Today’s Concepts:
A) Induction
B) RL Circuits
Where we are.....

Just finished introducing magnetism

Will now apply magnetism to AC circuits
Doing physics during vacation is the best
This one was rough, could we do a lot of examples in class?
Which direction does the current flow after an inductor becomes
the only thing powering a circuit.
will need to study the concepts behind the graphs; how current
and voltage behaves before and after switches are changed.
Dr. Carter, I may have found a loophole. What if there is a loop
within a loop? Can we call it loopception? Something is amiss
here..
Comparing the RL circuits confused me. However, I'm happy to be
done with the magnetism unit.
The whole idea of inductance is still a bit confusing. Current in a
loop creates magnetic flux which creates an oppositely directed
directed current?
Remember Example 17.6 (solenoid)??

1. Changing current in outer set of loops
2. Caused changing magnetic field in inner loops
3. Induced changing current in inner loops.

What if you only had the outer set of loops?

Would changing current in that induce anything?
Self Inductance

Define: \( L \equiv \frac{\Phi_B}{I} \)

\[ \mathcal{E} = -\frac{d\Phi_B}{dt} = -\frac{d(LL)}{dt} = -L \frac{dI}{dt} \]

Voltage drop in a coil

...caused by changes in the current in that same coil

Depends only on the geometry of the coils
What is the inductance of a long coil of wire (a solenoid)?
Two solenoids are made with the same cross sectional area and total number of turns. Inductor \( B \) is twice as long as inductor \( A \)

\[
L_B = \mu_0 n^2 \pi r^2 z
\]

Compare the inductance of the two solenoids

A) \( L_A = 4 \, L_B \)
B) \( L_A = 2 \, L_B \)
C) \( L_A = L_B \)
D) \( L_A = (1/2) \, L_B \)
E) \( L_A = (1/4) \, L_B \)
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E) \( L_A = (1/4) L_B \)

B) The length \( z \) doubles, but the turns per unit length halves and when it's squared it will be one fourth. The end result is that \( B \) becomes half of \( A \).

C) The only difference between the two is their length, \( z \), and by increasing the length the number of turns per unit length, \( n \), is cut in half so they cancel out

D) Everything else is the same except the length which is linearly proportional to the inductance of the solenoid.
Two solenoids are made with the same cross sectional area and total number of turns. Inductor B is twice as long as inductor A.

\[ L_B = \mu_0 n^2 \pi r^2 z \]

Compare the inductance of the two solenoids

A) \( L_A = 4 L_B \)
B) \( L_A = 2 L_B \)
C) \( L_A = L_B \)
D) \( L_A = (1/2) L_B \)
E) \( L_A = (1/4) L_B \)

B) \( z \) is twice the amount in b

B) If everything else is the same except length, then \( 2B = A \).

C) current per unit length is still constant
Increasing current

\[ L_B = \mu_0 n^2 \pi r^2 z \]
\[ = \mu_0 n^2 \times \text{volume} \]

\[ \varepsilon = -L \frac{dI}{dt} \]

\[ \Delta V < 0 \]
\[ V_A > V_B \]

Acts like a resistor
What the minus sign means…..

\[ \mathcal{E} = -L \frac{dI}{dt} \]

\( \Delta V \) > 0

\( V_A < V_B \)

Acts like a battery

However you try to change the current through an inductor, the inductor resists that change.
emf induced across $L$ tries to keep $I$ constant.

$$\mathcal{E}_L = -L \frac{dI}{dt}$$

Inductors prevent discontinuous current changes!

It's like inertia!

Units of inductance are Henrys (H) [$\text{Tm}^2/\text{A}$]
**Time Constant**

\[ I = \frac{V}{R} \left( 1 - e^{-t/\tau} \right) \]

\[ \tau = \frac{L}{R} \]
Example 18.2 (Current in Solenoid)

A solenoid has 6500 loops in a length of 10cm and a radius of 6cm. It is attached to a 120Ω resistor and a 12V battery.

What is the current through the resistor 0.01sec after the switch is closed?

What is the current through the resistor 2.0 sec after the switch is closed?

