Chapter 22: magnetism

# 22.4 magnetic field strength: force on a moving charge in a magnetic field

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| 1. | *What is the direction of the magnetic force on a positive charge that moves as shown in each of the six cases shown in Figure 22.50?* |
| Solution | (a) left (West)  (b) into the page  (c) up (North)  (d) no force  (e) right (East)  (f) down (South) |
| 2. | *Repeat Exercise 22.1 for a negative charge.* |
| Solution | (a) right (East)  (b) out of the page  (c) down (South)  (d) no force  (e) left (West)  (f) up (North) |
| 3. | *What is the direction of the velocity of a negative charge that experiences the magnetic force shown in each of the three cases in Figure 22.51, assuming it moves perpendicular to* |
| Solution | (a) right (East)  (b) into the page  (c) down (South) |
| 4. | *Repeat Exercise 22.3 for a positive charge.* |
| Solution | (a) left (West)  (b) out of the page  (c) up (North) |
| 5. | *What is the direction of the magnetic field that produces the magnetic force on a positive charge as shown in each of the three cases in the figure below, assuming  is perpendicular to ?* |
| Solution | (a) into the page  (b) left (West)  (c) out of the page |
| 6. | *Repeat Exercise 22.5 for a negative charge.* |
| Solution | (a) out of the page  (b) right (East)  (c) into the page |
| 7. | *What is the maximum force on an aluminum rod with a  charge that you pass between the poles of a 1.50-T permanent magnet at a speed of 5.00 m/s? In what direction is the force?* |
| Solution | Examining the equation , we see that the maximum force occurs when, so that:  The direction of the force is perpendicular to both the velocity and the magnetic field. |
| 8. | *(a) Aircraft sometimes acquire small static charges. Suppose a supersonic jet has a  charge and flies due west at a speed of 660 m/s over the Earth’s south magnetic pole, where the  magnetic field points straight up. What are the direction and the magnitude of the magnetic force on the plane? (b) Discuss whether the value obtained in part (a) implies this is a significant or negligible effect.* |
| Solution | (a)  The direction is south.  (b) The force is very small, so this implies that the effect of static charges on airplanes is negligible. |
| 9. | *(a) A cosmic ray proton moving toward the Earth at  experiences a magnetic force of . What is the strength of the magnetic field if there is a*  *angle between it and the proton’s velocity? (b) Is the value obtained in part (a) consistent with the known strength of the Earth’s magnetic field on its surface? Discuss.* |
| Solution | (a)  (b) This value for the magnetic field is on the same order of magnitude as the known strength of the Earth’s magnetic field. Since the actual magnetic field strength of the Earth varies based on where you are around the Earth, the value in part (a) seems consistent with the known value. |
| 10. | *An electron moving at  in a 1.25-T magnetic field experiences a magnetic force of . What angle does the velocity of the electron make with the magnetic field? There are two answers.* |
| Solution |  |
| 11. | *(a) A physicist performing a sensitive measurement wants to limit the magnetic force on a moving charge in her equipment to less than . What is the greatest the charge can be if it moves at a maximum speed of 30.0 m/s in the Earth’s field? (b) Discuss whether it would be difficult to limit the charge to less than the value found in (a) by comparing it with typical static electricity and noting that static is often absent.* |
| Solution | (a)  as the maximum field (the earth’s field).  (b) Common static electricity involves charges ranging from nanocoulombs to microcoulombs. Therefore, it would seem to be difficult to limit the charge to less than the value found in part (a) because that charge is smaller than typical static electricity. |

