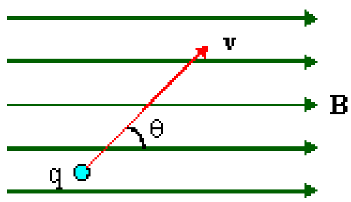
Physics 1100: Magnetism Solutions

1. In the diagrams below, draw or indicate the direction of the magnetic force on the moving charge and calculate its magnitude. State whether the magnetic force is into, or out of the page, or state which angle it makes to the positive x axis.

   The magnitude of the magnetic force is given by $F = |qvB\sin(\theta)|$. Determining the direction of the force involves the following. First the velocity vector, ***v***, and the magnetic field vector, ***B***, define a plane. The magnetic force is perpendicular to this plane, either into or out of it. We use the Right Hand Rule to determine which. We rotate our right hand palm in the most manner which is most comfortable. The thumb of the right hand is now perpendicular to the plane and a positive charge will experience a force in the direction along the thumb. A negative charge will be anti-parallel to the direction of the thumb.

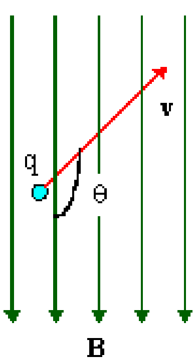
   (a) $q = +5.0\ \mu C$, $v = 15.0 \times 10^3$ m/s, $B = 0.25$ T, $\theta = 65°$

   $F = 1.699 \times 10^{-2}$ N

   The plane formed by ***v*** and ***B*** is the surface of the paper. Turning your palm from ***v*** to ***B***, your thumb points into the paper. The charge is positive, so the force is into the paper.

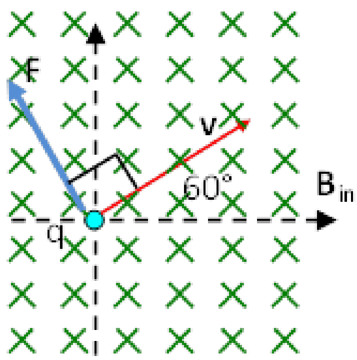
   (b) $q = -3.0\ \mu C$, $v = 6.0 \times 10^3$ m/s, $B = 0.25$ T, $\theta = 122°$

   $F = 3.816 \times 10^{-3}$ N

The plane formed by ***v*** and ***B*** is the surface of the paper. Turning your palm from ***v*** to ***B***, your thumb points into the paper. The charge is negative, so the force is out the paper.

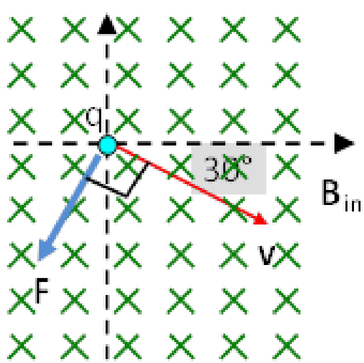
(c) q = +5.0 μC, v = 15.0 × 10^3 m/s, B = 0.25 T



Here θ = 90°, so F = 1.875 × 10^{-2} N

The edge of the plane formed by ***v*** and ***B*** runs along ***v*** and is the perpendicular to surface of the paper. Turning your palm from ***v*** into the paper along ***B***, your thumb points along the paper. The charge is positive, so the force is as shown in the diagram. Note **F** must be perpendicular to both **v** and **B**. **F** is 150° to the positive x axis.

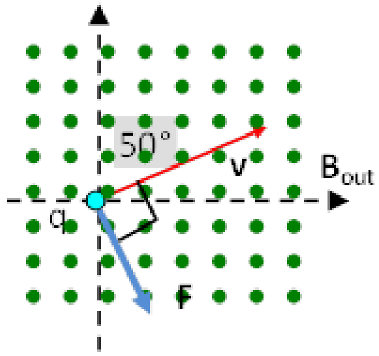
(d) q = −5.0 μC, v = 15.0 × 10^3 m/s, B = 0.25 T



Note θ = 90°, F = 1.875 × 10^{-2} N

The edge of the plane formed by ***v*** and ***B*** runs along ***v*** and is the perpendicular to surface of the paper. Turning your palm from ***v*** into the paper along ***B***, your thumb points along the paper. The charge is negative, so the force is as shown in the diagram. Note **F** must be perpendicular to both **v** and **B**. **F** is 120° below the positive x axis.

