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Ampere's Law Inquiry Lab
AP Physics C E&M

https://www.geogebra.org/m/NC7aXeRS

Objective: I can derive the magnitude of the magnetic field for certain current-carrying wires, describe the conclusions that can be made about magnetic field at a particular point in space, and derive an expression for the magnetic field of an ideal solenoid using Ampere's Law.

We have talked about electric field, and in our effort to calculate the electric field from solid, charged objects, we came across Gauss' Law, a very useful (in some cases) description of the electric flux through some imaginary "Gaussian surface". We have talked about a "Gauss' Law for Magnetism" (it actually has no official name!), but determined that it is not useful. Therefore, we have a question about how we can easily calculate magnetic field for cases with enough symmetry…

Prelab Questions

1. What does Gauss' Law (electricity) state? Magnetic field lines always form closed loops. Why might the total magnetic flux through any 3D "Gaussian surface" be zero, in light of this fact? Think about a bar magnet and the field lines caused by it.
   Gauss law says electric flux through surface is equal to the enclosed charge divided by epsilon_0. The total magnetic flux through any 3D gaussian surface is zero, because magnetic field lines are all closed loops, meaning anything that enters the surface will also exit, making the flux be zero.
2. Predict: which quantities (geometrical and physical) might be important for calculating the magnetic field in a simple case?
   Current, type of material, length of wire.

Procedure/Results/Discussion

Open the simulation above. Answer the four questions posed in the simulation and include screenshots to support your answers. In addition, analyze your conclusions by using what you know about the magnetic field to support your answer. For question 1, try a couple different loop configurations.

Lab Questions

1. What happens when the loop encloses no current?
   There is no magnetic field for any of the wires. This makes sense as there is no current present to produce a magnetic field.

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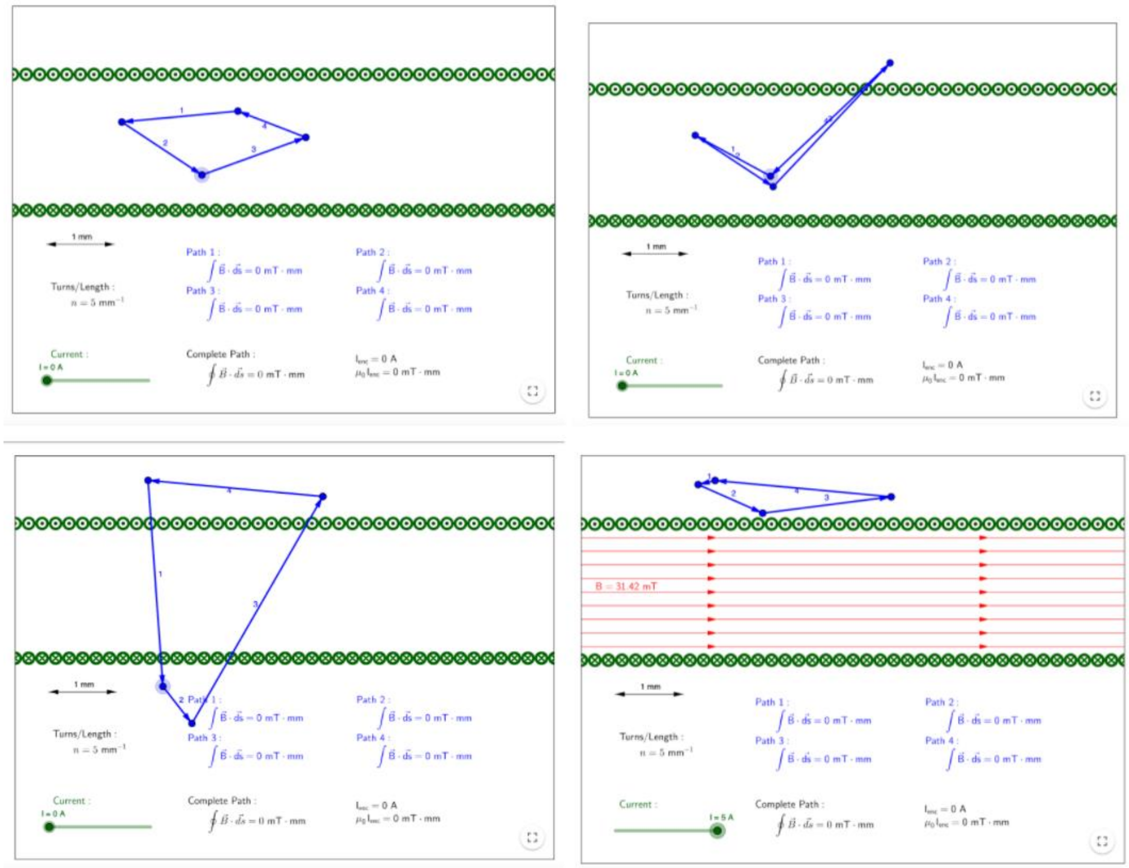