# 22.5 force on a moving charge in a magnetic field: examples and applications

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| 12. | *A cosmic ray electron moves at  perpendicular to the Earth’s magnetic field at an altitude where field strength is . What is the radius of the circular path the electron follows?* |
| Solution |  |
| 13. | *A proton moves at  perpendicular to a magnetic field. The field causes the proton to travel in a circular path of radius 0.800 m. What is the field strength?* |
| Solution | , so that |
| 14. | *(a) Viewers of* Star Trek *hear of an antimatter drive on the Starship* Enterprise*. One possibility for such a futuristic energy source is to store antimatter charged particles in a vacuum chamber, circulating in a magnetic field, and then extract them as needed. Antimatter annihilates with normal matter, producing pure energy. What strength magnetic field is needed to hold antiprotons, moving at  in a circular path 2.00 m in radius? Antiprotons have the same mass as protons but the opposite (negative) charge. (b) Is this field strength obtainable with today’s technology or is it a futuristic possibility?* |
| Solution | (a)  (b) This strength is definitely obtainable with today’s technology. Magnetic field strengths of 0.500 T are obtainable with permanent magnets. |
| 15. | *(a) An oxygen-16 ion with a mass of  travels at  perpendicular to a 1.20-T magnetic field, which makes it move in a circular arc with a 0.231-m radius. What positive charge is on the ion? (b) What is the ratio of this charge to the charge of an electron? (c) Discuss why the ratio found in (b) should be an integer.* |
| Solution | (a)  (b)  (c) This ratio must be an integer because charges must be integer numbers of the basic charge of an electron. There are no charges with values less than this basic charge, and all charges are integer multiples of this basic charge. |
| 16. | *What radius circular path does an electron travel if it moves at the same speed and in the same magnetic field as the proton in Exercise 22.13?* |
| Solution |  |
| 17. | *A velocity selector in a mass spectrometer uses a 0.100-T magnetic field. (a) What electric field strength is needed to select a speed of ? (b) What is the voltage between the plates if they are separated by 1.00 cm?* |
| Solution | (a)  (b) |
| 18. | *An electron in a TV CRT moves with a speed of , in a direction perpendicular to the Earth’s field, which has a strength of . (a) What strength electric field must be applied perpendicular to the Earth’s field to make the electron moves in a straight line? (b) If this is done between plates separated by 1.00 cm, what is the voltage applied? (Note that TVs are usually surrounded by a ferromagnetic material to shield against external magnetic fields and avoid the need for such a correction.)* |
| Solution | (a)  (b) |
| 19. | *(a) At what speed will a proton move in a circular path of the same radius as the electron in Exercise 22.12? (b) What would the radius of the path be if the proton had the same speed as the electron? (c) What would the radius be if the proton had the same kinetic energy as the electron? (d) The same momentum?* |
| Solution | (a)  (b)  (c)  Then,  (d) First, , so that    Then, |
| 20. | *A mass spectrometer is being used to separate common oxygen-16 from the much rarer oxygen-18, taken from a sample of old glacial ice. (The relative abundance of these oxygen isotopes is related to climatic temperature at the time the ice was deposited.) The ratio of the masses of these two ions is 16 to 18, the mass of oxygen-16 is , and they are singly charged and travel at  in a 1.20-T magnetic field. What is the separation between their paths when they hit a target after traversing a semicircle?* |
| Solution |  |
| 21. | *(a) Triply charged uranium-235 and uranium-238 ions are being separated in a mass spectrometer. (The much rarer uranium-235 is used as reactor fuel.) The masses of the ions are  and , respectively, and they travel at  in a 0.250-T field. What is the separation between their paths when they hit a target after traversing a semicircle? (b) Discuss whether this distance between their paths seems to be big enough to be practical in the separation of uranium-235 from uranium-238.* |
| Solution | (a)    (b) Yes, this distance between their paths is clearly big enough to separate the U-235 from the U-238, since it is a distance of 2.5 cm. |

# 22.6 the hall effect

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| 22. | *A large water main is 2.50 m in diameter and the average water velocity is 6.00 m/s. Find the Hall voltage produced if the pipe runs perpendicular to the Earth’s  field.* |
| Solution |  |
| 23. | *What Hall voltage is produced by a 0.200-T field applied across a 2.60-cm-diameter aorta when blood velocity is 60.0 cm/s?* |
| Solution |  |
| 24. | *(a) What is the speed of a supersonic aircraft with a 17.0-m wingspan, if it experiences a 1.60-V Hall voltage between its wing tips when in level flight over the north magnetic pole, where the Earth’s field strength is  (b) Explain why very little current flows as a result of this Hall voltage.* |
| Solution | (a)  (b) Once established, the Hall voltage would push charges one direction and the magnetic force acts in the opposite direction resulting in no net force on the charges. Therefore, there will be no current. |
| 25. | *A nonmechanical water meter could utilize the Hall effect by applying a magnetic field across a metal pipe and measuring the Hall voltage produced. What is the average fluid velocity in a 3.00-cm-diameter pipe, if a 0.500-T field across it creates a 60.0-mV Hall voltage?* |
| Solution | Since |
| 26. | *Calculate the Hall voltage induced on a patient’s heart while being scanned by an MRI unit. Approximate the conducting path on the heart wall by a wire 7.50 cm long that moves at 10.0 cm/s perpendicular to a 1.50-T magnetic field.* |
| Solution |  |
| 27. | *A Hall probe calibrated to read  when placed in a 2.00-T field is placed in a 0.150-T field. What is its output voltage?* |
| Solution |  |
| 28. | *What would the Hall voltage be if a 2.00-T field is applied across a 10-gauge copper wire (2.588 mm in diameter) carrying a 20.0-A current?* |
| Solution |  |
| 29. | *Show that the Hall voltage across wires made of the same material, carrying identical currents, and subjected to the same magnetic field is inversely proportional to their diameters. (Hint: Consider how drift velocity depends on wire diameter.)* |
| Solution | Since , where the width is twice the radius, , ,  , so  The Hall voltage is inversely proportional to the diameter of the wire. |
| 30. | *A patient with a pacemaker is mistakenly being scanned for an MRI image. A 10.0-cm-long section of pacemaker wire moves at a speed of 10.0 cm/s perpendicular to the MRI unit’s magnetic field and a 20.0-mV Hall voltage is induced. What is the magnetic field strength?* |
| Solution |  |

