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Over an arbitrary closed path, ∮B→·dl→=μ0I∮B→·dl→=μ0I where I is the total current passing through any open surface S whose perimeter is the path of integration. Also from symmetry, the radial lines, if they exist, must be directed either all inward or all outward from the wire. If the path dependence looks complicated, you can always go back to the Biot-Savart law and use that to find the magnetic field. Also, the drop-off outside the thick wire is similar to how an electric field drops off outside of a linear charge distribution, since the two cases have the same geometry and neither case depends on the configuration of charges or currents once the loop is outside the distribution. Calculating the Magnetic Field of a Thick Wire with Ampère's Law The radius of the long, straight wire of Figure 12.16 is a, and the wire carries a current I0I0 that is distributed uniformly over its cross-section. Positive currents flow with your right-hand thumb if your fingers wrap around in the direction of the loop. The variation of B with r is shown in Figure 12.17. Therefore, we can apply Ampère's law to the circular path as shown. Notice that one path (M) encloses the wire, whereas the other (N) does not. With B→B→ given by Equation 12.9, ∮B→·dl→=∮(μ0I2πr)rdθ=μ0I2π∮dθ.∮B→·dl→=∮(μ0I2πr)rdθ=μ0I2π∮dθ. Figure 12.14 The current I of a long, straight wire is directed out of the page. Thus for path N, ∮NB→·dl→=0.∮NB→·dl→=0. Therefore, the answer is ∮B→·dl→=μ0(2A)=2.51×10−6T·m.∮B→·dl→=μ0(2A)=2.51×10−6T·m.(c) The right-hand rule shows us the current going downward through the loop is in the positive direction. Thus, ∮B→·dl→=0.∮B→·dl→=0. Therefore, the total current is 9 A and ∮B→·dl→=μ0(9A)=1.13×10−5T·m.∮B→·dl→=μ0(9A)=1.13×10−5T·m.Significance If the currents all wrapped around so that the same current went into the loop and out of the loop, the net current would be zero and no magnetic field would be present. To determine whether a specific current I is positive or negative, curl the fingers of your right hand in the direction of the path of integration, as shown in Figure 12.14. Figure 12.17 Variation of the magnetic field produced by a current I 0 I 0 in a long, straight wire of radius a. Solution Over this path B→B→ is constant and parallel to dl→,dl→, so ∮B→·dl→=Bθ∮dl=Bθ(2πr).∮B→·dl→=Bθ∮dl=Bθ(2πr). If I passes through S in the same direction as your extended thumb, I is positive; if I passes through S in the direction opposite to your extended thumb, it is negative. Using Ampère's Law with Arbitrary Paths Use Ampère's law to evaluate ∮B→·dl→∮B→·dl→ for the current configurations and paths in Figure 12.18. The currents flowing toward a device and away from a device in a wire equal zero total current flow through an Ampère loop around these wires. 12.21 Path N, on the other hand, circulates through both positive (counterclockwise) and negative (clockwise) dθdθ (see Figure 12.14), and since it is closed, ∮Ndθ=0.∮Ndθ=0. Using Ampère's law, we obtain B(2πr)=μ0(r2a2)I0,B(2πr)=μ0(r2a2)I0, and the magnetic field inside the wire is B=μ0I02πra2(r≤a).B=μ0I02πra2(r≤a). In order to continue enjoying our site, we ask that you confirm your identity as a human. We now consider that derivation for the special case of an infinite, straight wire. Figure 12.18 Current configurations and paths for Example 12.8. Strategy Ampère's law states that ∮B→·dl→=μ0I∮B→·dl→=μ0I where I is the total current passing through the enclosed loop. A conservative vector field is one whose line integral between two end points is the same regardless of the path chosen. Significance The results show that as the radial distance increases inside the thick wire, the magnetic field increases from zero to a familiar value of the magnetic field of a thin wire. Find the magnetic field both inside and outside the wire. Instead, there is a relationship between the magnetic field and its source, electric current. Check Your Understanding Consider using Ampère's law to calculate the magnetic fields of a finite straight wire and of a circular loop of wire. Therefore, no stray magnetic fields can be present from cords carrying current. The integral ∮ d θ ∮ d θ equals 2 π 2 π and 0, respectively, for paths M and N. The right-hand rule shows us the current going downward through the loop is in the positive direction. (b) A cross-section of the same wire showing the radius a and the Ampère's loop of radius r. The radial component of the magnetic field must be zero because B→r·dl→=0.B→r·dl→=0. If there is no symmetry, use the Biot-Savart law to determine the magnetic field. The possible magnetic field components in this plane, BrBr and Bθ,Bθ, are shown at arbitrary points on a circle of radius r centered on the wire. This result is similar to how Gauss's law for electrical charges behaves inside a uniform charge distribution, except that Gauss's law for electrical charges has a uniform volume distribution of charge, whereas Ampère's law here has a uniform area of current distribution. This means, however, that there must be a net