

SECTION A – MagnetostaticsSolutionAnswer

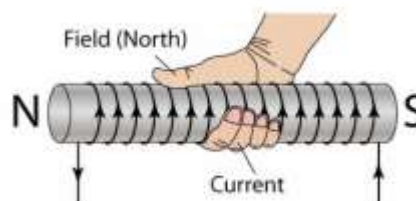
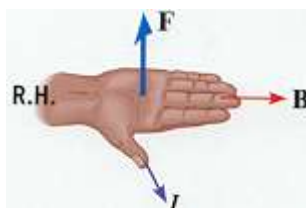
For the purposes of this solution guide. The following hand rules will be referred to.

RHR means right hand rule (for + current). LHR will be substituted for – current

RHRcurl

RHRflat

RHR–Solenoid



- Each wire contributes a B field given by $\mu_0 I / 2\pi a$ in a direction found using RHRcurl. The direction of each B field is as follows, (1)Top right wire: B up&left, (2)Top left wire: B up&right, (3)Bottom left wire: B up&left, (4)Bottom right wire: B down&left. Forces from 1 and 4 cancel leaving both 3 and 4 B fields acting up and left and adding together. C
- The B field at the location of the charge +e is created by the wire next to it and given by $B = \mu_0 I / 2\pi R$. Based on RHRcurl the direction of that B field is into the page at that location. Then the force on that charge is given by $F_b = qvB$, with $q=e$ and B from before so $F_b = ev(\mu_0 I / 2\pi R)$. Using the RHRflat for the + charge, the force comes out as down. E
- Charges moving through magnetic fields move in circles as in the diagram for question 39 E
- The compass is ABOVE the wire. Using RHRcurl on the wire, the B field points towards the right at the location above the wire. Since compasses follow B field lines, the compass will also point right, which is east. D
- To be undeflected, the electric and magnetic forces must balance.
 $F_e = F_b$ $Eq = qvB$ $B = E / v$ With v related to K by $K = \frac{1}{2} mv^2$
gives $B = E / \sqrt{(2K/m)}$... which is equivalent to choice D D
- Focus on + charge direction and use RHRcurl and you get into page A
- When cutting a magnet, you must end up with two new magnets having 2 poles each. For the top magnet the current N and S must stay as is, so the left of center part becomes a S and the right of center part becomes a N. There are now two opposite poles that attract. For the bottom magnet, by slicing it down the center you now have two magnets on top of each other. The poles would not change their current locations so you have two north and two south poles near each other on top and bottom which makes repulsion. E
- For this scenario, The circular motion is provided by the magnetic force. So that $F_{\text{net}(C)} = mv^2/r$
 $qvB = mv^2/r$ $qBr = mv$ $2 \times v \rightarrow 2 \times r$ B
- Focus on a single + charge in the wire that gets pushed to the right. So this + charge is moving in a magnetic field pointing into the page with a force directed right, based on RHRflat, the charge must be moving down. E
- When moving parallel to magnetic fields, no forces are experienced. C