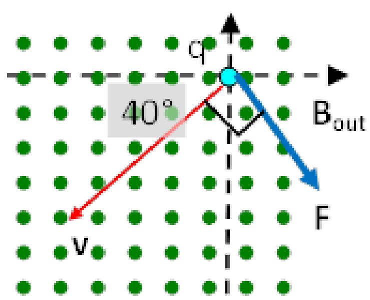
(e) q = +5.0 μC, v = 15.0 × 10^3 m/s, B = 0.25 T



Note θ = 90°, F = 1.875 × 10^{-2} N

The edge of the plane formed by ***v*** and ***B*** runs along ***v*** and is the perpendicular to surface of the paper. Turning your palm from ***v*** out of the paper along ***B***, your thumb points along the paper. The charge is positive, so the force is as shown in the diagram. Note **F** must be perpendicular to both **v** and **B**. **F** is 50° below the positive x axis.

(f) q = −5.0 μC, v = 15.0 x × 10^3 m/s, B = 0.25 T



Note θ = 90°, F = 1.875 × 10^{-2} N

The edge of the plane formed by ***v*** and ***B*** runs along ***v*** and is the perpendicular to surface of the paper. Turning your palm from ***v*** out of the paper along ***B***, your thumb points along the paper. The charge is negative, so the force is as shown in the diagram. Note **F** must be perpendicular to both **v** and **B**. **F** is 50° below the positive x axis.

Top

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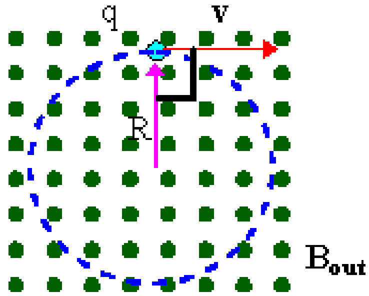
2. A beam of protons moves in a circle of radius 0.25 m. The beam moves perpendicular to a 0.30 T magnetic field. (a) What is the speed of each proton? (b) Determine the magnitude of the centripetal force on each proton. The mass of a proton is m_p = 1.67 × 10^{-27} kg and it has a charge of +e where e = 1.609 × 10^{-19} C.

First we sketch the behaviour or the protons, assuming that the magnetic field points out of the paper.



The magnetic force is $F = qvB\sin(90°) = qvB$. It is directed to the centre of the circle, so it is the centripetal force. Applying Newton's Second Law

$$qvB = mv^2/R \,.$$

Solving for v, we get

$$v = qBr/m = (1.609\times10^{-19}\ \text{C})(0.30\ \text{T})(0.25\ \text{m})/(1.67\times10^{-27}\ \text{kg}) = 7.226 \times 10^{6}\ \text{m/s} \,.$$

Note that the magnitude of the charge of a proton is the same as that of an electron.

Thus

$$F = qvB = (1.609\times10^{-19}\ \text{C})(7.226\times10^{6}\ \text{m/s})(0.30\ \text{T}) = 3.488 \times 10^{-13}\ \text{N} \,.$$

Top

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3. A mass spectrometer uses a potential difference of 2.00 kV to accelerate a singly charged ion (+e) to high speed. It enters a mass spectrometer where a 0.400-T magnetic field then bends the ion into a circular path of radius 0.226 m. What is the mass of the ion? Multiply this mass by Avagadro's Number, 6.022×10^{23}, and you get the atomic mass of a mole of these atoms in kg. Use a periodic table to identify the element.

We have a formula for the ion mass, $m = qB^2r^2/2V$. A singly ionized atom has the same magnitude of charge as the electron it lost. Using the given information,

$$m = (1.609\times10^{-19}\ \text{C})(0.4\ \text{T})^2(0.226\ \text{m})/(2\ 2000\ \text{V}) = 3.269 \times 10^{-25}\ \text{kg} \,.$$

The ion has a mass of 3.27×10^{-25} kg.

