CHAPTER 16 -- MAGNETIC FIELDS

QUESTION & PROBLEM SOLUTIONS

16.1) What is the symbol for a magnetic field? What are its units? Also, what are magnetic fields, really?

Solution: As a vector, the symbol for a magnetic field is ***B***. Its units are *teslas*. In reality, magnetic forces are relativistic effects produced by charge in relative motion. This phenomenon was observed before Einstein's relativity existed. As a consequence, the observers attributed to the phenomenon a new, special vector field. They called that vector field a *magnetic field*.

16.2) What are magnetic forces? That is, how do magnetic forces act; what do they act on; what, in general, do they do?

Solution: Within the context of what has become known as *the classical theory of magnetism*, magnetic fields create forces on charges whose motion cuts across magnetic field lines. That is, magnetic fields are associated with magnetic forces, but they aren't modified force fields the way electric fields are. Magnetic forces accelerate moving charge centripetally according to the relationship $\mathbf{F} = q\mathbf{v}x\mathbf{B}$, where q is the size of the charge moving with velocity $\mathbf{v}$ through the magnetic field $\mathbf{B}$.

16.3) Give two ways you can tell if a magnetic field exists in a region of space.

Solution: The easiest way to detect a magnetic field is with a compass. A more obscure way is to shoot a charged particle through the region. If its path arcs, assuming the change of direction can't be attributed to gravity, you probably have a magnetic field in the region.

16.4) The direction of an electric field line is defined as the direction a positive test charge would accelerate if put in the field at the point of interest. How are magnetic field lines defined?

Solution: The direction of a magnetic field line at a particular point is defined as the direction a compass would point if put at that point.

16.5) What does the magnitude of a magnetic field tell you?

Solution: The magnitude of a magnetic field tells you the amount of *magnetic flux per unit area* associated with a particular point. Magnetic flux has the units of *webers*, so the units for the magnetic field are technically *webers per square meter*.

16.6) What kind of forces do magnetic fields produce?

Solution: A magnetic force will not change the magnitude of a charged particle's velocity. What it will change is the *direction* of a moving, charged particle's velocity. That is, magnetic forces act centripetally.

16.7) You put a stationary positive charge in a magnetic field whose direction is upwards toward the top of the page. Ignoring gravity:

a.) What will the charge do when released?

Solution: A stationary charge in a magnetic field will do absolutely nothing. ELECTRIC FIELDS are modified force fields. Release a stationary charge in an electric field and the field will change the charge's velocity--the charge will accelerate along the line of the field. Magnetic fields are *not* modified force fields. Magnetic fields affect charges only if the charge is in motion, and only then if there is a component of the motion that cuts across magnetic field lines. In short, a charge released from rest in a magnetic field will just sit there.

b.) How would the answer to *Part 7a* change if the charge had been negative?

Solution: Generally, negative charges do exactly the opposite of positive charges. In this particular case, given the fact that a positive charge would do nothing in the magnetic field, one would expect that a negative charge would also do nothing.

c.) In what direction would the charge have to move to feel a magnetically produced force *into the page*? If allowed to move freely, would the charge continue to feel that force into the page?

Solution: The direction of the magnetic field is toward the top of the page. To determine the direction of a magnetic force on a moving charge, you need to evaluate ***vxB*** (i.e., you need to use the *right hand rule*). The direction of that *cross product* will give you the direction of that force. You know the direction of that force--it's into the page--and you know the direction of ***B***--it's toward the top of the page. In other words, the question becomes, *in what direction would you have to extend your hand (i.e., in what direction is **v**?--this is what you are looking for) so that when you curl your fingers toward the top of the page (i.e., in the direction of **B**), your thumb extends into the page (i.e., in the direction of the magnetic force)*? The velocity direction that satisfies this question points *to the left*. Note that, as always with a *cross product*, the direction of the *cross product* (i.e., the direction of ***F***) is perpendicular to the plane defined by the two vectors (i.e., ***v*** and ***B***). As to whether that force would be felt continuously in that direction, the answer is *no*! As the charge begins to move into the page, motivated by the original magnetic force, the direction of the charge's velocity vector would change, the direction of the *cross product* ***vxB*** would change, and the direction of the magnetic force ***F*** would change. In short, the charge would *circle* into the page motivated by a magnetic force that was always *perpendicular* to the charge's motion. So, the force *wouldn't* always be directed *into the page*.

d.) How would the answer to *Part 7c* change if the charge had been negative?

Solution: Negative charges do the exact opposite of positive charges. In this case, a negative charge would have to move *to the right* to feel a force *into the page* due to a magnetic field directed upward toward the top of the page.

e.) The positive charge is given an initial velocity of 2 m/s directed upward toward the top of the page. How will its velocity change with time?

Solution: A moving charge has to *cross* magnetic field lines before a magnetic force is felt. As this charge is traveling *along* the magnetic field lines, there is *no force* on the charge and its motion will continue unchanged.

16.8) Six particles with the same mass move through a *magnetic field* directed into the page (Figure II).

a.) Identify the positively charged, negatively charged, and electrically neutral masses. (Hint: How would you expect a positively charged particle to move when traveling through a **B**-field directed into the page?)