11. Assume R is north. Based on the lines, T would have to be north and so would Y. This makes X and Z south and S north. D
12. Using RHRcurl, we get into the page C
13. Parallel current wires with same direction current attract. A
14. Focus on a single + charge in the wire that gets pushed to the right. So this + charge is moving down with a force directed right, based on RHRflat, the magnetic field must point into the page. A
15. By definition, E fields exert forces on + charges in the same direction as the E field. So the force from the E field must be UP. To maintain a constant velocity, this upwards force must be counterbalanced by a downwards force, which in this case it is to be provided by the magnetic field. With a + charge moving right, and a magnetic force down, RHRflat gives a magnetic field pointing out of the page. B
16. A coil of wire (solenoid) like this becomes an electromagnet when the current runs through it. Use the RHR–solenoid to determine that the right side of this electromagnet becomes the north side. Now pretend that the electromagnet is simply a regular magnet with a N pole on the right and a S pole on the left and draw the field lines. In doing so, the lines end up pointing to the left at the location of the compass. Since compasses follow magnetic field lines, the compass will also point left. A
17. Due to action reaction the forces must be the same. Another way to look at it is that wire A creates the field that wire B is sitting in based on its current I, $B_a = \mu_0 I_a / 2\pi R$. The force on wire B is dependent on the field from A, and also the current in wire B itself and is given by $F_b = B_a I_b L$ $F_b = (\mu_0 I_a / 2\pi R) I_b L$. So since both currents from A and B affect each respective force, they should share the same force. E
18. Think about this as if you are looking down at a table top with the + particle on it. An E field is pointed down into the table so an electric force acts down into the table also. The electric force pushing down will not move the charge. A magnetic field comes up out of the table, but since the charge is at rest, the magnetic field exerts zero force on it. So $F_e > F_b$ A
19. As described above, a charge not moving will not experience a magnetic force E
20. First of all we should state that a larger current makes a bigger B field and the further from the wire the less the B field. Using RHRcurl, the 4A wire has decreasing magnitude B fields pointing down in regions II and III on the axis and upwards on region I. The 3A wire has B fields pointing upwards in region III and downwards in regions II and I. To cancel, fields would have to oppose each other. Region I is a possibility but since the distance from the 4A wire is smaller at every point and it also has a larger current it will always have a larger B field so there is no way to cancel. Region II has fields in the same direction and cannot cancel. Region III has opposing fields. Since the 4A wire has a larger current but also a larger distance away from any point in Region III and the 3A wire has a smaller current but a closer distance to any point in Region III it is possible that these two factors compensate to make equal B fields that oppose and could cancel out. C
21. Using RHR–solenoid the top of the loop is N and the bottom is S. Drawing a field line out of the top and looping outside down to the bottom, you have to continue up through the solenoid to complete the field line so the direction is UP. (Note: this may seem counterintuitive because the field line points from the south to the north which is opposite of what you might think but this is INSIDE the solenoid (magnet). Only outside, do lines come out of N and into S.) D

22. Use RHR-flat A
23. We first need to determine the direction of the B field at P due to the other wires using RHRcurl. The top wire creates a B field pointing up&right, the bottom wire creates a B field pointing up&left. The left and right parts of these cancel out making a field only up from these two wires. The wire on the left also produces a field only up so the net B field points up at location P. Now using RHRflat for the right wire, the force is left. A
24. First determine the B field direction created by the current wire at the location above the wire using RHRcurl. This gives B out of page. Then use LHRflat for the negative charge to get force acting down. E
25. In region I, the electric field pushes the negative electron with a force opposite the direction of the E field (out of the page). For the charge to not be pushed out, the magnetic field must create a force into the page to resist this. Based on LHRflat the B field must point up. Then in region II based on how the charge gets pushed, its magnetic force is up initially. Using LHRflat again in region II gives B field direction out of the page. C
26. Based on RHR-flat the magnetic force is directed into the page. To be undeflected, the E field must create a force out of the page to resist this, and since it's a + charge the E field points out. C
27. This is a loop. Current flows clockwise around the loop. Using the RHR-solenoid for the single loop the B field in the center is pointing into the page. A
28. Charges moving without energy loss have to maintain a constant radius circle. For the circle to decrease in radius, energy would be radiated out from it. Since its an electron we use LHRflat to get a force pointing down making it follow path D. D
29. Use RHRflat C
30. Use RHRcurl E
31. Using RHRcurl we find the direction of the magnetic field from each wire. To the right of the leftmost wire, its field points down along the axis with a decreasing magnitude as you move away from it. For the rightmost wire its field also points down when you move left of it. Since both fields point down between the wires, they will add and cannot cancel. On the far right side of the arrangement, the leftmost wire makes a field down and the rightmost wire makes a field up but since the distances to any location are different from each wire the magnitude of the fields would be different so no way to cancel. The same would happen on the far left of the wires. E
32. Use LHRflat A
33. To induce a current, the flux through the spring loop must change. When moving the spring parallel to the magnetic field, the same B field and the same area is enclosed in the loop so the flux stays constant and there is no induced current. D
34. When moving in a circle at constant velocity, no work is done as explained in previous answers. A
35. Choose 1 proton moving in the circle. For this proton. $F_{\text{net}(C)} = mv^2/r$ $F_b = mv^2/r$ $qvB = mv^2/r$ $v = qBr/m = 1.6 \times 10^{-19} (0.1)(0.1) / (1.67 \times 10^{-27}) \sim 10^{-21} / 10^{-27}$ C
36. As described in question 17, the force on either wire is $F_b = (\mu_o I_a / 2\pi R) I_b L$. So doubling both I's in the equation gives 4x the force. C