The mass of one mole of these ions is

$$M = N_{\text{Avagadro}}\, m = (6.022 \times 10^{23})(3.269 \times 10^{-25}\ \text{kg}) = 0.197\ \text{kg} = 197\ \text{g} \,.$$

Examining a Periodic Table, one finds that Au, gold, has this atomic mass.

Top

4. Suppose that an ion source in a mass spectrometer produces doubly ionized gold ions (Au^{++}), each with a mass of 3.27×10^{-25} kg. The ions are accelerated from rest through a potential difference of 1.00 kV. Then, a 0.500-T magnetic field causes the ions to follow a circular path. Determine the radius of the path.

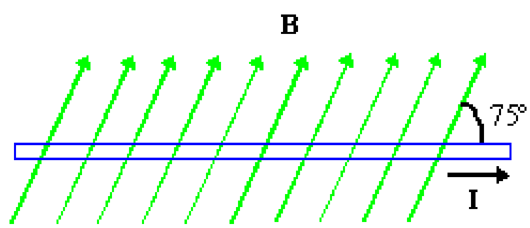
   We have a formula for the ion mass, $m = qB^2r^2/2V$. Rearranging it for r, yields $r = [2mV/qB^2]^{½}$. A doubly-ionized atom has the same magnitude of charge as the electrons it lost, i.e. 2e. Using the given information,

   $$r = [2(3.27\times10^{-25}\text{ kg})(1000\text{ V})/\{(2\ 1.609\times10^{-19}\text{ C})(0.5\text{ T})^2]^{½} = 0.090\text{ m}.$$

   The radius of the path is 9.0 cm.

Top

5. A electric power line carries a current of 1400 A in a location where the earth's magnetic field is 5.0×10^{-5} T. The line makes an angle of 75° with respect to the field. Determine the magnitude of the magnetic force on a 120-m length of line.

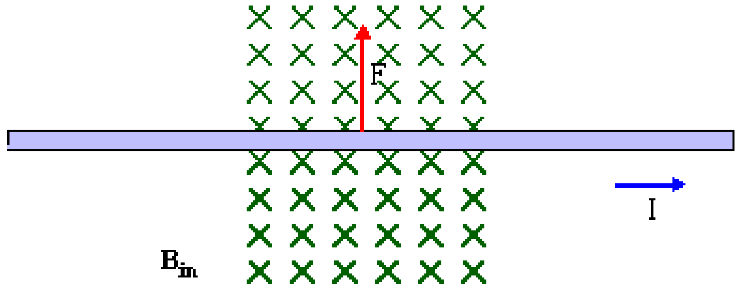
   The magnitude of the magnetic force is given by $F = ILB\,sin(\theta)$. Here,

   $$F = (1400\text{ A})(120\text{ m})(5\times10^{-3}\text{ T})\,sin(75°) = 8.11\text{ N}.$$

   The 120-m line experiences a total magnetic force of 8.11 N. Note that the direction of the force would be out of the paper.

Top

6. In the diagram below, a 6.00 m long wire carrying a current of 120 A is immersed in a uniform magnetic field of magnitude 0.200 T and width 3.50 m. Determine the magnetic force on the wire.



Only the portion of the wire in the magnetic field experience the force. The magnitude of the magnetic force is given by F = ILB$sin(\theta)$. Here,

$$F = (120\ A)(3.50\ m)(0.200\ T)sin(90°) = 84.0\ N\ .$$

The line experiences a total magnetic force of 84.0 N. Note that the direction of the force would be towards the top of the paper.

Top

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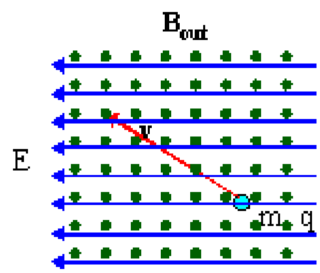
7. A charge of +55 μC and mass 0.013 kg has, at the moment shown below, a speed of 15000 m/s in the direction shown. It is travelling in a region near the surface of the earth where the magnetic field is uniform and has a magnitude of 0.125 T. There is also an electric field E = 2500 N/C. Draw a free body diagram showing all three forces and determine the acceleration of the charge. The velocity of the charge is perpendicular to the magnetic field but makes an angle of 40.0° with the electric field.