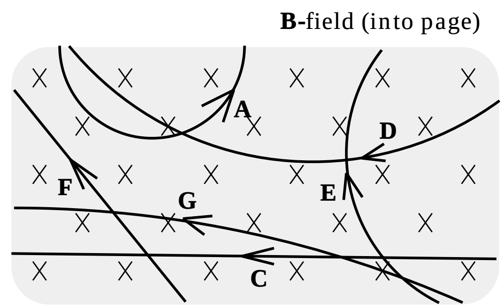


FIGURE II

Solution: The cross product in $\boldsymbol{F} = q\boldsymbol{v}\times\boldsymbol{B}$ allows us to determine the *DIRECTION of the force* on a *positive charge* moving in a **B**-field. Using the right hand rule ($\boldsymbol{v} \times \boldsymbol{B}$) on a charge moving in the figure, we will see positive charge bend in the direction of that force while negative charge bends *opposite* that direction. Noting that non-charged particles do not deviate in the **B**-field at all, we can write:

--*Charges A* and *G* must be positive;
--*Charges D* and *E* must be negative;
--*Charges C* and *F* must be neutral.

b.) Assuming all the particles have the same *charge-magnitude*, which one is moving the *fastest*? (Hint: For a fixed charge, how is charge velocity and radius of motion related? Think!)

Solution: Assuming $\boldsymbol{v}$ and $\boldsymbol{B}$ are perpendicular to one another (i.e., the sine of the angle between the two vectors is *one*), the magnitude of the magnetic force will be $F = qvB$. Noting that all magnetic forces are centripetal in nature, we can use N.S.L. to write:

$\underline{\Sigma F_{cent}}$:

$$qvB = ma_c$$
$$= m(v^2/R)$$

or

$$v = qBR/m.$$

In other words, for a fixed *q, B,* and *m*, the velocity is proportional to the radius of the motion. The largest radius in the picture appears to be that associated with *charge G* (*charge D* is a close second), therefore *charge G* is moving the fastest.

c.) Assuming all the particles have the same *velocity*, which one has the greatest *charge*? (Same hint as above, but reversed.)

Solution: Re-manipulating the previous N.S.L. equation above, we get:

$$q = mv/BR.$$

For a given *m, v,* and *B*, the charge is indirectly proportional to the radius of motion. In other words, holding all else constant, a large charge will have a small radius (this makes sense--the bigger the charge, the bigger the magnetic force on the particle and, hence, the tighter the circle). As such, the greatest charge should be *charge A*.

16.9) A positive charge $q = 4x10^{-9}$ *coulombs* and mass $m = 5x10^{-16}$ *kilograms* accelerates from rest through a *potential difference* of $V_o = 2000$ *volts*. Once accelerated, it enters a known *magnetic field* whose magnitude is $B = 1.8$ *teslas*.

a.) On the sketch in Figure IV, draw in an approximate representation of the charge's path.

Solution: The fact that the charge is positive coupled with the cross product ***F*** = *qv*x***B*** allows us to draw the path of the particle as it moves through the **B**-field (see Figure 2 to the right).

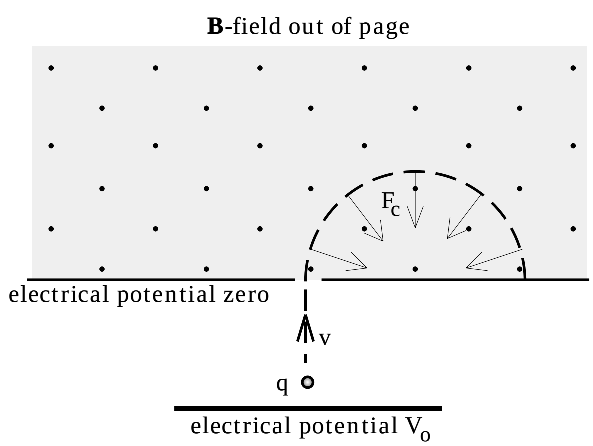


FIGURE 2

b.) We would like to know the *velocity* of the charge just as it enters the **B**-field. Use *conservation of energy* and your knowledge about the *electrical potentials* to determine the charge's *velocity* at the end of the acceleration (yes, this is a review-type question).

Solution: This is a *conservation of energy* problem (you have a charge "falling" through a potential difference). As such:

$$\Sigma KE_1 + \Sigma U_1 + \Sigma W = \Sigma KE_2 + \Sigma U_2$$
$$0 + qV_o + 0 = (1/2)mv^2 + 0$$
$$\Rightarrow \quad v = [2 \quad q \quad V_o \quad / \quad m]^{1/2}$$
$$= [2(4x10^{-9}\ C)(2000\ V)/(5x10^{-16}\ kg)]^{1/2}$$
$$= 1.79x10^5\ m/s.$$

c.) Determine the particle's *radius* of motion once in the **B**-field.

Solution: The centripetal aspect of the magnetic force (assuming the angle between ***B*** and ***v*** is a right angle) yields:

$\underline{SF_{cent}:}$

$$q\ v\ B\ \sin q = m\ a_c$$
$$= m(v^2/R)$$
$$\Rightarrow \quad R = mv/qB$$
$$= (5x10^{-16}\ kg)(1.79x10^5\ m/s)/(4x10^{-9}\ C)(1.8\ T)$$
$$= .0124\ meters.$$

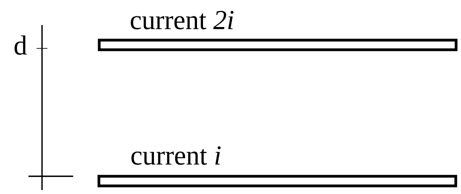
16.10) In what direction is the magnetic field associated with a wire whose current is coming *out of the page*?

