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## Batteries, DC Circuits, DC Generators, & DC Motors

**Course Number:** EE-02-308

**PDH:** 6

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## Module 3: DC Circuits

### Learning Objectives

By the end of this section, you will be able to:

- **Describe** the interaction between current flow, magnetic fields, and stored energy in reactive components.
- **Calculate** total inductance and capacitance for series and parallel circuit configurations.
- **Evaluate** the time constants for RL and RC circuits to determine transient response behavior.

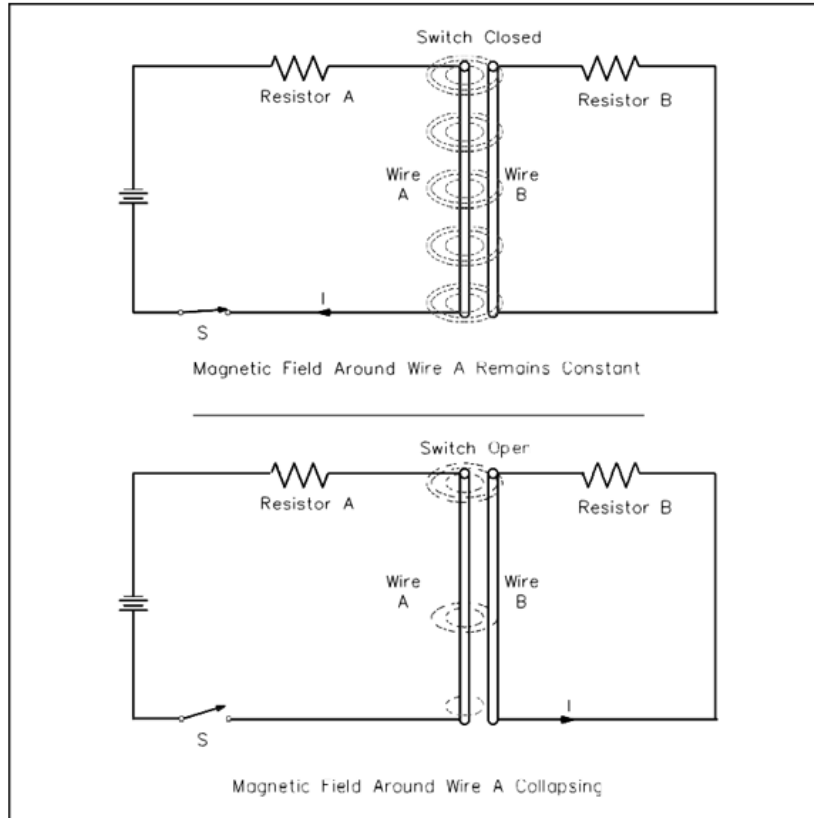
*Executive Summary:* Module 3 details the operational characteristics of inductance and capacitance within DC circuits. These components are defined by their ability to store energy—inductance via magnetic fields and capacitance via electric fields—and their inherent opposition to changes in current and voltage, respectively. Understanding these principles, including the calculation of time constants and equivalent values in various configurations, is essential for predicting the behavior of DC systems during switching and transient states.

### Inductors

Experiments investigating the unique behavioral characteristics of inductance led to the invention of the transformer. An **inductor** is a circuit element that will store electrical energy in the form of a **magnetic field**. It is usually a coil of wire wrapped around a core of permeable material. The magnetic field is generated when current is flowing through the wire.

### Induced EMF

If two circuits are arranged as in Figure 1, a magnetic field is generated around Wire A, but there is no electromotive force (EMF) induced into Wire B because there is no relative motion between the magnetic field and Wire B. If we now open the switch, the current stops flowing in Wire A, and the magnetic field collapses. As the field collapses, it moves relative to Wire B. When this occurs, an EMF is induced in Wire B.