The forces acting on the charge are its weight, mg, the Coulomb force, F_C = qE, and the magnetic force, F_m = qvB$sin(\theta)$. Since the charge is positive, the Coulomb force point to the left along the electric field. Using the Right Hand Rule, the magnetic force is in the plane of the paper and perpendicular to the particle's velocity, so θ = 90°. Furthermore, some geometry indicates that the magnetic force makes a 50° angle to the positive x axis.

The magnitude of the Coulomb force is

$$F_C = |qE| = (55\times10^{-6})(2500\ N/C) = 0.1375\ N\ .$$

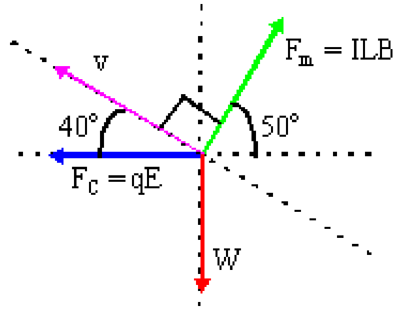
The magnitude of the magnetic force is

$$F_m = qvBsin(90°) = (55\times10^{-6}\ C)(15000\ m/s)(0.125\ T) = 0.103125\ N\ .$$

The weight is

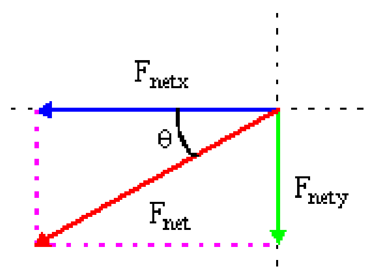
$$W = mg = (0.013\ \text{kg})(9.81\ \text{m/s}^2) = 0.12753\ \text{N}\ .$$

The direction of the acceleration is unknown, so we will need to determine the direction of the net force. According to **F** = m**a**, the two are in the same direction. We sketch a free body diagram and do the vector addition.



i	***j***
$F_{Cx} = -0.1375$	$F_{Cy} = 0$
$W_x = 0$	$W_y = -0.12753\ \text{N}$
$F_{mx} = F_m \cos(50°)$ $= 0.06629$	$F_{my} = F_m \sin(50°)$ $= 0.07900$
$F_{net\ x} = -0.07121$	$F_{net\ y} = -0.04853$

Sketching the components, we have



Using the Pythagorean Equation,

$$F_{net} = [(F_{net\ x})^2+(F_{net\ y})^2]^{½} = [(-0.07121)^2+(-0.04853)^2]^{½} = 0.08618\ \text{N}\ .$$

The angle is given by

$$\theta = \arctan(|F_{net\ y}/F_{net\ x}|) = \arctan(|-0.04853/-0.07121|) = 34.3°\ .$$

The net force is 0.086 N at 214.3°.

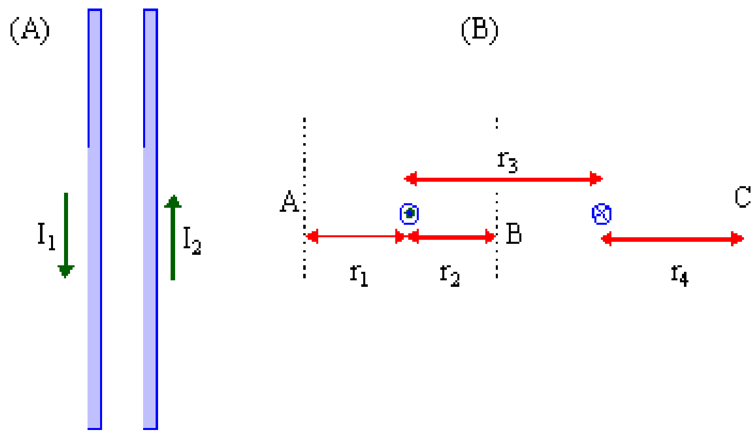
The magnitude of the acceleration is given by

$$a = F/m = 0.08618\ \text{N}\ /0.013\ \text{kg} = 6.63\ \text{m/s}^2\ .$$

Thus the acceleration of the charge is 6.63 m/s^2 at 214.3 °.