Solution: Magnetic field lines circulate around a current-carrying wire. The sense of the circulation (i.e., clockwise or counterclockwise as viewed from the end of the wire) depends upon the current's direction. The easiest way to determine this is with the *right thumb rule*. Point the thumb of your right hand in the direction of current flow. The direction your fingers curl gives the sense of circulation of the field. In this case, a right thumb pointing out of the page produces fingers that curl counterclockwise. (Note that you now have two rules connected with the right hand. What has been called *the right hand rule*, associated with cross products, gives you the direction of the MAGNETIC FORCE on either a moving charge (***F*** = q***vxB***) or a current-carrying wire (***F*** = i***LxB***) in a magnetic field. The *right thumb rule* is associated with determining the SENSE OF CIRCULATION of a magnetic field around a field-producing, current-carrying wire.)

16.11) You have two current-carrying wires, one on the left and one on the right, positioned perpendicularly to the page. The magnitude of the current in each is the same. You are told that the current flow in the wire on the left is *into* the page. If you are additionally told that there is *no place* between the wires where the magnetic field is zero, in what direction is the current in the wire on the right?

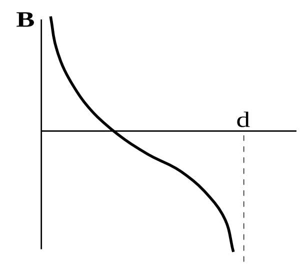
Solution: This is a job for the *right thumb rule*. Between the wires, the magnetic field due to the left wire is oriented toward the bottom of the page. That is, if you orient your right thumb so that it is directed into the page in the direction of the left wire's current, the fingers of the right hand . . . and the circulation of the magnetic field . . . is clockwise. That means that in between the wires, the magnetic field is oriented downward. That means that to insure the field will not be zero anywhere between the wires, the field due to the right wire must *not* be upward--it must also be downward. That would mean the current in the right hand wire must produce a counterclockwise magnetic field. The thumb orientation that produces a counterclockwise rotation is oriented out of the page. That is the direction of the current in the wire to the right.

16.12) You have two current-carrying wires in the plane of the page. The magnitude of the current in the upper wire is twice the magnitude of the current in the lower wire. Do a quick sketch of the magnetic field between the wires if:



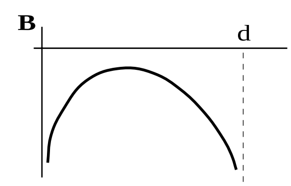
a.) Both currents are to the right.

Solution: Assume the distance between the wires is d, and that our coordinate origin (i.e., $y = 0$) is located at the bottom wire. Using the *right thumb rule*, the magnetic field due to the lower wire will be *out of* the page between the wires (we'll take *out of the page* to be the positive direction), and the magnetic field due to the upper wire will be *into* the page. With the lower wire having the smaller current, it will dominate the net field direction only for small values of y. At some point $y < d/2$, the field will add to zero. On the other side of this zero will be a field *into the page*. We could use the magnetic field expression for a wire to determine exactly where this zero occurs, but all we were asked for was a sketch, so that's all we'll do. In any case, the field will look something like the field shown.

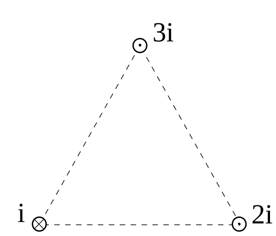


b.) The top current is to the right while the bottom current is to the left.

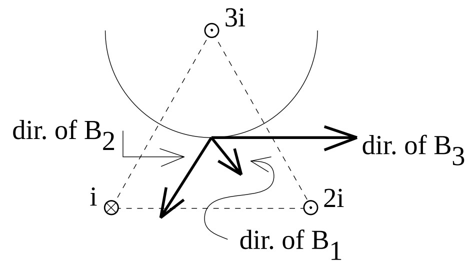
Solution: Using the *right thumb rule* again, the magnetic field due to the upper wire will still be *into* the page between the wires (we'll still call this *negative*), but the magnetic field due to the lower wire will now also be *into* the page. That means there will be no place where the net field will be zero. In fact, the field will go to infinity at the wires with the turn-around point being at the same point where the *zero point* was in *Part 10a*. The sketch is shown to the right.



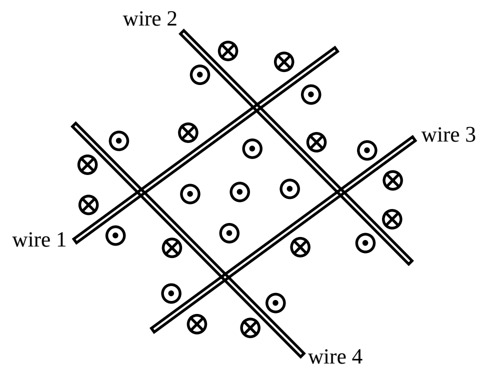
16.13) Three wires with different currents as shown are perpendicular to the page as depicted in the sketch. In what direction is the magnetic field at the center of the triangle?