# 22.7 magnetic force on a current-carrying conductor

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| 31. | *What is the direction of the magnetic force on the current in each of the six cases in Figure 22.53?* |
| Solution | (a) left (West)  (b) into the page  (c) up (North)  (d) no force  (e) right (East)  (f) down (South) |
| 32. | *What is the direction of a current that experiences the magnetic force shown in each of the three cases in Figure 22.54, assuming the current runs perpendicular to ?* |
| Solution | (a) left (West)  (b) out of the page  (c) up (North) |
| 33. | *What is the direction of the magnetic field that produces the magnetic force shown on the currents in each of the three cases in Figure 22.55, assuming  is perpendicular to ?* |
| Solution | (a) into the page  (b) left (West)  (c) out of the page |
| 34. | *(a) What is the force per meter on a lightning bolt at the equator that carries 20,000 A perpendicular to the Earth’s  field? (b) What is the direction of the force if the current is straight up and the Earth’s field direction is due north, parallel to the ground?* |
| Solution | (a)  (b) West |
| 35. | *(a) A DC power line for a light-rail system carries 1000 A at an angle of  to the Earth’s  field. What is the force on a 100-m section of this line? (b) Discuss practical concerns this presents, if any.* |
| Solution | (a)  (b) This means that the right-rail power lines must be attached in order not to be moved by the force caused by the earth’s magnetic field. |
| 36. | *What force is exerted on the water in an MHD drive utilizing a 25.0-cm-diameter tube, if 100-A current is passed across the tube that is perpendicular to a 2.00-T magnetic field? (The relatively small size of this force indicates the need for very large currents and magnetic fields to make practical MHD drives.)* |
| Solution | Using , where  is the diameter of the tube, we can find the force on the water: |
| 37. | *A wire carrying a 30.0-A current passes between the poles of a strong magnet that is perpendicular to its field and experiences a 2.16-N force on the 4.00 cm of wire in the field. What is the average field strength?* |
| Solution |  |
| 38. | *(a) A 0.750-m-long section of cable carrying current to a car starter motor makes an angle of  with the Earth’s  field. What is the current when the wire experiences a force of ? (b) If you run the wire between the poles of a strong horseshoe magnet, subjecting 5.00 cm of it to a 1.75-T field, what force is exerted on this segment of wire?* |
| Solution | (a)  (b) |
| 39. | *(a) What is the angle between a wire carrying an 8.00-A current and the 1.20-T field it is in if 50.0 cm of the wire experiences a magnetic force of 2.40 N? (b) What is the force on the wire if it is rotated to make an angle of  with the field?* |
| Solution | (a)  (b) |
| 40. | *The force on the rectangular loop of wire in the magnetic field in Figure 22.56 can be used to measure field strength. The field is uniform, and the plane of the loop is perpendicular to the field. (a) What is the direction of the magnetic force on the loop? Justify the claim that the forces on the sides of the loop are equal and opposite, independent of how much of the loop is in the field and do not affect the net force on the loop. (b) If a current of 5.00 A is used, what is the force per tesla on the 20.0-cm-wide loop?* |
| Solution | (a) The net force is in the southern direction (down the page). The forces on the sides are equal in magnitude because , , , and  are the same for each. But they are in opposite directions, by the right hand rule, since the currents are in opposite directions.  (b) |

# 22.8 torque on a current loop: motors and meters

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| 41. | *(a) By how many percent is the torque of a motor decreased if its permanent magnets lose 5.0% of their strength? (b) How many percent would the current need to be increased to return the torque to original values?* |
| Solution | (a)  So  decreases by 5.00% if *B* decreases by 5.00%.  (b) |
| 42. | *(a) What is the maximum torque on a 150-turn square loop of wire 18.0 cm on a side that carries a 50.0-A current in a 1.60-T field? (b) What is the torque when  is* |
| Solution | (a) The maximum torque occurs when , so the maximum torque is:    (b) Now set , so: |
| 43. | *Find the current through a loop needed to create a maximum torque of  The loop has 50 square turns that are 15.0 cm on a side and is in a uniform 0.800-T magnetic field.* |
| Solution |  |
| 44. | *Calculate the magnetic field strength needed on a 200-turn square loop 20.0 cm on a side to create a maximum torque of if the loop is carrying 25.0 A.* |
| Solution |  |
| 45. | *Since the equation for torque on a current-carrying loop is , the units of  must equal units of . Verify this.* |
| Solution |  |
| 46. | *(a) At what angle  is the torque on a current loop 90.0% of maximum? (b) 50.0% of maximum? (c) 10.0% of maximum?* |
| Solution | (a)  (b)  (c) |
| 47. | *A proton has a magnetic field due to its spin on its axis. The field is similar to that created by a circular current loop  in radius with a current of  (no kidding). Find the maximum torque on a proton in a 2.50-T field. (This is a significant torque on a small particle.)* |
| Solution |  |
| 48. | *(a) A 200-turn circular loop of radius 50.0 cm is vertical, with its axis on an east-west line. A current of 100 A circulates clockwise in the loop when viewed from the east. The Earth’s field here is due north, parallel to the ground, with a strength of . What are the direction and magnitude of the torque on the loop? (b) Does this device have any practical applications as a motor?* |
| Solution | (a) The torque,  is clockwise as seen from directly above the loop. Using , we find the maximum torque to be:  (b) If the loop was connected to a wire, this is an example of a simple motor (see Figure 22.30). When current is passed through the loops, the magnetic field exerts a torque on the loops, which rotates a shaft. Electrical energy is converted to mechanical work in the process. |
| 49. | *Repeat Exercise 22.48 but with the loop lying flat on the ground with its current circulating counterclockwise (when viewed from above) in a location where the Earth’s field is north, but at an angle  below the horizontal and with a strength of .* |
| Solution | points to the west (the loops will rotate about an east/west axis clockwise as viewed from the east) |