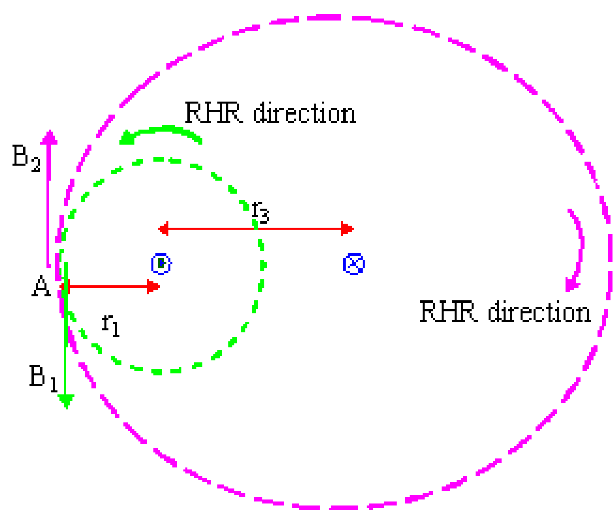
Top

8. In diagram A below, two wires are carrying currents, $I_1 = 30.0$ A and $I_2 = 22.0$ A, in opposite directions. Diagram B gives a head on perspective. Determine the direction and magnitude of the net magnetic field at points A, B, and C where $r_1 = 0.250$ m, $r_2 = 0.350$ m, $r_3 = 0.700$ m, and $r_4 = 0.500$ m.



The magnetic field is tangential to the cross-section of a wire. The direction is clockwise or counterclockwise using a Right Hand Rule. To use the Right Hand Rule, you curl your hand around the wire with your thumb pointing in the direction of the current. The magnetic field "circulates" in the same direction that your hand is curling.

Point A:



The magnitude of the magnetic field due to a wire is given by $B = \mu_0 I/2\pi R$. Thus

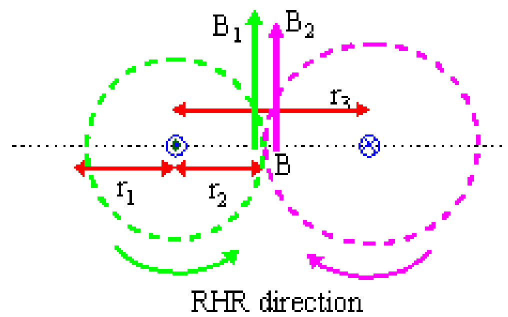
$B_1 = \mu_0 I_1/2\pi R_1 = (4\pi \times 10^{-7}\ \text{T-m/A})(30\ \text{A})/\{2\pi(0.25\ \text{m})\} = 2.40 \times 10^{-5}$ T,

$B_2 = \mu_0 I_2/2\pi\{r_1+r_3\} = (4\pi \times 10^{-7}\ \text{T-m/A})(22\ \text{A})/\{2\pi(0.25\ \text{m} + 0.70\ \text{m})\} = 4.632\ 10^{-6}$ T,

The net magnetic field is thus

$B_{net} = B_2 - B_1 = -1.937 \times 10^{-5}$ T . The minus sign indicates that it is directed down.