magnetic flux across an arbitrary cylinder concentric with the wire. To begin, let's consider ∮B→·dl→∮B→·dl→ over the closed paths M and N. Using Ampère's Law to Calculate the Magnetic Field Due to a Wire Use Ampère's law to calculate the magnetic field due to a steady current I in an infinitely long, thin, straight wire as shown in Figure 12.15. Strategy This problem has the same geometry as Example 12.6, but the enclosed current changes as we move the integration path from outside the wire to inside the wire, where it doesn't capture the entire current enclosed (see Figure 12.16). Thank you very much for your cooperation. I 0 . Consider first a circular path that is inside the wire (r≤a)(r≤a) such as that shown in part (a) of Figure 12.16. Strategy Consider an arbitrary plane perpendicular to the wire, with the current directed out of the page. Calculate the line integral ∮B→·dl→∮B→·dl→ around the closed loop. Thus Ampère's law reduces to Finally, since BθBθ is the only component of B→,B→, we can drop the subscript and write This agrees with the Biot-Savart calculation above. Figure 12.16 (a) A model of a current-carrying wire of radius a and current I 0 . Equate ∮B→·dl→∮B→·dl→ with μ0Iencμ0Ienc and solve for B→.B→. The radial component is zero because the angle between the magnetic field and the path is at a right angle. Why is it not useful for these calculations? This will tell us the sign of the answer. The quickest way to evaluate the integral is to calculate μ0Iμ0I by finding the net current through the loop. Figure 12.15 The possible components of the magnetic field B due to a current I, which is directed out of the page. There are 7A+5A=12A7A+5A=12A of current going downward and –3 A going upward. Calculate the current inside the loop. Solution For any circular path of radius r that is centered on the wire, ∮B→·dl→=∮Bdl=B∮dl=B(2πr).∮B→·dl→=∮Bdl=B∮dl=B(2πr). 12.22 The extension of this result to the general case is Ampère's law. Significance Ampère's law works well if you have a path to integrate over which B→·dl→B→·dl→ has results that are easy to simplify. Therefore, the current density of a part of the wire is equal to the current density in the whole area. We can consider this ratio because the current density J is constant over the area of the wire. It is expressed in terms of the line integral of B→B→ and is known as Ampère's law. By the end of this section, you will be able to: Explain how Ampère's law relates the magnetic field produced by a current to the value of the current Calculate the magnetic field from a long straight wire, either thin or thick, by Ampère's law A fundamental property of a static magnetic field is that, unlike an electrostatic field, it is not conservative. (b) The only current to consider in this problem is 2A because it is the only current inside the loop. Only currents inside the path of integration need be considered. The magnetic field lines are circles directed counterclockwise and centered on the wire. To calculate the magnetic field created from current in wire(s), use the following steps: Identify the symmetry of the current in the wire(s). Choose a path loop where the magnetic field is either constant or zero. This law can also be derived directly from the Biot-Savart law. For the infinite wire, this works easily with a path that is circular around the wire so that the magnetic field factors out of the integration. From Ampère's law, this equals the total current passing through any surface bounded by the path of integration. It's equal to the current density J times the area enclosed. This is why wires are very close to each other in an electrical cord. Since the current is uniform, the current density inside the path equals the current density in the whole wire, which is I0/πa2.I0/πa2. Since the field is cylindrically symmetric, neither BrBr nor BθBθ varies with the position on this circle. Since the field lines are circular, B→·dl→B→·dl→ is the product of B and the projection of dl onto the circle passing through dl→.dl→. Solution (a) The current going downward through the loop equals the current going out of the loop, so the net current is zero. Therefore the current I passing through the area enclosed by the path is I=πr2πa2I0=r2a2I0.I=πr2πa2I0=r2a2I0. Figure 12.14 shows an arbitrary plane perpendicular to an infinite, straight wire whose current I is directed out of the page. Magnetic fields do not have such a property. Outside the wire, the situation is identical to that of the infinite thin wire of the previous example; that is, B=μ0I02πr(r≥a).B=μ0I02πr(r≥a). Outside the wire, the field drops off regardless of whether it was a thick or thin wire. 12.20 For path M, which circulates around the wire, ∮Mdθ=2π∮Mdθ=2π and ∮MB→·dl→=μ0I.∮MB→·dl→=μ0I. We need the current I passing through the area enclosed by the path. If the radius of this particular circle is r, the projection is rdθ,rdθ, and B→·dl→=Brdθ.B→·dl→=Brdθ. Determine the direction of the magnetic field created by the wire(s) by right-hand rule 2.

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