Would the current have been at 0.01sec if the inductor had an internal resistance of 20Ω?

\[ I = \frac{V}{R} \left(1 - e^{-t/\tau}\right) \]

\[ \tau = \frac{L}{R} \]
How to think about RL circuits:

When no current is flowing initially:

At $t = 0$:
- $I = 0$
- $V_L = V_{BATT}$
- $V_R = 0$
  ($L$ is like a giant resistor)

At $t \gg L/R$:
- $V_L = 0$
- $V_R = V_{BATT}$
- $I = V_{BATT}/R$
  ($L$ is like a short circuit)

$\tau = \frac{L}{R}$

Electricity & Magnetism  Lecture 18, Slide 15
In the circuit, the switch has been open for a long time, and the current is zero everywhere.

At time $t = 0$ the switch is closed.

What is the current $I$ through the vertical resistor immediately after the switch is closed? (+ is in the direction of the arrow)

A) $I = V/R$
B) $I = V/2R$
C) $I = 0$
D) $I = -V/2R$
E) $I = -V/R$
What is the current $I$ through the vertical resistor immediately after the switch is closed?

(+ is in the direction of the arrow)

A) $I = \frac{V}{R}$  
B) $I = \frac{V}{2R}$  
C) $I = 0$  
D) $I = -\frac{V}{2R}$  
E) $I = -\frac{V}{R}$

A) The resistance is parallel with the inductor, so it shouldn't be affected.

B) The inductor resists a change in current. So at $t=0$, there should be no current going through the inductor and all the current should be going through the 2 resistors. $I$ would then be equal to $I = \frac{V}{2R}$.

C) Since there is no resistance through $L$, no current will travel through the vertical resistor.
What is the current $I$ through the vertical resistor immediately after the switch is closed? (+ is in the direction of the arrow)

A) $I = \frac{V}{R}$
B) $I = \frac{V}{2R}$
C) $I = 0$
D) $I = -\frac{V}{2R}$
E) $I = -\frac{V}{R}$

**C) there is no current at $t=0$**

I mean a little “$dt$” of time after $t=0$
What is the current $I$ through the vertical resistor after the switch has been closed for a long time?

(+ is in the direction of the arrow)

A) $I = \frac{V}{R}$
B) $I = \frac{V}{2R}$
C) $I = 0$
D) $I = -\frac{V}{2R}$
E) $I = -\frac{V}{R}$

After a long time in any static circuit: $V_L = 0$
After a long time, the switch is opened, abruptly disconnecting the battery from the circuit.

What is the current $I$ through the vertical resistor immediately after the switch is opened?

($+ \text{ is in the direction of the arrow}$)

A) $I = \frac{V}{R}$
B) $I = \frac{V}{2R}$
C) $I = 0$
D) $I = -\frac{V}{2R}$
E) $I = -\frac{V}{R}$
What is the current $I$ through the vertical resistor immediately after the switch is opened? (+ is in the direction of the arrow)

A) $I = V/R$
B) $I = V/2R$
C) $I = 0$
D) $I = -V/2R$
E) $I = -V/R$

A) The voltage across the solenoid is initially $V$, so the resistor must have an equal voltage drop $V$ and current will be $V/R$.
C) After a long time, the current through $L$ will be zero. After a long time in a static circuit, the current will go to zero because the $V_l$ goes to zero.
E) I think it will go the opposite way because that was the direction that the current was flowing into the inductor right before the switch was opened.
When steady current is flowing initially:

At $t = 0$:

$I = \frac{V_{BATT}}{R}$

$V_R = IR$

$V_L = V_R$

At $t >> L/R$:

$I = 0$

$V_L = 0$

$V_R = 0$
Why is there Exponential Behavior?

\[ V = L \frac{dI}{dt} \]

\[ V = IR \]

\[ L \frac{dI}{dt} + IR = 0 \]

\[ I(t) = I_0 e^{-tR/L} = I_0 e^{-t/\tau} \]

where \[ \tau = \frac{L}{R} \]
Quick comment...

Lecture:

$$I(t) = \frac{V_b}{R} e^{-\frac{2Rt}{L}}$$

$$|V_L(t)| = -2V_b e^{-\frac{2Rt}{L}}$$

Prelecture:

Did we mess up?

No: The resistance is simply twice as big in one case.
“Can you have capacitors and inductors in the same circuit? Why inductors are important as opposed to capacitors. Why use one instead of the other?”