Point B:



The magnitude of the magnetic field due to a wire is given by $B = \mu_0 I/2\pi R$. Thus

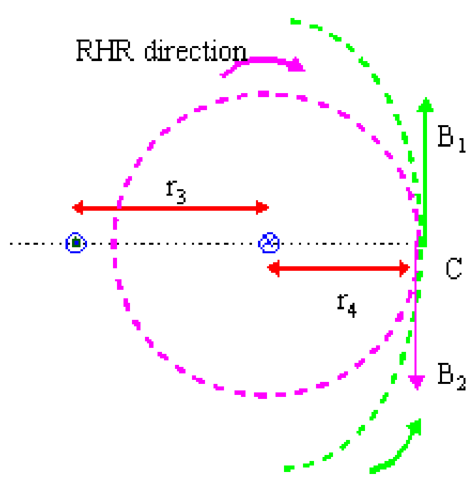
$B_1 = \mu_0 I_1/2\pi R_2 = (4\pi \times 10^{-7}$ T-m/A)(30 A)/{2π(0.35 m)} $= 1.714 \times 10^{-5}$ T,

$B_2 = \mu_0 I_2/2\pi\{r_3 - r_2\}$ = $(4\pi \times 10^{-7}$ T-m/A)(22 A)/{2π(0.70 m - 0.35 m)} = $1.257\ 10^{-5}$ T,

The net magnetic field is thus

$B_{net} = B_1 + B_2 = +2.971 \times 10^{-5}$ T . The plus sign indicates that it is directed up.

Point C:



The magnitude of the magnetic field due to a wire is given by $B = \mu_0 I/2\pi R$. Thus

$B_1 = \mu_0 I_1/2\pi\{r_3 + r_4\}$ = $(4\pi \times 10^{-7}$ T-m/A)(30 A)/{2π(0.70 m + 0.50 m)} = $5.000\ 10^{-6}$ T,

$B_2 = \mu_0 I_2/2\pi R_4 = (4\pi \times 10^{-7}$ T-m/A)(22 A)/{2π(0.50 m)} $= 8.800 \times 10^{-6}$ T,

The net magnetic field is thus

$B_{net} = B_1 - B_2 = -3.80 \times 10^{-6}$ T . The minus sign indicates that it is directed down.

Top

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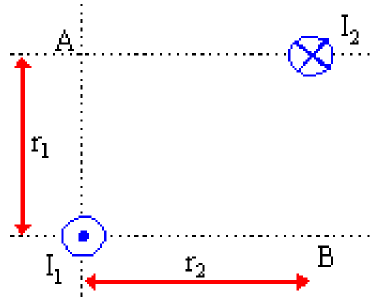
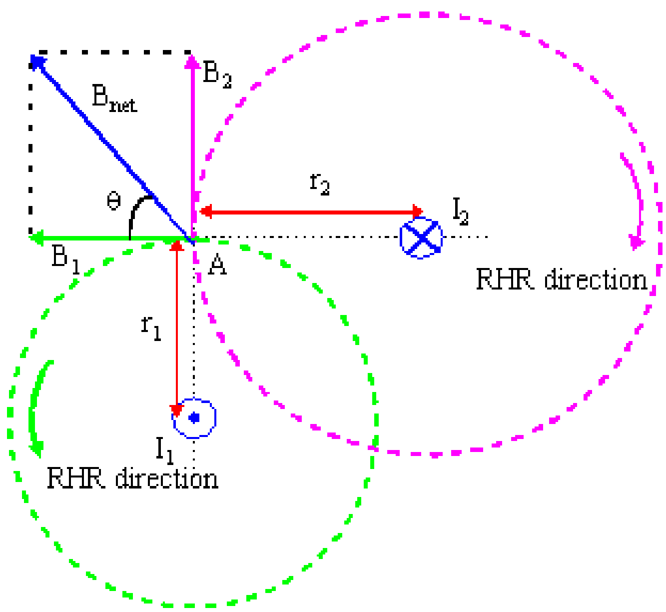
9. Determine the direction and magnitude of the net magnetic field at point A and B due to the two wires shown below. Wire 1 carries a current I_1 = 650 mA and I_2 = 475 mA. Point A is a distance r_1 = 1.20 m from wire 1 and point B is r_2 = 2.20 m away.



The magnetic field is tangential to the cross-section of a wire. The direction is clockwise or counterclockwise using a Right Hand Rule. To use the Right Hand Rule, you curl your hand around the wire with your thumb pointing in the direction of the current. The magnetic field "circulates" in the same direction that your hand is curling.