Figure 1. Cases when the loop encloses no current

2. What happens when the loop encloses both positive (out of the screen) and negative (into the screen) current?
The total enclosed current is the sum of both the negative and positive current. When we add up the paths below we see this is true.

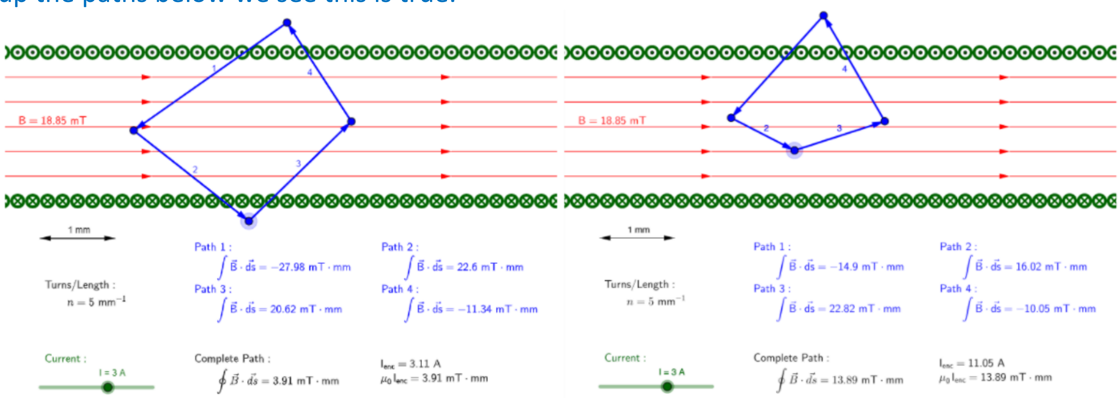

Figure 2. Cases when the loop encloses with positive and negative current

3. The four sides of the path contribute different amounts to the total integral. Under which circumstances will the contribution from a side be zero?
A side will contribute 0 to the total integral when it is perfectly normal to the magnetic field B. since magnetic field is perpendicular to current, when the path is perpendicular to current, the velocity ends up parallel to the magnetic field, which means it has no effect on it.

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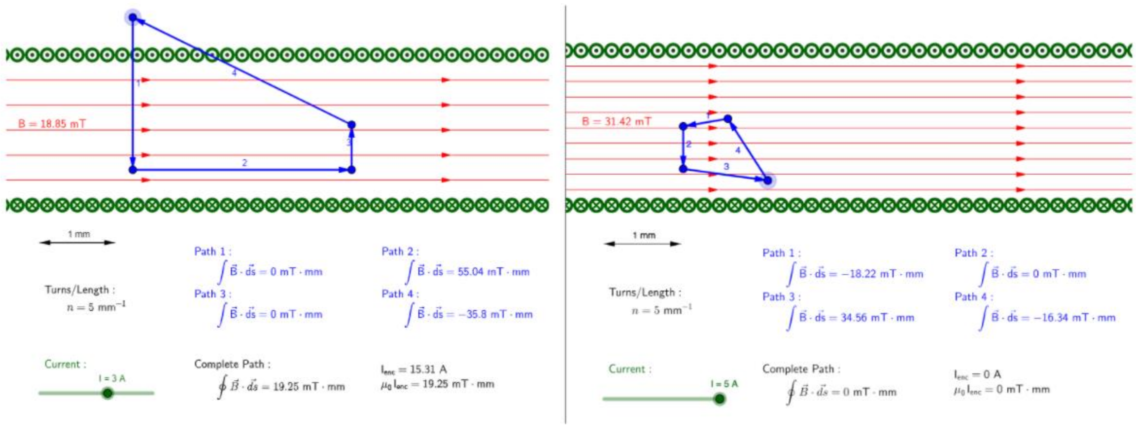

Figure 3. Cases when the contribution of at least one side is 0

4. The magnetic field within a solenoid is uniform. By playing around with this simulation, can you explain why that must be the case?
After playing around with the simulation, one can realize that the magnetic field in a solenoid does not actually depend on the position of the solenoid. In other words, where we put the loop in the solenoid doesn't actually change magnetic field strength, so it must be constant throughout.