Solution: If you want to determine the direction of the magnetic field due to a single current-carrying wire, the easiest way to do so is to visualize a circle passing through the point of interest that is additionally centered on the current-carrying wire. The magnetic field due to the wire will be *tangent to that circle*. That is, magnetic fields *circulate* around current-carrying wires. Using the *right thumb rule* allows you to determine in which direction the field is circulating. For the *3i* current, the *right thumb rule* maintains that its magnetic field circulates counterclockwise. At the center of the triangle, this translates into a magnetic field direction that is to the right (see the sketch). The other fields are also shown in the sketch. The net field would be the vector sum of the parts.



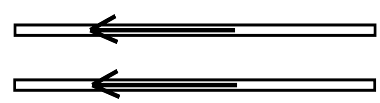
16.14) A group of current-carrying wires is shown to the right. The current is the same in each wire and the direction of the magnetic field is shown at various places in the configuration. From what you have been told, identify the direction of each wire's current.



Solution: To get a sense of the direction of current flow in a particular wire, the best thing to do is to look to see what the magnetic field looks like close to the wire.

The right thumb rule should do the rest. That is, for wire 1, the magnetic field is into the page above the wire and out of the page below the wire. A right thumb directed in that direction will produce a finger-curl that moves into the page above the wire and out of the page below the wire. This suggests that the current is downward toward the left. Wire 2's current is directed upward and to the left; wire 3's current is directed upward and to the right; wire 4's current is directed downward and to the right.

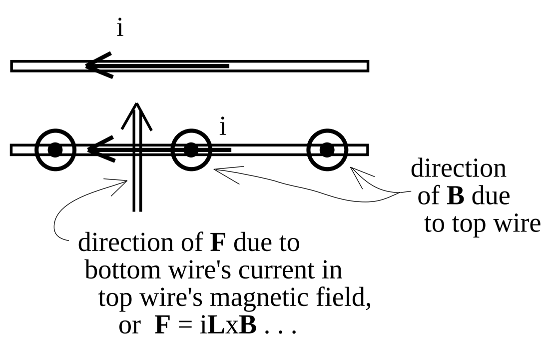
16.15) Two parallel wires have equal currents passing through them. The currents are toward the left. The



top wire's current produces a magnetic field which, impinging upon the current-carrying bottom wire, produces a force on the bottom wire. The bottom wire produces a similar force on the top wire.

a.) Draw on the sketch the direction of both forces.

Solution: See sketch.



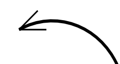
b.) Are the two forces alluded to in *Part 15a* N.T.L. force couples? Explain.

Solution: Yes. One way to see if a pair of forces are N.T.L. couples is to see if the force expression for one is identical to the force expression for the other. The force in this case is $i_1 LB$ (the angle between $\boldsymbol{L}$ and $\boldsymbol{B}$ is 90^{o}, so the sine is *one*), where i_1 is the current in the wire that is feeling the force (we'll take that to be the bottom wire). The magnetic field produced by the current (i_2) in the field-producing wire (that would be the bottom wire in this case) will equal $(\mu_o i_2)/(2\pi r)$. Putting it all together yields $i_1 L(\mu_o i_2)/(2\pi r)$. If we looked at the expression for the force on the top wire due to the presence of the bottom wire, the i terms would switch places but the net force would be the same. These are, indeed, force couples.

c.) If you doubled the distance between the wires, how would the magnitude of the force on the bottom wire change?

Solution: The magnitude of the force is $iLB = iL(\mu_o i)/(2\pi r)$. If you double the distance between the wires, the magnetic field halves. According to the relationships shown, that means this force will also halve.

16.16) A negative charge passes through a magnetic field. It follows the path shown in the sketch.



a.) In what direction is the field?

Solution: If the charge had been positive, it would have curved upward. That is, if we can determine the direction of $\boldsymbol{B}$ that produces an upward force on a *positive charge*, we will have the direction of $\boldsymbol{B}$ that will send a negative charge on the downward path we were given. The field expression for the force on a positive charge is $q\boldsymbol{v}x\boldsymbol{B}$. The right-hand rule maintains that when the length of your right hand moves in the direction of $\boldsymbol{v}$ with the fingers of that hand curling in the direction of $\boldsymbol{B}$, the direction of the right thumb must be upward and to the right (again, we are assuming a positive charge is in motion). Given the velocity and force directions required, the direction of $\boldsymbol{B}$ must be *out of* the page.

b.) In what direction would a positive charge take in the field?

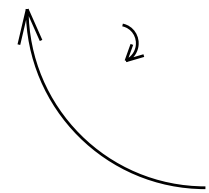
Solution: As was pointed out above, the direction of the force on a positive charge in this $\boldsymbol{B}$ *field* will be opposite the direction of the force on a negative charge. In short, a positive charge would curve upward.

c.) If the size of the magnetic field had been doubled, how would the radius of the motion have been changed?

Solution: The point of order here is that magnetic forces are centripetal. Assuming that $\boldsymbol{v}$ and $\boldsymbol{B}$ are perpendicular to one another, we can write $qvB = mv^2/r$, where r is the radius of the arc upon which the body moves. From this, doubling the magnetic field while keeping everything else constant will halve the radius.

d.) If the magnitude of the velocity had been doubled, how would the radius of the motion have been changed?