# 22.10 magnetic force betwEen two parallel conductors

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| 50. | *(a) The hot and neutral wires supplying DC power to a light-rail commuter train carry 800 A and are separated by 75.0 cm. What is the magnitude and direction of the force between 50.0 m of these wires? (b) Discuss the practical consequences of this force, if any.* |
| Solution | (a)  The force is repulsive because the currents are in opposite directions.  (b) This force is repulsive and therefore there is never a risk that the two wires will touch and short circuit. |
| 51. | *The force per meter between the two wires of a jumper cable being used to start a stalled car is 0.225 N/m. (a) What is the current in the wires, given they are separated by 2.00 cm? (b) Is the force attractive or repulsive?* |
| Solution | (a)  (b) The force is repulsive because the currents are in opposite directions. |
| 52. | *A 2.50-m segment of wire supplying current to the motor of a submerged submarine carries 1000 A and feels a 4.00-N repulsive force from a parallel wire 5.00 cm away. What is the direction and magnitude of the current in the other wire?* |
| Solution | in the opposite direction. |
| 53. | *The wire carrying 400 A to the motor of a commuter train feels an attractive force of  due to a parallel wire carrying 5.00 A to a headlight. (a) How far apart are the wires? (b) Are the currents in the same direction?* |
| Solution | (a)  (b) Yes, the currents are in the same direction. |
| 54. | *An AC appliance cord has its hot and neutral wires separated by 3.00 mm and carries a 5.00-A current. (a) What is the average force per meter between the wires in the cord? (b) What is the maximum force per meter between the wires? (c) Are the forces attractive or repulsive? (d) Do appliance cords need any special design features to compensate for these forces?* |
| Solution | (a)  (b)  (c) The force is repulsive because the currents are in opposite directions.  (d) These forces are rather small, so the casing around the wires is all that is needed to keep the wires from pushing apart. |
| 55. | *Figure 22.57 shows a long straight wire near a rectangular current loop. What is the direction and magnitude of the total force on the loop?* |
| Solution | and  are equal and opposite and hence cancel.    The force is repulsive. |
| 56. | *Find the direction and magnitude of the force that each wire experiences in Figure 28.58(a), using vector addition.* |
| Solution | Opposites repel, likes attract, so we need to consider each wire’s relationship with the other two wires. Let *f* denote force per unit length, then by    Look at each wire separately:  Wire A  Wire B  Wire C  For wire A:Macintosh HD:Users:alinamarieslavik:Desktop:Screen Shot 2014-06-27 at 10.36.36.png      For Wire B:      For Wire C: |
| 57. | *Find the direction and magnitude of the force that each wire experiences in Figure 22.58(b), using vector addition.* |
| Solution | Wire A  Wire C        *Note:*    By symmetry, the forces on wires B and D are the same as on A and C, respectively, except the sign of the *x* component is opposite. |