Post-lab Questions

1. Fill out the following statements.
Claim (what is Ampere's Law? What does the B-field depend on?):

$$\oint B \cdot dl = \mu_0 I_{enc}$$

Ampere's Law is a good shortcut to calculating the B-field without resorting to complex integrals. Our claim: B field depends on length the loop and enclosed current.

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Evidence (What observations back up your claim?):
Changing current changes the B field because there is now more enclosed current. Increasing the size of the loop also increases the enclosed charge. Both changes will increase the strength of the magnetic field.

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Reasoning (Why/how do the observations back up your claim?):
The observations back up our claim because dragging the points around to change the amount of the solenoid inside the region made the B field change. Also changing the current in the wires affected the B field as well.

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2. Assume that your loop is a rectangle with Side 1 very far outside the solenoid, Side 3 inside the solenoid. Sides 2 and 4 point directly up and down. Use your conclusions above and the simulation to help you derive the expression for the magnetic field through a solenoid (Answer: $\mu_0 In$). Congratulations! This is your first time using Ampere's Law.
In this case, since line 1 is very far away and line 2 and 4 are normal to the B field, then

$$\oint B \cdot dl = BL_3 = \mu_0 I_{enc}$$

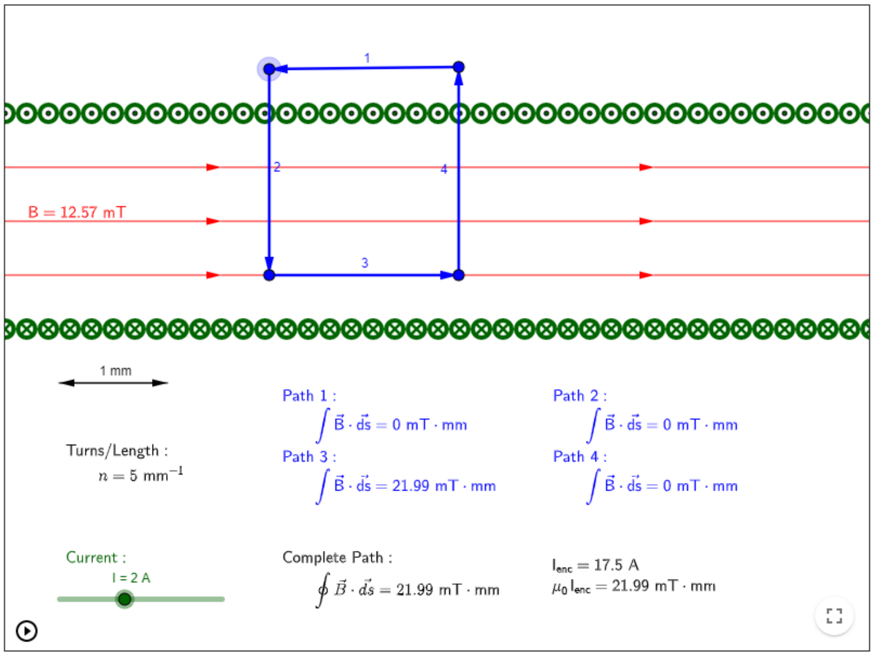

Figure 4. Rectangle showing that the integral is only dependent on path 3

3.

a. If Ampere's Law gives a value of zero, what does this mean for the magnetic field? Does it have to be 0?

It means the magnetic field contains the Amperian loop, so not many conclusions can be drawn. It does not have to be zero because the only value that is zero is the enclosed current, which doesn't draw any conclusion about the magnetic field. All the current that goes inside the loop also passes again back outside.

b. Can you explain why this might be the case given the formula for Ampere's Law (again, use the complete loop quantities for this)?

$$\oint B \cdot dl = \mu_0 I_{enc}$$

When taking the integration, in the case where B is varying between positive and negative, the integration over the loop could be zero.

i. If you are stuck on this, think about Gauss' Law: did a zero enclosed charge mean no electric field anywhere, or did it mean something else for the electric field?

Gauss law: $\int E \cdot dA = \frac{Q_{enc}}{\epsilon_0}$

Enclosed charge could be zero, but over the Gaussian surface, the E field could vary from negative and positive, which makes the integration be 0.