Solution: Again, we can write $qvB = mv^2/r$, where r is the radius of the arc upon which the body moves and v the magnitude of the body's velocity. Manipulating this, we get $qB = mv/r$. Doubling the velocity while keeping everything else constant will double the radius.



16.17) Two charges move through a given magnetic field as shown.

a.) If we assume the velocities and masses are the same, which charge must be larger?

Solution: As was the case in *Problem 15*, the force on a charge moving in a magnetic field is $qvB = mv^2/r$, where r is the radius of the arc upon which the body moves and v the magnitude of the body's velocity. With all else constant, this means that the charge will be proportional to $1/r$. That is, the smaller the radius, the larger the charge.

b.) If we assume the charges and masses are the same, which charge must have the larger velocity?

Solution: The force on a charge moving in a magnetic field is $qvB = mv^2/r$, or $qB = mv/r$. With all else held constant, this means that the velocity will be proportional to r. That is, the smaller the radius, the smaller the velocity.

c.) If the magnetic field is oriented out of the page, what is the sign of each charge (i.e., positive or negative)?

Solution: Using the right-hand rule, the direction of the force on a *positive charge* moving in a magnetic field is consistent with the direction the charges are actually curving through. Both charges are positive.

16.18) An electric field E is oriented toward the bottom of the page. In the same space is a magnetic field B. A negative charge passes straight through the region moving in the *+x direction*. As a consequence of both fields, the negative charge moves through the region *without changing its direction of motion*. Ignoring gravity:

a.) What is the direction of the magnetic force in this case?

Solution: For the charge to continue on in a straight line in the magnetic field, the field either has to be oriented along the line of motion, or there must be a second force in the system to counteract the magnetic force. As there is an electric field in the system, the latter situation must be the case. The negative charge will feel a force upward due to the presence of the downward electric field. To counteract that force, there must be a magnetic force that is oriented downward.

b.) What is the direction of the magnetic field in this case?

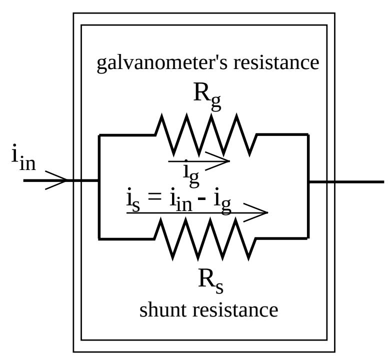
Solution: The charge is moving in the *+x direction*. The magnetic field must produce a force that is *downward* on a negative charge (it would produce a force that was *upward* on a positive charge). How do you determine this? You should know by now! Mess with the right-hand rule until $\boldsymbol{v}\mathrm{x}\boldsymbol{B}$ orients your thumb in the appropriate direction (a downward force on a negative charge will produce an upward force on a positive charge--as the $\boldsymbol{v}\mathrm{x}\boldsymbol{B}$ technique is for positive charge, you are looking for $\boldsymbol{B}$ such that $\boldsymbol{v}x\boldsymbol{B}$ is upward). In this case, that will be a direction that is *into* the page.

16.19) Galvanometers are based on what principle?

Solution: A pinned, current-carrying coil in a magnetic field will feel a force, hence torque, that will rotate the coil. If a pointer is put on the coil and a restoring torque is provided by a spring coil, the amount of rotation from equilibrium will be proportional to the current in the coil.

16.20) An ammeter can be built using a galvanometer and what kind of circuit? How do you determine the value for any extra resistors used in the circuit (i.e., extra beyond the resistance of the galvanometer)?

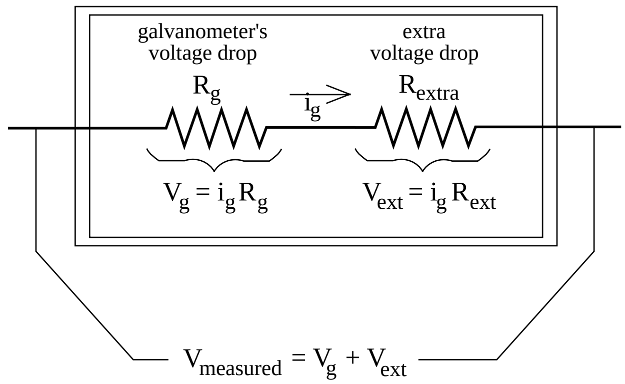
Solution: The general circuit is shown to the right. As for numbers, you have to realize that a galvanometer's needle will move full deflection when $5\mathrm{x}10^{-4}$ amps passes through the galvanometer. You can use a galvanometer to measure a larger current if you are clever. Specifically, let's assume you want to create a 1 amp ammeter (i.e., a meter that executes full deflection when 1 amp passes through it). The trick is to create a situation in which a 1 amp input moves $5\mathrm{x}10^{-4}$ amps through a galvanometer in the system with the rest of the current going somewhere else. This can be done by placing the galvanometer in parallel with a second, shunt resistor, as shown in the sketch to the right. To get the appropriate value for this shunt resistor, note that the voltage across the galvanometer (i.e., $V_g = i_g R_g = (5x10^{-4}\ amps)(R_g)$ . . . where the resistance R_g of the galvanometer must be known) will equal the voltage across the shunt resistor (i.e., $V_s = i_s R_s = (1 - 5x10^{-4})(R_s)$). Equating the two will allow you to determine R_s.



ammeter circuit

16.21) A voltmeter can be built using a galvanometer and what kind of circuit? How do you determine the value for any extra resistor(s) used in the circuit (i.e., extra beyond the resistance of the galvanometer)?

