its circumference? If you look at all the segments of the wire, it is true that they will have various vertical and horizontal components. But exactly which components add and which cancel? Think it over again. For wire 1, all the horizontal components will cancel each other. For wire 3, maybe not all the horizontal components cancel. But how to can we compare the magnitude of force on wire 3 and 2? Thanks So I cannot just change the "L" with length of the circular wire, which is its circumference? indeed, F=BL (sin(θ)) works for straight segments only however if u divide it up into several segments, for each segment F= B sin(θ) ΔL since B is constant, then u can sum this up For wire 1, all the horizontal components will cancel each other. For wire 3, maybe not all the horizontal components cancel. But how to can we compare the magnitude of force on wire 3 and 2? Thanks what makes you think that? do a detailed mathematical analysis of the wires (split it into tiny, essentially straight segments and add the force contributions to each segment) and see what happens. it might be useful to separate each ΔL into vertical and horizontal components, rearrange which ones you add first, and see what happens. So I cannot just change the "L" with length of the circular wire, which is its circumference? No, since the force on each segment acts in a different direction. indeed, F=BL (sin(θ)) works for straight segments only however if u divide it up into several segments, for each segment F= B sin(θ) ΔL since B is constant, then u can sum this up what makes you think that? do a detailed mathematical analysis of the wires (split it into tiny, essentially straight segments and add the force contributions to each segment) and see what happens. it might be useful to separate each ΔL into vertical and horizontal components, rearrange which ones you add first, and see what happens. Sorry I don't know how to do a detailed mathematical analysis. But I am pretty sure that for wire 1, all the horizontal components will cancel each other because the direction of force at each segment will be like "radially outward". For wire 3, I divide it to 4 segments: segment 1 --> from (a) until the letter "i" segment 2 --> the "lower curve" segment 3 --> the straight part until number "3" segment 4 --> from "3" to "b" Assume segment 1 and 4 are symmetry, the horizontal components will cancel out each other, as the case of wire 1 Assuming segment 2 has a smooth and symmetry curve, the horizontal components will also cancel out each other, as the case of wire 1 Assuming segment 3 is straight line, there will be force directed upwards. But I think my analysis is very weak.... since i have yet to figure out how to draw on physics forums i will use texts and hope it doesnt get too confusing. (you may find it helpful to draw on a piece of paper) let us establish a 3d cartesian plane, with x axis points to the right., y axis points up, and the z axis points out of the page. let us suppose the magnetic field B, points along the z axis, out of the page, and the wires solely lie in the xy plane. suppose a wire goes from (0,0,0) to (1,1,0) and carries current I. since this is a straight wire F=BlIsin(θ) applies. find the force on the wire along with its direction, name this F1 (bold denoting it a vector) now consider a wire that goes from O(0,0,0) to A(1,0,0) then to B(1,1,0) which also carries current I. use F=IBLsin θ on the two segments OA and OB separately (since each segment is straight the formula applies) to find the net force F2, yup another vector. you should be able to show F1=F2 in both magnitude and direction. now comes the fruit of the argument, you should be able to reason that any small straight wire could be separate into x and y components with the net force on the segment unchanged. also notice that once you divide the wires into components the order at which the compoenents appear doesnt matter since the field is uniform. apply the above argument to the 3 wires in the problem by dividing each wire into infinitisimal (so essentially straight) segments, and separate each into x,y compoenents, by rearranging you should be able to see clearly which components cancel and which dont. (you dont have to do very sophisticated math, just an argument)