Ampere's Law Inquiry Lab

AP Physics C E&M

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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 states the charge enclosed by a three-dimensional surface is equal to the total electric flux through the surface multipled by a constant. If magnetic field lines always form closed loops, then any magnetic flux/field lines that enter a 3D surface would also exit the surface, so that the net flux would be 0.

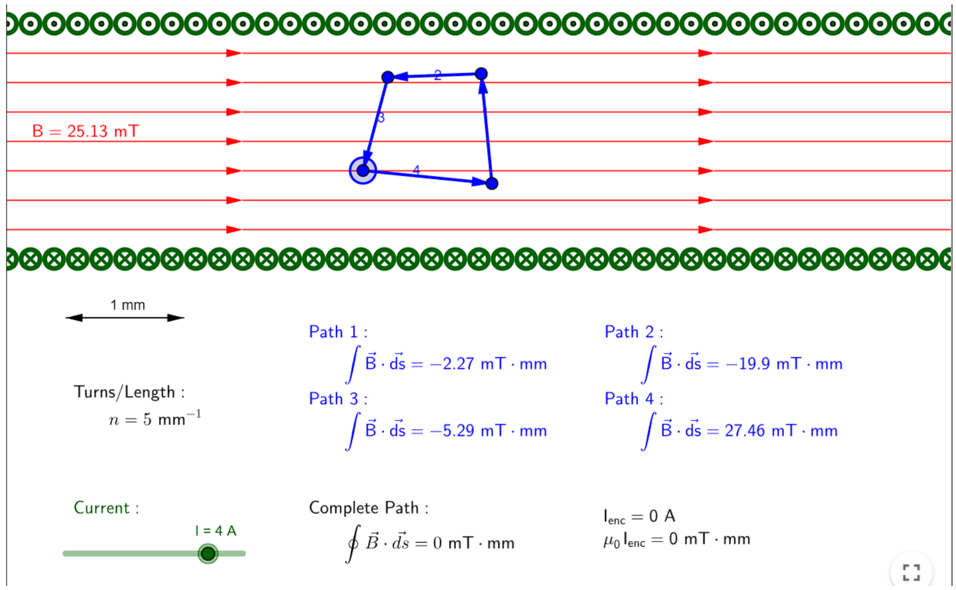
2. Predict: which quantities (geometrical and physical) might be important for calculating the magnetic field in a simple case?

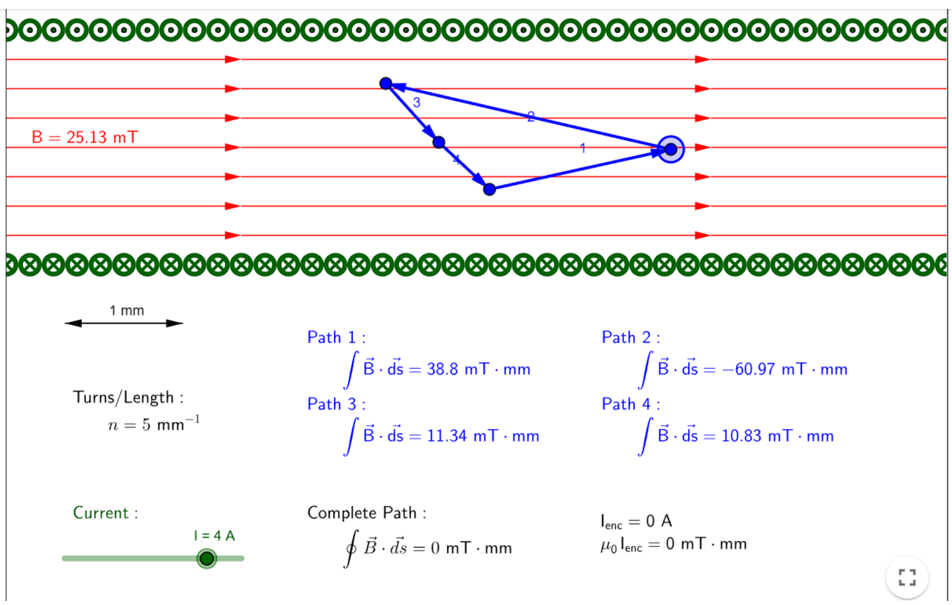
Permittivity of some sort, the perimeter/length of the objects that the magnetic field goes through, current?