Inside your i-clicker
After switch moved, which case has larger time constant?

A) Case 1  
B) Case 2  
C) The same

\[ \tau_1 = \frac{L}{2R} \quad \tau_2 = \frac{L}{3R} \]
After long time at 0, moved to 1

Before switch moved:
\[ I = \frac{V}{R} \]

Immediately after switch moved, in which case is the voltage across the inductor larger?

A) Case 1
B) Case 2
C) The same

After switch moved:
\[ V_{L1} = \frac{V}{R} 2R \]
\[ V_{L2} = \frac{V}{R} 3R \]

CheckPoint 3B

Compare RL Circuits: Question 3 (N = 38)
CheckPoint 3C

After long time at 0, moved to 1

After switch moved for finite time, in which case is the current through the inductor larger?

A) Case 1
B) Case 2
C) The same

Immediately after: \( I_1 = I_2 \)

After awhile
\[
I_1 = I e^{-t/\tau_1},
\]
\[
I_2 = I e^{-t/\tau_2},
\]
\( \tau_1 > \tau_2 \)
Energy Stored

\[ Power = \frac{d(energy)}{dt} = VI \]

\[ E_{\text{stored}} = \frac{1}{2} LI^2 \]

For inductor

\[ E_{\text{stored}} = \frac{1}{2} \frac{Q^2}{C} \]

Recall for capacitor

Energy stored in the magnetic field

Energy stored in the electric field
A solenoid has 6500 loops in a length of 10cm and a radius of 6cm. It is attached to a 120Ω resistor and a 12V battery.

What is the energy stored in the inductor 0.01sec after the switch is closed?

What is the energy stored in the inductor 2.0 sec after the switch is closed?

\[ E_{\text{stored}} = \frac{1}{2} LI^2 \]
The switch has been in the open position for a long time in the circuit drawn above. What is the total current out of the battery, $I_{\text{tot}}$, immediately after the switch is closed? (The inductor is “ideal”.)

A. 0A  
B. 4A  
C. 6A  
D. 12A  
E. -4A
The switch has been in the open position for a long time in the circuit drawn above. What is the current across the resistor, $I_1$, immediately after the switch is closed? (The inductor is “ideal”.)

A. 0A  
B. 4A  
C. 6A  
D. 12A  
E. -4A
The switch has been in the open position for a long time in the circuit drawn above. What is the current across the inductor, $I_2$, immediately after the switch is closed? (The inductor is “ideal”.)

A. 0A  
B. 4A  
C. 6A  
D. 12A  
E. -4A
The switch has been in the open position for a long time in the circuit drawn above. What is the voltage drop across the inductor immediately after the switch is closed? (The inductor is “ideal”.)

A. 0V  
B. 80V  
C. 90V  
D. 120V  
E. 240V
The switch has been in the *closed* position for a long time in the circuit drawn above. What is the current across the inductor, $I_2$? (The inductor is “ideal”.)

A. 0A  
B. 4A  
C. 6A  
D. 12A  
E. -4A
The switch has been in the *closed* position for a long time in the circuit drawn above. What is the voltage difference across the inductor immediately after the switch is opened? (The inductor is “ideal”.)

A. 0V  
B. 80V  
C. 90V  
D. 120V  
E. 240V
The switch has been in the **closed** position for a long time in the circuit drawn above. What is the current across the inductor, $I_2$ immediately after the switch is open? (The inductor is “ideal”.)

A. 0A  
B. 4A  
C. 6A  
D. 12A  
E. -4A
The switch has been in the **closed** position for a long time in the circuit drawn above. What is the rate change for the current through the inductor immediately after the switch is opened? (The inductor is “ideal”.)

A. 6A/sec  
B. 80A/sec  
C. 90A/sec  
D. 120A/sec  
E. 240A/sec
The switch has been in the open position for a long time in the circuit drawn above. Which point has a higher electrical potential immediately after the switch is closed? (The inductor is “ideal”.)

A. \( V_A > V_B \)
B. \( V_A = V_B \)
C. \( V_A < V_B \)
The switch has been in the closed position for a long time in the circuit drawn above. Which point has a higher electrical potential? (The inductor is “ideal”.)

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