37. Not a magnetism question, but lets review. Since the charge magnitude is the same, they will experience the same forces based on $F_e = Eq$, but move in opposite directions. Since the masses are different, the same forces will affect each object differently so that the smaller mass electron accelerates more, thus gains more speed and covers more distance in equal time periods. So only the force is the same. E
38. To be undeflected, the electric and magnetic forces must balance.
 $F_e = F_b$ $Eq = qvB$ $v = E / B = 6 / 2$ C
39. Same as question 36 D
40. Since the particle is moving parallel to the field it does not cut across lines and has no force. D
41. Using RHRcurl for each wire, the left wire makes a field pointing down&right at P and the right wire makes a field pointing up&right. The up and down parts cancel leaving only right. E
42. The electric force would act upwards on the proton so the magnetic force would act down. Using RHRflat, the B field must point out of the page. D
43. $F_e = F_b$ $Eq = qvB$ $E = vB$ $B = E/v$ A
44. RHRflat E
45. Based on ... $F_{\text{net}(C)} = mv^2/r$... $F_b = mv^2/r$... $qvB = mv^2/r$... $r = mv/qB$... inverse B
46. Wires with current flowing in the same direction attract. B
47. From question 17, $F_b = (\mu_0 I_a / 2\pi R) I_b L$... R is x2 and both I's are x2 so it's a net effect of x2. D
48. Using RHR–solenoid, the B field at the center of that loop is directed right. Since the other loop is further away, its direction is irrelevant at the left loop will dominate. C
49. Based on the axis given. The left side wire is on the axis and makes no torque. The top and bottom wires essentially cancel each other out due to opposite direction forces, so the torque can be found from the right wire only. Finding the force on the right wire ...
 $F_b = BIL = (0.05)(2)(0.3) = .03 \text{ N}$, then torque = $Fr = (0.03)(0.3)$. B
50. The field from a single wire is given by $\mu_0 I_a / 2\pi R$. The additional field from wire Y would be based on this formula with $R = 3R$, so in comparison it has 1/3 the strength of wire X. So adding wire X's field B_o + the relative field of wire Y's of 1/3 B_o gives a total of 4/3 B_o . D
51. First we use RHRcurl to find the B field above the wire as into the page, and we note that the magnitude of the B field decreases as we move away from it. Since the left AB and right CD wires are sitting in the same average value of B field and have current in opposite directions, they repel each other and those forces cancel out. Now we look at the wire AD closest to the wire. Using RHRflat for this wire we get down as a force. The force on the top wire BC is irrelevant because the top and bottom wires have the same current but the B field is smaller for the top wire so the bottom wire will dominate the force direction no matter what. Therefore, the direction is down towards the wire. A
52. Using RHRflat for the magnetic field direction given, the magnetic force would be up (+z). To counteract this upwards force on the + charge, the E field would have to point down (– z). E

53. A little tricky since its talking about fields and not forces. To move at constant velocity the magnetic FORCE must be opposite to the electric FORCE. Electric fields make force in the same plane as the field (ex: a field in the x plane makes a force in the x plane), but magnetic fields make forces in a plane 90 degrees away from it (ex: a field in the x plane can only make magnetic forces in the y or z plane). So to create forces in the same place, the fields have to be perpendicular to each other. B
54. First we have ... $F_{\text{net}(C)} = mv^2/r$... $F_b = mv^2/r$... $qvB = mv^2/r$... $v = qBr/m$ Then using $v = 2\pi R / T$ we have $qBr/m = 2\pi R / T$... radius cancels so period is unchanged and frequency also is unaffected by the radius. Another way to think about this with the two equations given above is: by increasing R, the speed increases, but the $2\pi R$ distance term increases the same amount so the time to rotate is the same. A
55. Pick any small segment of wire. The force should point to the center of the circle. For any small segment of wire, use RHRflat and you get velocity direction is CCW. Equation is the same as the problem above ... $qvB = mv^2/r$... $eBr = mv$. C
56. Same as in question 54 ... $qBr/m = 2\pi R / T$... $T = 2\pi m / eB$. C
57. The left and right sides of the loop wires are parallel to the field and experience no forces. Based on RHRflat, the top part of the loop would have a force out of the page and the bottom part of the loop would have a force into of the page which rotates as in choice C. C
58. Each wire creates a magnetic field around itself. Since all the currents are the same, and wire Y is closer to wire X, wire X's field will be stronger there and dominate the force on wire Y. So we can essentially ignore wire Z to determine the direction of the force. Since X and Y are in the same direction they attract and Y gets pulled to the left. E
59. Wires with current in the same direction are attractive. Using RHRcurl for each wire at the location shown has the top wire having B_{in} and the bottom wire making B_{out} . Since its at the midpoint the fields are equal and cancel to zero. B