Solution: The circuit is shown on the next page. As was mentioned in *Problem 22*, a galvanometer's needle will move full deflection when $5\mathrm{x}10^{-4}$ amps passes through the galvanometer. And again, if you are clever, you can use the needle swing of a galvanometer to measure the voltage difference across a circuit element. Specifically, let's assume you want to create a 5 volt voltmeter (i.e., a meter that executes full deflection when 5 volts is placed across it). The trick is to realize that at full voltmeter circuit



deflection, the voltage drop across the galvanometer will be its *maximum deflection current* times its *known resistance*, or *(5x10^{-4} amps)(R_g)*. Let's say the galvanometer's resistance is 20 ohms. The voltage across the galvanometer at full deflection will, therefore, be 10^{-2} volts. Unfortunately, we want the galvanometer's needle to move full deflection when *5 volts* is placed across the meter. So how do we insure that this will happen? By placing just the right sized secondary resistor in series with the galvanometer, the sum of the voltage drops across the galvanometer and this second resistor can be made to equal *5 volts*. To get the value of this extra resistor, the galvanometer's voltage plus the resistor's voltage must equal the maximum deflection voltage (i.e., *5 volts* in this case). Remembering that the current through both elements will be the same in the series combination, the algebraic expression for this relationship becomes $V_g + V_{extra} = V_{max.for\ meter}$ = *(10^{-2} volts) - (5x10^{-4} amps)(R_{extra}) = (5 volt)*. Solving for R_{extra} finishes the problem.

16.22) How can one piece of iron be magnetized while a second piece is not?

<u>Solution</u>: Domains are regions within a ferromagnetic material where the magnetic fields of all of the atoms making up that region are in alignment. The problem is that one domain will not necessarily be aligned with the domains on its perimeter. When such an alignment exists, we observe a net magnetic field from the material. When such an alignment is scrambled, we observe no magnetic field.

16.23) What does the earth's magnetic field really look like, and why?

<u>Solution</u>: Solar winds (charged and uncharged subatomic particles ejected at high speeds from the sun) constantly buffet the earth. On the sun-side of the earth, their presence pushes the earth's magnetic field *in closer to the earth*. On the night-side of the earth, their presence pushes the earth's magnetic field *out away from the earth*.

16.24) *Magnet A* is a light, weak, bar magnet. *Magnet C* is a heavy, strong, bar magnet. You place *magnet A* on a table so that it can move freely.

a.) If you pick up *magnet C* and approach *magnet A* so that C's north pole comes close to A's south pole, what will happen and why?

<u>Solution</u>: Remember, *unlike* magnetic poles attract. At some point in the approach, the attraction between the opposite magnetic poles will overcome friction between *magnet A* and the surface upon which it sits, and *magnet A* will be attracted to *magnet C* . . . most probably accelerating toward *magnet C* suddenly.

b.) If you pick up *magnet C* and approach *magnet A* so that C's south pole comes close to A's south pole, what would you expect to happen and why?

Solution: Remember, *like* magnetic poles repulse. At some point in the approach, the repulsion between the like magnetic poles will overcome friction between *magnet A* and the surface upon which it sits, and *magnet A* will move away from *magnet C*. At least, that is what you would expect.

c.) If you said the magnets would repulse one another for *Part 16.24b*, you could be wrong. In fact, there is a good chance that if you actually tried this, the two magnets would attract. THIS DOESN'T MEANS *LIKE POLES ATTRACT*! What does it mean?

Solution: If *magnet A* were sitting on a frictionless surface, it would respond to *magnet C* by repulsing as expected, moving away as expected. But if the friction between *magnet A* and the surface upon which it sits is large enough, *magnet C* might be able to get close enough to *magnet A* to literally rearrange *magnet A*'s domain alignment, thereby switching *magnet A*'s magnetic polarity. In other words, you could re-magnetize *magnet A* so that the end labeled "N" would become a south pole . . . and vice versa. In that case, the newly opposite poles would attract and the two magnets would come together, doing something in the process that would be, on the surface, totally unexpected.

16.25) A wire carries 8 amps. The earth's magnetic field is approximately $6\text{x}10^{-5}$ teslas.

a.) How far from the wire will the *earth's magnetic field* and the *wire's magnetic field* exactly cancel one another?

Solution: The equation governing the magnitude of a **B**-field generated by a wire is:

$$B = \mu_o I/(2\pi r),$$

where $\mu_o = 4\pi x10^{-7}$ *volt·second/amp* (or $1.26x10^{-6}$--these units are also *henrys/meter* or *tesla·meters/amp*), I is the current through the wire, and r the distance from the wire. We want the distance r at which the magnitude of B_{wire} is $6\text{x}10^{-5}$ teslas. Manipulating the above equation we get:

$$r = \frac{\left(4\pi x10^{-7}\,T \bullet m / A\right)(8\ A)}{2\pi\left(6x10^{-5}\,T\right)}$$

$$= .0267 \text{ meters.}$$

b.) How must the wire be oriented (i.e., north/south, or south-east/north-west, or what?) to effect the situation outlined in *Part a*? (Assume there is no "dip" in the earth's **B**-field)?