# 22.11 more applications of magnetism

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| 58. | *Indicate whether the magnetic field created in each of the three situations shown in Figure 22.59 is into or out of the page on the left and right of the current.* |
| Solution | (a) Right: into the page, Left: out of the page  (b) Right: out of the page, Left: into the page  (c) Right: out of the page, Left: into the page |
| 59. | *What are the directions of the fields in the center of the loop and coils shown in Figure 22.60?* |
| Solution | (a) Out of the page  (b) To the right  (c) To the left |
| 60. | *What are the directions of the currents in the loop and coils shown in Figure 22.61?* |
| Solution | (a) Clockwise  (b) Clockwise as seen from the left  (c) Clockwise as seen from the right |
| 61. | *To see why an MRI utilizes iron to increase the magnetic field created by a coil, calculate the current needed in a 400-loop-per-meter circular coil 0.660 m in radius to create a 1.20-T field (typical of an MRI instrument) at its center with no iron present. The magnetic field of a proton is approximately like that of a circular current loop  in radius carrying . What is the field at the center of such a loop?* |
| Solution | Inside the MRI solenoid,  For the proton “loop”: |
| 62. | *Inside a motor, 30.0 A passes through a 250-turn circular loop that is 10.0 cm in radius. What is the magnetic field strength created at its center?* |
| Solution |  |
| 63. | *Nonnuclear submarines use batteries for power when submerged. (a) Find the magnetic field 50.0 cm from a straight wire carrying 1200 A from the batteries to the drive mechanism of a submarine. (b) What is the field if the wires to and from the drive mechanism are side by side? (c) Discuss the effects this could have for a compass on the submarine that is not shielded.* |
| Solution | (a)  (b) There is no field since the net current is zero.  (c) If the wires to and from the drive mechanism are not side-by-side, a compass on the submarine would read the wrong magnetic field, and therefore the submarine’s navigational system would not work properly. If the wires are side-by-side, then there would be no effect on the compasses, and the system would be just fine. |
| 64. | *How strong is the magnetic field inside a solenoid with 10,000 turns per meter that carries 20.0 A?* |
| Solution |  |
| 65. | *What current is needed in the solenoid described in Exercise 22.64 to produce a magnetic field  times the Earth’s magnetic field of ?* |
| Solution |  |
| 66. | *How far from the starter cable of a car, carrying 150 A, must you be to experience a field less than the Earth’s  Assume a long straight wire carries the current. (In practice, the body of your car shields the dashboard compass.)* |
| Solution |  |
| 67. | *Measurements affect the system being measured, such as the current loop in Figure 22.56. (a) Estimate the field the loop creates by calculating the field at the center of a circular loop 20.0 cm in diameter carrying 5.00 A. (b) What is the smallest field strength this loop can be used to measure, if its field must alter the measured field by less than 0.0100%?* |
| Solution | (a)  (b) |
| 68. | *Figure 22.56 shows a long straight wire just touching a loop carrying a current . Both lie in the same plane. (a) What direction must the current  in the straight wire have to create a field at the center of the loop in the direction opposite to that created by the loop? (b) What is the ratio of  that gives zero field strength at the center of the loop? (c) What is the direction of the field directly above the loop under this circumstance?* |
| Solution | (a) To the left  (b)  (c) Into the page. Outside the loop, the field into the page is outside the loop. |
| 69. | *Find the magnitude and direction of the magnetic field at the point equidistant from the wires in Figure 22.58(a), using the rules of vector addition to sum the contributions from each wire.* |
| Solution |  |
| 70. | *Find the magnitude and direction of the magnetic field at the point equidistant from the wires in Figure 22.58(b), using the rules of vector addition to sum the contributions from each wire.* |
| Solution | The field in the *y* direction is zero, by symmetry. The *y*-components of and cancel each other, as do the *y*-components of and . |
| 71. | *What current is needed in the top wire in Figure 22.58(a) to produce a field of zero at the point equidistant from the wires, if the currents in the bottom two wires are both 10.0 A into the page?* |
| Solution | First, find the field from the bottom two wires.    The field in the *y* direction is zero, by symmetry.  and    must be to the left and of magnitude  (into page) |
| 72. | *Calculate the size of the magnetic field 20 m below a high voltage power line. The line carries 450 MW at a voltage of 300,000 V.* |
| Solution | Current .  Now |
| 73. | ***Integrated Concepts*** *(a) A pendulum is set up so that its bob (a thin copper disk) swings between the poles of a permanent magnet as shown in Figure 22.63. What is the magnitude and direction of the magnetic force on the bob at the lowest point in its path, if it has a positive  charge and is released from a height of 30.0 cm above its lowest point? The magnetic field strength is 1.50 T. (b) What is the acceleration of the bob at the bottom of its swing if its mass is 30.0 grams and it is hung from a flexible string? Be certain to include a free-body diagram as part of your analysis.* |
| Solution | (a) so that    The force acts up.  (b) At the bottom of the swing, the acceleration due to the pendulum motion is zero. Just before entering the magnetic field, . To calculate the acceleration just after entering the magnetic field, , so that the acceleration is:  , or |
| 74. | ***Integrated Concepts*** *(a) What voltage will accelerate electrons to a speed of* *? (b) Find the radius of curvature of the path of a proton accelerated through this potential in a 0.500-T field and compare this with the radius of curvature of an electron accelerated through the same potential.* |
| Solution | (a)  (b)    The ratio of the radius of the proton to the electron is |
| 75. | ***Integrated Concepts*** *Find the radius of curvature of the path of a 25.0-MeV proton moving perpendicularly to the 1.20-T field of a cyclotron.* |
| Solution |  |
| 76. | ***Integrated Concepts*** *To construct a nonmechanical water meter, a 0.500-T magnetic field is placed across the supply water pipe to a home and the Hall voltage is recorded. (a) Find the flow rate in liters per second through a 3.00-cm-diameter pipe if the Hall voltage is 60.0 mV. (b) What would the Hall voltage be for the same flow rate through a 10.0-cm-diameter pipe with the same field applied?* |
| Solution | (a)  (b) |