Point A:



The magnitude of the magnetic field due to a wire is given by $B = \mu_0 I/2\pi R$. Thus

$B_1 = \mu_0 I_1/2\pi R_1 = (4\pi \times 10^{-7}$ T-m/A)(0.65 A)/{2π(1.20 m)} $= 1.0833 \times 10^{-7}$ T ,

$B_2 = \mu_0 I_2/2\pi R_2 = (4\pi \times 10^{-7}$ T-m/A)(0.475 A)/{2π(2.20 m)} $= 4.3182 \times 10^{-8}$ T .

Thus $\mathbf{B}_{net} = -\boldsymbol{i}\, B_1 + \boldsymbol{j}\, B_2 = -\boldsymbol{i}[1.0833 \times 10^{-7}] + \boldsymbol{j}[4.3182 \times 10^{-8}]$.

Using the Pythagorean Equation,

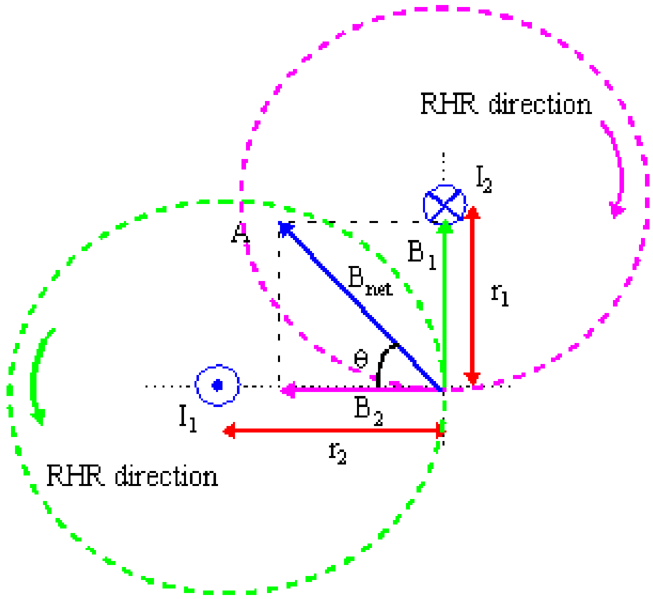
$$B_{net} = [(B_1)^2+(B_2)^2]^{½} = [(1.0833×10^{-7})^2+(4.3182×10^{-8})^2]^{½} = 1.1662 × 10^{-7}\ T .$$

The angle is given by

$$\theta = arctan(|B_2/B_1|) = arctan(|0.43182/1.0833|) = 21.7° .$$

The net magnetic field at point A is $1.17 × 10^{-7}$ T at 158.3° above the line formed by r_2.

Point B:



The magnitude of the magnetic field due to a wire is given by $B = \mu_0 I/2\pi R$. Thus

$$B_1 = \mu_0 I_1/2\pi R_2 = (4\pi × 10^{-7}\ T\text{-}m/A)(0.65\ A)/\{2\pi(2.20\ m)\} = 5.9091 × 10^{-8}\ T ,$$

$$B_2 = \mu_0 I_2/2\pi R_1 = (4\pi × 10^{-7}\ T\text{-}m/A)(0.475\ A)/\{2\pi(1.20\ m)\} = 7.9166 × 10^{-8}\ T .$$

Thus $\mathbf{B}_{net} = \mathbf{-i}\ B_2 + \mathbf{j}\ B_1 = \mathbf{-i}[7.9166 × 10^{-8}] + \mathbf{j}[5.9091 × 10^{-8}]$.

Using the Pythagorean Equation,

$$B_{net} = [(B_1)^2+(B_2)^2]^{½} = [(5.9091×10^{-8})^2+(7.9166×10^{-8})^2]^{½} = 9.879 × 10^{-8}\ T .$$

The angle is given by

$$\theta = arctan(|B_2/B_1|) = arctan(|5.9091/7.9166|) = 36.7° .$$

The net magnetic field at point A is $9.88 × 10^{-8}$ T at 143.3° above the line formed by r_2.

Top

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