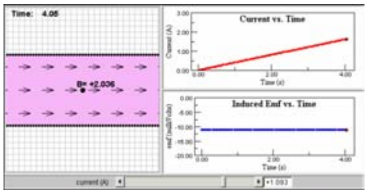
Worksheet for Exploration 29.5: Self-inductance



This animation shows a cross section of a solenoid (think of a long tube cut length wise down the cylinder and then looking at the edge) so that the black dots represent the current carrying wires coming into and out of the screen. The arrows show the direction and magnitude of the magnetic field. You can drag the black dot around to measure the field in different spots **(position is given in centimeters, the magnetic field strength is given in millitesla, 10^{-3} T, and current is given in amperes)**. You can either change field by varying the current in the wires with the slider or you can choose to change the current linearly as a function of time.

Faraday's law tells us that when a loop is in a changing magnetic field, an induced emf in the loop will result. But, what if the loop itself has a changing current? With a changing current, the loop has a changing magnetic field. Wouldn't it make sense, then, for there to be an induced emf and an induced current to oppose the changing flux? The answer is that there are: if the current is changed in a current loop, there is a self-induced back emf. The measure of the back emf produced when a current is changed in a loop is called its self inductance, or simply inductance, represented by L and measured in Henries, H (1 H = 1 T m^2/A). From Faraday's law, emf = - $d\Phi/dt$, the self-inductance is the back emf = - L (dI/dt).

This is a lot like for a capacitor, it took some "effort" or pushing of charge to charge it up. Here it takes some "effort" to establish a current. The inductance describes how difficult it is to establish the current (sounds like we do some work…..we do). The back emf is in response to the magnetic field produced by the current being pushed through. So in our expression from Faradays law, the flux depends on magnetic field, which in turn depends on current and geometry. The geometry does not change. So the change in flux results from changing the current. All the rest of the stuff that determines the emf (geometry dependent stuff) is lumped together and called L (the self inductance). Recall that this is like capacitance, which also could be determined only from geometry, but could alternately be measured from the definition of capacitance. Faradays law for this case tells us how to measure L without messing around in the geometry. But just as for capacitors, if there is a simple geometry we can figure out how to predict what L should be for a given special case.

Run the change field by varying the current in the wires with the slider. Instead of considering a loop, we will look at a solenoid (it is easier to calculate the magnetic field inside a long solenoid).

a. For the solenoid above, adjust the current with the slider and determine how the magnetic field varies with current.
   i. You should make several measurements of B vs. I.

b. For this solenoid (given the value of the magnetic field at the current chosen), how many loops per meter are there?

n=________

Run change the current linearly as a function of time.

c. What is the back emf?
   i. Note it is the back emf (or equivalently the induced emf) that is measured. The situation here is that an external emf source (battery) is applied to the solenoid directly. According to Kirchhoffs loop rule (conservation of energy) the sum of emf's and drops is zero. If resistances are small (battery and solenoid wire) then the back emf is equal and opposite to the applied or external emf. Even if the resistance is large, it can be measured and accounted for, thus allowing for a measure of the back emf.

emf_{back}=________

d. Using the equation for the back emf, what is the inductance, L?

$L_{measured}$=_________

e. Using Faraday's law and the equation for the back emf, show that L = (Φ/ I) N for an inductor with N loops.

f. Therefore, show that the inductance, L, of a solenoid is $\mu_0 N^2 A/(\text{length})$ where N is the number of loops, A is the cross-sectional area, and length is the length of the solenoid (so that N/length is the number of loops per meter).

g. If this solenoid is 2 m long, calculate the inductance and compare it to your answer in part (d) above.

$L_{predicted}$=________