| 77. | ***Integrated Concepts*** *(a) Using the values given for an MHD drive in Exercise 22.36, and assuming the force is uniformly applied to the fluid, calculate the pressure created in  (b) Is this a significant fraction of an atmosphere?* |
| Solution | (a)  (b) No, this is not a significant fraction of an atmosphere. |
| 78. | ***Integrated Concepts*** *(a) Calculate the maximum torque on a 50-turn, 1.50 cm radius circular current loop carrying  in a 0.500-T field. (b) If this coil is to be used in a galvanometer that reads  full scale, what force constant spring must be used, if it is attached 1.00 cm from the axis of rotation and is stretched by the  arc moved?* |
| Solution | (a)  (b)  Since , |
| 79. | ***Integrated Concepts*** *A current balance used to define the ampere is designed so that the current through it is constant, as is the distance between wires. Even so, if the wires change length with temperature, the force between them will change. What percent change in force per degree will occur if the wires are copper?* |
| Solution | Force is proportional to the length of the wires. Copper has |
| 80. | ***Integrated Concepts*** *(a) Show that the period of the circular orbit of a charged particle moving perpendicularly to a uniform magnetic field is . (b) What is the frequency ? (c) What is the angular velocity ? Note that these results are independent of the velocity and radius of the orbit and, hence, of the energy of the particle. (Figure 22.64.)* |
| Solution | (a)  (b)  (c) |
| 81. | ***Integrated Concepts*** *A cyclotron accelerates charged particles as shown in Figure 22.64. Using the results of the previous problem, calculate the frequency of the accelerating voltage needed for a proton in a 1.20-T field.* |
| Solution |  |
| 82. | ***Integrated Concepts*** *(a) A 0.140-kg baseball, pitched at 40.0 m/s horizontally and perpendicular to the Earth’s horizontal  field, has a 100-nC charge on it. What distance is it deflected from its path by the magnetic force, after traveling 30.0 m horizontally? (b) Would you suggest this as a secret technique for a pitcher to throw curve balls?* |
| Solution | (a) The baseball will follow a curved path of radius:    For this large of a radius, arc length ≈ horizontal distance      (b) No, the deflection is so small that it would not be very helpful. |
| 83. | ***Integrated Concepts*** *(a) What is the direction of the force on a wire carrying a current due east in a location where the Earth’s field is due north? Both are parallel to the ground. (b) Calculate the force per meter if the wire carries 20.0 A and the field strength is . (c) What diameter copper wire would have its weight supported by this force? (d) Calculate the resistance per meter and the voltage per meter needed.* |
| Solution | (a) Use the right hand rule-1. The direction of the force is up from the ground (out of the page).  (b) , or  (c)  We want the force of the magnetic field to balance the weight force, so .  Now, to calculate the mass, recall , where the volume is , so and , or |
|  | (d)  Also |
| 84. | ***Integrated Concepts*** *One long straight wire is to be held directly above another by repulsion between their currents. The lower wire carries 100 A and the wire 7.50 cm above it is 10-gauge (2.588 mm diameter) copper wire. (a) What current must flow in the upper wire, neglecting the Earth’s field? (b) What is the smallest current if the Earth’s  field is parallel to the ground and is not neglected? (c) Is the supported wire in a stable or unstable equilibrium if displaced vertically? If displaced horizontally?* |
| Solution | (a)  (b)  for the earth’s field is , which helps support the wire. Balancing the force gives    (c) Displaced vertically: Yes, it is stable since pulling the top wire up causes reduction in repulsion from the field of the lower wire and vice-versa.  Displaced horizontally: If the upper (supported) wire has sufficient slack, this will be an unstable equilibrium since the vertical component arising from the lower wire is continually reduced. Also the wire receives a push horizontally from the lower wire. |
| 85. | ***Unreasonable Results*** *(a) Find the charge on a baseball, thrown at 35.0 m/s perpendicular to the Earth’s  field, that experiences a 1.00-N magnetic force. (b) What is unreasonable about this result? (c) Which assumption or premise is responsible?* |
| Solution | (a)  (b) It is impossible to have such a large separated charge on such a small object.  (c) The 1.00 N force is much too great to be realistic in the earth’s field. |
| 86. | ***Unreasonable Results*** *A charged particle having mass  (that of a helium atom) moving at  perpendicular to a 1.50-T magnetic field travels in a circular path of radius 16.0 mm. (a) What is the charge of the particle? (b) What is unreasonable about this result? (c) Which assumptions are responsible?* |
| Solution | (a)  (b) It is not an integral multiple of electron charge; it is approximately .  (c) The radius is not possible for the given mass and velocity. |
| 87. | ***Unreasonable Results*** *An inventor wants to generate 120-V power by moving a 1.00-m-long wire perpendicular to the Earth’s  field. (a) Find the speed with which the wire must move. (b) What is unreasonable about this result? (c) Which assumption is responsible?* |
| Solution | (a)  (b) The speed is too high to be practical at ≤1% the speed of light.  (c) The assumption that you could generate such a voltage with a single wire in the earth’s field is unreasonable. |
| 88. | ***Unreasonable Results*** *Frustrated by the small Hall voltage obtained in blood flow measurements, a medical physicist decides to increase the applied magnetic field strength to get a 0.500-V output for blood moving at 30.0 cm/s in a 1.50-cm-diameter vessel. (a) What magnetic field strength is needed? (b) What is unreasonable about this result? (c) Which premise is responsible?* |
| Solution | (a)  (b) We cannot achieve a magnetic field this great in a laboratory.  (c) The assumed 0.500 V output is much too great, probably 1 to 2 orders of magnitude too high. |
| 89. | ***Unreasonable Results*** *A surveyor 100 m from a long straight 200-kV DC power line suspects that its magnetic field may equal that of the Earth and affect compass readings. (a) Calculate the current in the wire needed to create a  field at this distance. (b) What is unreasonable about this result? (c) Which assumption or premise is responsible?* |
| Solution | (a)  (b) This current is unreasonably high. It implies a total power delivery in the line of which is much too high for standard transmission lines.  (c) 100 meters is a long distance to obtain the required field strength. Also coaxial cables are used for transmission lines so that there is virtually no field for DC power lines, because of cancellation from opposing currents. The surveyor’s concerns are not a problem for his magnetic field measurements. |