Solution: If the wire runs North-South (or vice versa), it will produce no ***B**-field* IN the *N-S* direction (remember, ***B**-fields* CIRCLE around wires) and, hence, will not add to or subtract from the earth's field. That means the wire must run East-West. If the current runs West (assuming no dip to the earth's field, and remembering the earth's field lines go from the South geographic pole to the North geographic pole), the fields will cancel 2.67 centimeters *below* the wire. If the current runs East, the fields will cancel 2.67 centimeters above the wire.

16.26) The Hall Effect was an experiment designed to determine the *kind* of charge that flows through circuits (electrons were suspected but there was no proof). The device is shown in Figure VI. It consists of a battery attached to a broad, thin plate that is bathed in a constant magnetic field. Using the device, how might you determine the kind of charge carriers that move in electrical circuits?

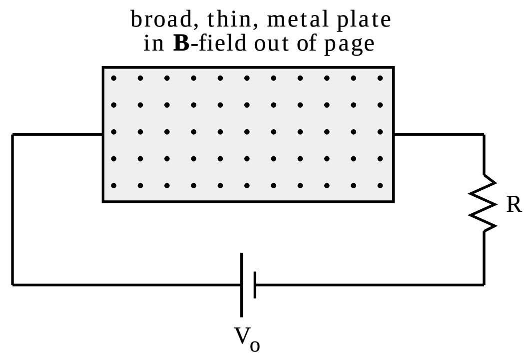


FIGURE VI

Step #1: Assume electrons flow in the circuit. What path, on average, will those negative charges take as they pass through the plate in the magnetic field? Which side of the plate will be the *high voltage side*?

Step #2: Do the same exercise as suggested in *Step #1* assuming *positive* charge flow.

Culmination: If you didn't know whether the situation depicted in *Step 1* or *Step 2* was the real situation, how could the use of a *voltmeter* help?

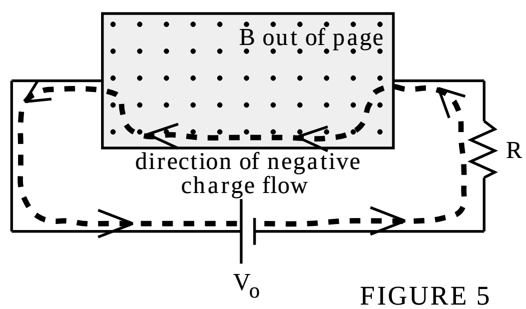


FIGURE 5

Solution: The sketch in Figure 5 shows the device assuming NEGATIVE CHARGE flows in the circuit (this was *Step 1*). Note the preponderance of negative charge on the *bottom side* of the plate making the *top side* the *high voltage side*.

Figure 6 shows the device assuming POSITIVE CHARGE moves in the circuit (this was *Step 2*). Note the preponderance of positive charge on the *bottom side* of the plate making the *bottom side* the *high voltage side*.

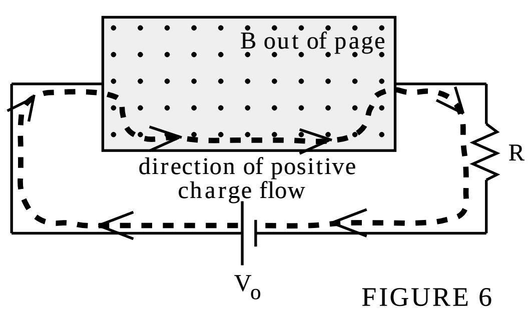


FIGURE 6

A voltmeter has both a *high voltage* and a *low voltage* terminal.

If you attach the *high voltage terminal* to, say, the *bottom of the plate*, the meter's needle will swing appropriately *if the charge flow is that of positive charge.* If, in fact, you were to try this, you would find that the needle would swing *in the wrong direction*. What does that mean? It means that the *high voltage side of the plate* must not be the *bottom side*, which means that the current flow in the circuit is not made up of *positive charges*.

16.27) Assuming the resistance of a galvanometer is 12 ohms, draw the circuit design for and determine all pertinent data required to build:

a.) A 300 volt *voltmeter*;

<u>Solution</u>: A voltmeter is designed to measure the *voltage difference* between two points, usually on either side of a circuit element. If we want a *300 volt (max) voltmeter*, we need a meter-circuit such that when 300 volts is placed across it, $5\text{x}10^{-4}$ amps flow through the internal galvanometer causing the galvanometer to register *full deflection*.