SECTION B – Induction

<u>Solution</u>	<u>Answer</u>
1. Based on the formula $\varepsilon = \Delta\Phi/t$	C
2. We first need to determine the direction of the B field at P due to the other wires using RHRcurl. The top wire creates a B field pointing up&right, the bottom wire creates a B field pointing up&left. The left and right parts of these cancel out making a field only up from these two wires. The wire on the left also produces a field only up so the net B field points up at location P. Now using RHRflat for the right wire, the force is left.	A
3. A complex problem. On the left diagram, the battery shows how + current flows. Based on this it flows left through the resistor and then down on the front side wires of the solenoid. Using the RHR–solenoid, the right side of the solenoid is the North pole. So field lines from the left solenoid are pointing to the right plunging into the solenoid core of the right side circuit. As the resistance in the left side increases, less current flows, which makes the magnetic field lines created decrease in value. Based on Lenz law, the right side solenoid wants to preserve the field lines so current flows to generate field lines to the right in order to maintain the flux. Using the RHR–solenoid for the right hand solenoid, current has to flow down on the front side wires to create the required B field. Based on this, current would then flow down the resistor and to the left through the ammeter.	A
4. Similar to the problem above. The field lines from the bar magnet are directed to the left through the solenoid. As the magnet is moved away, the magnitude of the field lines directed left in the solenoid decrease so by Lenz law the solenoid makes additional leftward field to maintain the flux. Based on RHR–solenoid, the current would flow up the front side wires of the solenoid and then to the right across the resistor. This also means that the left side of the solenoid is a N pole so it attracts the S pole of the nearby magnet.	C
5. As the magnet falls down towards the pipe, which is a looped conductor, the magnetic field lines plunging into that conductor increase in magnitude. Based on Lenz's law, current flows in the conductor to oppose the gain in field and maintain the flux. The copper loop will create a B field upwards to maintain flux and this upwards B field will be opposite from the magnets B field which will make it slow.	B
6. Plug into $\varepsilon = BLv$	D
7. Based on $\varepsilon = BLv$	D
8. This is a fact. It is best thought about through example and thinking about how non–conservative forces are at play. Lenz law says opposing fields are induced for moving magnets, this slows them ... if the opposite was true you would get accelerated systems where energy would not be conserved	D
9. Use $\varepsilon = \Delta\Phi / t$ $\varepsilon = (BA_f - BA_i) / t$ $\varepsilon = (0 - (2)(0.5 \times 0.5)) / 0.1$	C
10. The rail makes a loop of wire as shown by the current flow. Using Lenz law, as the loop expands with the motion of the bar, it is gaining flux lines in whatever direction the B field is and the loop current flows in a direction to oppose that gain. Using RHR–solenoid for the single loop, the B field induced is directed out of the page so it must be opposing the gain of B field that is already there going into the page.	B