# Test Prep For AP® Courses

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| 1. | *A bar magnet is oriented so that the north pole of the bar magnet points North. A compass needle is placed to the North of the bar magnet. In which direction does the north pole of the compass needle point?*   1. North 2. East 3. South 4. West |
| Solution | (a) |
| 2. | *Assume for simplicity that the Earth’s magnetic north pole is at the same location as its geographic north pole. If you are in an airplane flying due west along the equator, as you cross the prime meridian (0° longitude) facing west and look down at a compass you are carrying, you see that the compass needle is perpendicular to your direction of motion, and the north pole of the needle dipole points to your right. As you continue flying due west, describe how and why the orientation of the needle will (or will not) change.* |
| Solution | The needle’s orientation should remain constant. As you travel west around the equator, the direction of Earth’s north pole will always be exactly on your right. The compass needle will always be perpendicular to the direction of your motion. |
| 3. | *Describe how the magnetic domains in an unmagnetized iron rod will respond to the presence of a strong external magnetic field.*   1. The domains will split into monopoles. 2. The domains will tend to align with the external field. 3. The domains will tend to orient themselves perpendicular to the external field. 4. The domains will tend to align so as to cancel out the external field. |
| Solution | (b) |
| 4. | *Describe what steps must be undertaken in order to convert an unmagnetized iron rod into a permanently magnetized state. As part of your answer, explain what a magnetic domain is and how it responds to the steps described.* |
| Solution | First, expose the unmagnetized rod to a strong external magnetic field, then expose the rod to significant heat (but do not raise the temperature of the rod above the Curie temperature). Magnetic domains are small regions with magnetic dipole properties within the rod, initially oriented randomly. Upon exposure to the external magnetic field, the domains tend to align their dipoles with the external field. Exposure to heat allows the dipoles to change their structure slightly so as to make the alignment permanent. |
| 5. | *Iron is ferromagnetic and lead is diamagnetic, which means its magnetic domains respond in the opposite direction of ferromagnets but many orders of magnitude more weakly. The two blocks are placed in a magnetic field that points to the right. Which of the following best represents the orientations of the dipoles when the field is present?*  Iron Lead  a)  b)  c)  d) |
| Solution | (b) |
| 6. | *A weather vane is some sort of directional arrow parallel to the ground that may rotate freely in a horizontal plane. A typical weather vane has a large cross-sectional area perpendicular to the direction the arrow is pointing, like a “One Way” street sign. The purpose of the weather vane is to indicate the direction of the wind. As wind blows past the weather vane, it tends to orient the arrow in the same direction of the wind. Consider a weather vane’s response to a strong wind. Explain how this is both similar to and different from a magnetic domain’s response to an external magnetic field. How does each affect its surroundings?* |
| Solution | Like a magnetic domain responding to an external field, the weather vane will align itself with the wind, but the alignment is very rapid and precise. Magnetic domains tend to align themselves with an external field, but the alignment is often not precise. Also, with heating or tapping, a magnetic domain alignment can be permanent whereas the alignment of a weather vane is always variable and subject to the wind direction at any given moment. Additionally, the ferromagnet itself is now the source of a magnetic field and can affect other ferromagnets around it. The weather vane, although aligned with the wind, is not itself a source of wind, and it does not affect other weather vanes around it. |
| 7. | *A proton moves in the –x-direction and encounters a uniform magnetic field pointing in the +x-direction. In what direction is the resulting magnetic force on the proton?*   1. The proton experiences no magnetic force. 2. +*x*-direction 3. −*y*-direction 4. +*y*-direction |
| Solution | (a) |
| 8. | *A proton moves with a speed of 240 m/s in the +x-direction into a region of a 4.5-T uniform magnetic field directed 62° above the +x-direction in the x,y-plane. Calculate the magnitude of the magnetic force on the proton.* |
| Solution | The magnitude of the force can be found using the formula    In this case, |
| 9. | *A wire oriented north-south carries current south. The wire is immersed in the Earth’s magnetic field, which is also oriented north-south (with a horizontal component pointing north). The Earth’s magnetic field also has a vertical component pointing down. What is the direction of the magnetic force felt by the wire?*   1. West 2. East 3. Up 4. North |
| Solution | (b) |