Procedure/Results/Discussion

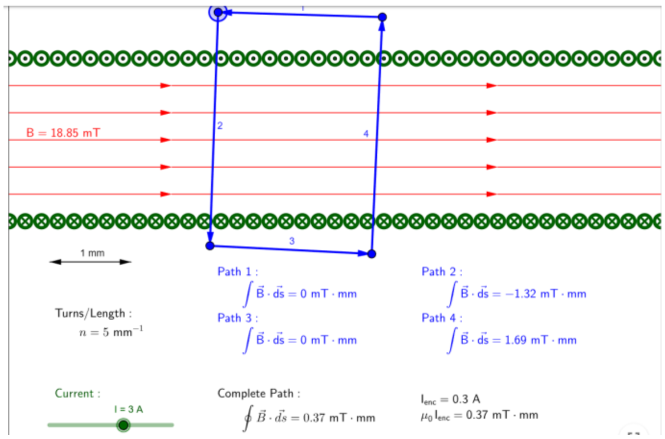
Open the simulation above. Answer the four questions posed in the simulation and include screenshots to support your answers. In addition, analyze your conclusions by using what you know about the magnetic field to support your answer. For question 1, try a couple different loop configurations.

1] All paths experience a net non-zero magnetic flux. The total magnetic flux through the loop is 0. This makes sense: any magnetic field line enter the loop appears to also exit it through another path.





2] The parts of the wire not enclosed by the solenoid experience no magnetic flux. Interestingly enough, the net magnetic flux through the loop changes to a non-zero value. Moving charges cause magnetic fields, and currents are moving charges, so enclosing a current would entail enclosing a magnetic field leading to non-zero flux.



3] When the path is outside the solenoid. (See screenshot for 2). The magnetic field is only present in the solenoid, so no field lines would go through paths that were completely outside the solenoid.
4] The solenoid is approximated as a bunch of identical loops of current stacked on top of each other. Each loop has identical current, so they would produce identical magnetic fields, so stacking them on top of each other would produce a uniform magnetic field through the entire solenoid. Because the spacing in between loops is small compared to the length of the loop. (this is an analytic justification, no screenshots/empirical evidence needed).

Post-lab Questions

1. Fill out the following statements.
   Claim (what is Ampere's Law? What does the B-field depend on?):
   The magnetic flux through a 2-D surface is dependent on the current enclosed by the surface and the perimeter of the surface. The B-field depends on the strength of the current.
   Evidence (What observations back up your claim?):
   The magnetic flux through the loop is only a non-zero value when the loop enclosed a current. As the current was increased, the magnetic flux also increased. Paths that were longer tended to have a higher magnetic flux than paths that were shorter.
   Reasoning (Why/how do the observations back up your claim?):
   The magnetic flux only being a non-zero value on the loop enclosed a current implies that without a current, there is no magnetic flux, suggesting the opposite conclusion: if there is a current, then there is magnetic flux. Magnetic flux increased as current increased, so it can be infered that magnetic flux would depend on current. As magnetic flux is a measure of the strength of the magnetic field through a line/surface, it would also entail that the B-field depends on the strengt hof the enclosed current.
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: $\frac{\mu_0 I}{2r}$.

Mu_0 * I / 2r
 Congratulations! This is your first time using Ampere's Law.

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?

No, it just means the path integral around the wire has the same magnetic fields entering/exiting.

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)?
    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?

It means that there are no currents exiting/entering that don't exit/enter the region – this means there are no currents enclosed within the Amperian Loop.