11. Take a small section of wire on the loop at the top, bottom, right and left hand sides and find the forces on them. For example, the section of wire on the top has current pointing left and B pointing out ... using RHRflat for that piece gives a force pointing up. At all of the positions, the force acts in a manner to pull the loop outwards and expand it. A
12. The induced emf occurs in the left side vertical wire as that is where the charge separation happens. Looking at that wire, the induced emf is given by $\varepsilon = BLv$. This emf then causes a current I to flow in the loop based on $V=IR$, so I is given as BLv / R . The direction of that current is found with Lenz law as there is a loss of flux into the page, RHR-solenoid shows current must flow CW to add back flux into the page and maintain it. C
13. As long as the flux inside the loop is changing, there will be an induced current. Since choice E has both objects moving in the same direction, the flux through the loop remains constant so no need to induce a current. E
14. Same as question 35, different numbers. C
15. Looking at the primary coil, current flows CCW around it so based on RHR-solenoid the magnetic field lines from that coil are pointing to the left and they extend into the secondary coil. To induce a current in the secondary coil, the flux through the secondary coil needs to be changed so an induced current will flow based on Lenz law. Choice A means spinning the coil in place like a hula-hoop or a spinning top and this will not cause a change in flux. A
16. Based on Lenz law, as the flux pointing up decreases, current flows in the loop to add back that lost flux and maintain it. Based on RHR-solenoid, current would have to flow CCW A
17. Based on $\varepsilon = BLv$, its a linear variation A
18. We are looking to find rate of change of magnetic field $\Delta B/t$ so we need to arrange equations to find that quantity. Using induced emf for a loop we have. $\varepsilon = \Delta\Phi / t = \Delta BA/t$, and substituting $V=IR$, and area = a^2 we have ... $IR = \Delta B (a^2) / t$... isolate $\Delta B/t$ to get answer. A
19. $\Phi = BA = (2)(0.05)(0.08)$ C
20. From Lenz law, as the flux decreases the loop induces current to add back that declining field. Based on RHR-solenoid, current flows CCW to add field coming out of page. D
21. Since both loops contain the same value of BA and it is changing the same for both of them, the quantity $\Delta BA/t$ is the same for both so both have the same induced emf. C
22. Above the wire is a B field which is directed into the page based on RHRcurl. That B field has a decreasing magnitude as you move away from the wire. Loop 1 is pulled up and therefore is losing flux lines into the page. By Lenz Law current flows to maintain those lines into the page and by RHR-solenoid current would have to flow CW to add lines into the page and maintain the flux. Loop 2 is moving in a direction so that the magnitude of flux lines is not changing and therefore there is no induced current C
23. This is best done holding a small circular object like a small plate and rotating it towards you keeping track of the current flow. Grab the top of the plate and pull it towards you out of the page and move down at the same time to rotate it. This will increase the flux lines into the loop as you rotate and cause a current to flow to fight the increase until it becomes flat and you have moved 90 degrees in relations to the rotation you are making. Then as you pass this point and begin pushing the part of the loop you are holding down and into the page away from you, you start to lose field lines and current will flow the other way to try and maintain the flux lines until your hand has moved what was once the top of the loop all the way to the bottom. At this point you are 180 degrees through the rotation and have changed D

direction once. As you pass through 180, you will notice that the current flows the same way to maintain the zero flux you get at the 180 location (even though you might think there should be a change here, this is where the physical object helps). Then as you move up the back and do the same thing on the reverse side to return the part of the loop you are holding to the top you will undergo another direction change at 270 degrees so you have 2 direction changes total in one revolution. Do it two more times and you get 6 reversals.

24. Since the bar is not cutting across field lines and has no component in a perpendicular direction to the field line there will be no induced emf. B
25. As you enter region II, flux into the page is gained. To counteract that, current flows to create a field out of the page to maintain flux. Based on RHR–solenoid, that current is CCW. When leaving the region, the flux into the page is decreasing so current flows to add to that field which gives CW. D
26. First use $\varepsilon = \Delta\Phi / t$ $\varepsilon = (BA_f - BA_i) / t$ $\varepsilon = (0 - (0.4)(0.5 \times 0.5)) / 2$ $\varepsilon = 0.05 \text{ V}$ B
 Then use $V = IR$ $0.05 \text{ V} = I(0.01)$ $I = 5 \text{ A}$
 Direction is found with Lenz law. As the field out decreases, the current flows to add outward field to maintain flux. Based on RHR–solenoid, current flows CCW.
27. Loop 2 initially has zero flux. When the circuit is turned on, current flows through loop 1 in a CW direction, and using RHR–solenoid it generates a B field down towards loop 2. As the field lines begin to enter loop 2, loop 2 has current begin to flow based on lenz law to try and maintain the initial zero flux so it makes a field upwards. Based on RHR–solenoid for loop 2, current would have to flow CCW around that loop which makes it go from X to Y. A
28. After a long time, the flux in loop 2 becomes constant and no emf is induced so no current flows. In circuit 1, the loop simply acts as a wire and the current is set by the resistance and $V = IR$. C
29. As the magnet moves down, flux increase in the down direction. Based on Lenz law, current in the loop would flow to create a field upwards to cancel the increasing downwards field. Using RHR–solenoid, the current would flow CCW. Then, when the magnet is pulled upwards, you have downward flux lines that are decreasing in magnitude so current flows to add more downward field to maintain flux. Using RHR–solenoid you now get CW. E
30. Since the wire is not cutting across the field lines, there is no force and no charge separation E
31. As the loop is pulled to the right, it loses flux lines right so current is generated by Lenz law to add more flux lines right. This newly created field to the right from the loop is in the same direction as the magnetic field so makes an attractive force pulling the magnet right also. A
32. Use a 1 second time period, the field would decrease to 2.5 T in that time. A
 Then apply $\varepsilon = \Delta\Phi / t$
 $\varepsilon = (BA_f - BA_i) / t$... $\varepsilon = A(B_f - B_i)$... $\varepsilon = (0.4)(3 - 2.5) / 1$