| 10. | *An airplane wingspan can be approximated as a conducting rod of length 35 m. As the airplane flies due north, it is flying at a rate of 82 m/s through the Earth’s magnetic field, which has a magnitude of 45 μT toward the north in a direction 57° below the horizontal plane. (a) Which end of the wingspan is positively charged, the east or west end? Explain. (b) What is the Hall emf along the wingspan?* |
| Solution | For part (a), the right-hand rule indicates positive charges will experience a force oriented toward the west, so the west end of the wing will be positively charged.  For part (b), use the formula    to find the answer 0.13 V. |
| 11. | *An experimentalist fires a beam of electrons, creating a visible path in the air that can be measured. The beam is fired along a direction parallel to a current-carrying wire, and the electrons travel in a circular path in response to the wire’s magnetic field. Assuming the mass and charge of the electrons is known, what quantities would you need to measure in order to deduce the current in the wire?*   1. the radius of the circular path 2. the average distance between the electrons and the wire 3. the velocity of the electrons 4. two of the above 5. all of the above |
| Solution | (e) |
| 12. | *Electrons starting from rest are accelerated through a potential difference of 240 V and fired into a region of uniform 3.5-mT magnetic field generated by a large solenoid. The electrons are initially moving in the +x-direction upon entering the field, and the field is directed into the page. Determine (a) the radius of the circle in which the electrons will move in this uniform magnetic field and (b) the initial direction of the magnetic force the electrons feel upon entering the uniform field of the solenoid.* |
| Solution | The velocity of the electrons can be determined from the work-energy theorem. Assuming that the electric force is the only force doing any work on the electrons in this part of the problem, we can start with the basic statement relating total work and kinetic energy:    The work done by the electric force can be found from the electric potential difference, and the change in kinetic energy is just equal to the final kinetic energy since the initial kinetic energy is zero (electrons start from rest):      Note that the potential difference is +240 V. In order for an electron to accelerate, it must follow a path opposite the direction of the electric field. Since the electric field lines point from higher potential to lower potential, that means that the voltage at the final location of the electrons is high, and the initial voltage is lower. Thus, the voltage difference (final voltage – initial voltage) is positive. Solving for *v* gives |
| 13. | *Equation 22.34 gives us the formula for the radius of a circular path of a charged particle in an external field:*      *In terms of the direction of force, we use the left-hand rule. Pointing your thumb in the +x-direction with the velocity and fingers of the left hand into the page reveals that the magnetic force points down toward the bottom of the page in the –y-direction.*  *A wire along the y-axis carries current in the +y-direction. In what direction is the magnetic field at a point on the +x-axis near the wire?*   1. away from the wire 2. vertically upward 3. into the page 4. out of the page |
| Solution | (c) |
| 14. | *Imagine the xy coordinate plane is the plane of the page. A wire along the z-axis carries current in the +z-direction (out of the page, or ). Draw a diagram of the magnetic field in the vicinity of this wire indicating the direction of the field. Also, describe how the strength of the magnetic field varies according to the distance from the z-axis.* |
| Solution | The student should draw magnetic field lines in concentric counterclockwise circles centered on the origin (where the *z*-axis intersects the *xy* coordinate plane). The direction of the field at any given location should be tangent to the circle centered on the origin and counterclockwise. The magnetic field strength is inversely proportional to the distance from the origin. |
| 15. | *Two parallel wires carry equal currents in the same direction and are separated by a small distance. What is the direction of the magnetic force exerted by the two wires on each other?*   1. No force since the wires are parallel. 2. No force since the currents are in the same direction. 3. The force is attractive. 4. The force is repulsive. |
| Solution | (c) |
| 16. | *A wire along the y-axis carries current in the +y-direction. An experimenter would like to arrange a second wire parallel to the first wire and crossing the x-axis at the coordinate  so that the total magnetic field at the coordinate  is zero. In what direction must the current flow in the second wire, assuming it is equal in magnitude to the current in the first wire? Explain.* |
| Solution | The second wire must carry a current in the same direction as the first wire. The magnetic field at  due to the first wire points into the page. In order to have a net magnetic field of zero, the magnetic field of the second wire to the left of the second wire must point out of the page, which implies a current flowing in the +*y*-direction. |

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