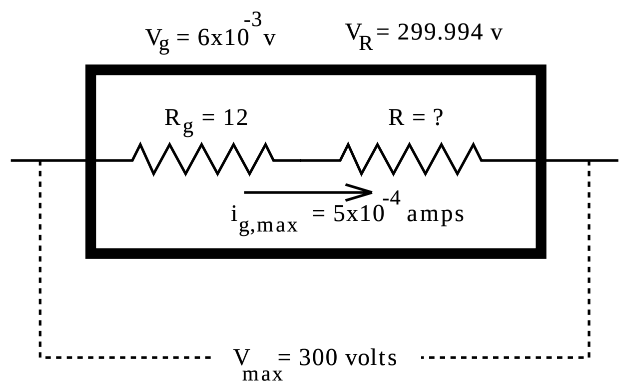


FIGURE 7

The kind of circuit that will do the trick is shown in Figure 7. Noting that the current is the same for the extra resistor as it is for the galvanometer (the two are in series), and remembering that full deflection of the galvanometer needle will occur when $5\text{x}10^{-4}$ amps flow through the galvanometer, we can sum the voltage drops across the individual elements when full deflection occurs and end up with:

$$V_{max} \quad = \quad V_{galv,max} \quad + \quad V_R$$
$$(300 \text{ volts}) = (i_{galv,max})(R_{galv}) + (i_{galv,max})(R)$$
$$(300 \text{ volts}) = (5\text{x}10^{-4} \text{ A})\ (12 \text{ W}) + (5\text{x}10^{-4} \text{ A})\ \ R$$
$$\Rightarrow \quad R = 6\text{x}10^{5}\ \Omega \ \ . . . \text{(large as expected)}$$

b.) A .25 amp *ammeter*.

<u>Solution</u>: An ammeter is designed to measure the current that passes *through it*. That means that if we want a *.25 amp (max) ammeter*, we need a circuit such that when .25 amps pass through it, a current of $5\text{x}10^{-4}$ amps flows through the internal galvanometer. That also

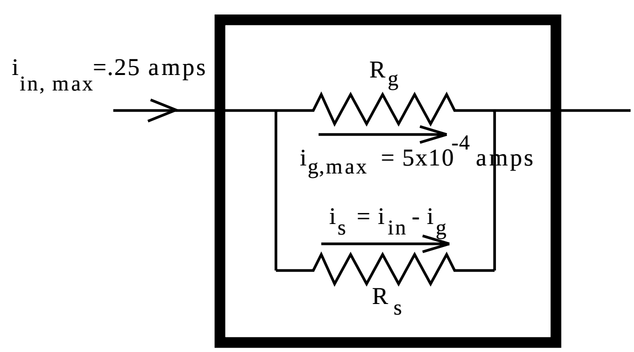


FIGURE 8

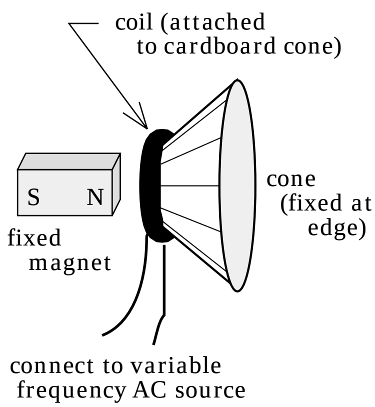
means that the rest of the current has to be shunted off elsewhere. That *elsewhere* is a parallel resistor called a *shunt resistor* R_{shunt}. Figure 8 shows the circuit.

As the voltage across a parallel combination is the same for each branch, we can write the following for our *.25 amp ammeter*:

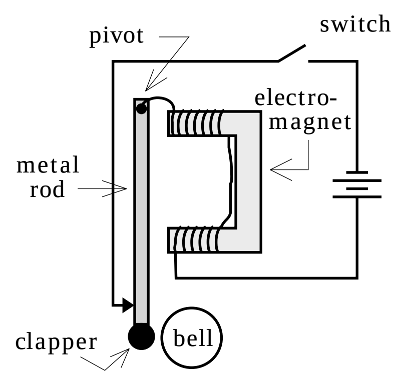
$$V_R = V_{shunt}$$
$$i_{galv,max} R_g = (.25 - i_{g,max}) R_s$$
$$(5\text{x}10^{-4}\text{ A})(12\ \Omega) = (.2495\text{ A}) R_s$$
$$\Rightarrow \quad R_s = .024\ \Omega \ \ . . . \text{(small as expected)}$$

16.28) What do you suppose will happen when AC is piped through the coil of the device shown in *sketch a*, and DC is provided to the circuitry shown in *sketch b*?

a.)



b.)



Solution: For circuit A, put AC through the cone-attached coil in the magnetic field and the cone will vibrate at the same frequency at which the AC oscillates. For circuit B, a magnetic field will be set up in the iron horseshoe as long as current flows through the circuit. This will attract the metal bar which, upon moving, will strike the bell. But once the bar moves, the circuit will be broken at the arrow headed contact, the magnetic field will turn off, and after hitting the bell the bar will swing back to the arrowhead contact. That will reactivate the magnetic field which will start the process all over again. In other words, the bar will vibrate back and forth as the magnetic field turns on and off, striking the bell repeatedly. In my country, we call this a DC driven *door bell*.

16.29) What is the difference between a motor and a generator?

Solution: A generator is a shaft-mounted coil in a magnetic field. When the shaft is turned, AC is produced across the leads of the coil. That is, mechanical energy is put into the system and electrical energy comes out. A motor is a shaft-mounted coil in a magnetic field. When AC is run through the coil, the shaft turns. That is, electric energy is put into the system and mechanical energy comes out. In short, there is no difference between a motor and a generator. What matters is whether the shaft is being turned mechanically (thereby creating a generator) or the shaft is being turned electrically (thereby creating a motor).