**Figure 1: Induced EMF**

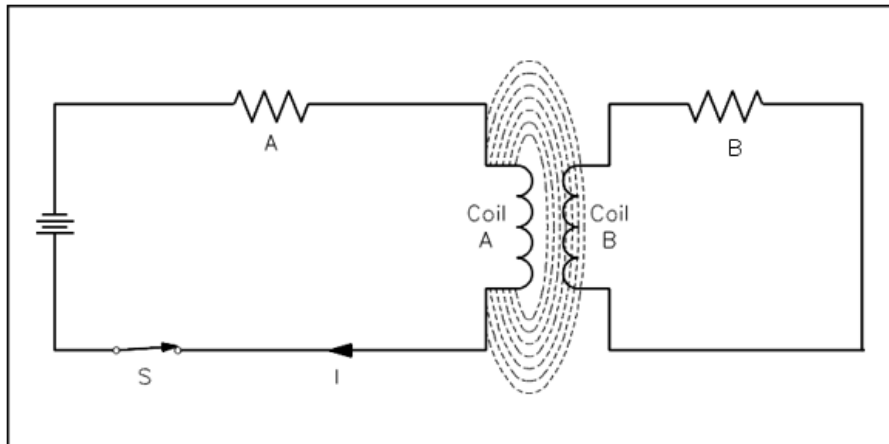
This is an example of **Faraday's Law**, which states that a voltage is induced in a conductor when that conductor is moved through a magnetic field, or when the magnetic field moves past the conductor.

When the EMF is induced in Wire B, a current will flow whose magnetic field opposes the change in the magnetic field that produced it. For this reason, an induced EMF is sometimes called **counter EMF** or **CEMF**. This is an example of **Lenz's Law**, which states that the induced EMF opposes the EMF that caused it.

The three requirements for inducing an EMF are:

1. A **conductor**
2. A **magnetic field**
3. **Relative motion** between the two

The faster the conductor moves, or the faster the magnetic field collapses or expands, the greater the induced EMF. The induction can also be increased by **coiling the wire** in either Circuit A or Circuit B, or both, as shown in Figure 2.

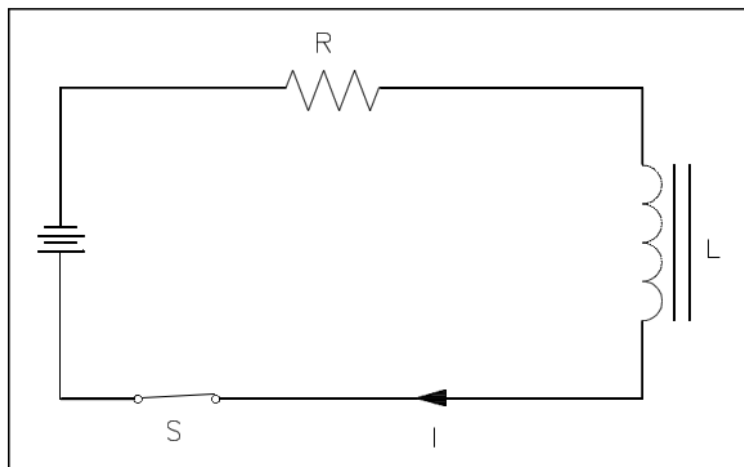


**Figure 2:** Induced EMF in Coils

### Self-Induced EMF

Self-induced EMF is another phenomenon of induction. The circuit shown in Figure 3 contains a coil of wire called an inductor ( $L$ ). As current flows through the circuit, a large magnetic field is set up around the coil. Since the current is not changing, there is no EMF produced. If we open the switch, the field around the inductor collapses. This collapsing magnetic field produces a voltage in the coil. This is called **self-induced EMF**.

The polarity of self-induced EMF is governed by Lenz's Law. The polarity is in the direction that opposes the change in the magnetic field that induced the EMF. The result is that the current caused by the induced EMF tends to maintain the same current that existed in the circuit before the switch was opened. It is commonly said that an inductor tends to **oppose a change in current flow**.



**Figure 3:** Self-Induced EMF

## Inductance Calculations

The induced EMF, or counter EMF, is proportional to the time rate of change of the current. The proportionality constant is called the **inductance (L)**. Inductance is a measure of an inductor's ability to induce CEMF, measured in **henries (H)**.

**Equation 3-1:**

$$CEMF = -L \frac{\Delta I}{\Delta t}$$

**Where:**

- **CEMF** = induced voltage (volts)
- **L** = inductance (henries)
- **$\Delta I / \Delta t$**  = time rate of change of current (amp/sec)

**⚠ Safety Constraint:** The minus sign indicates that the CEMF is opposite in polarity to the applied voltage.

## Inductors in Series and Parallel

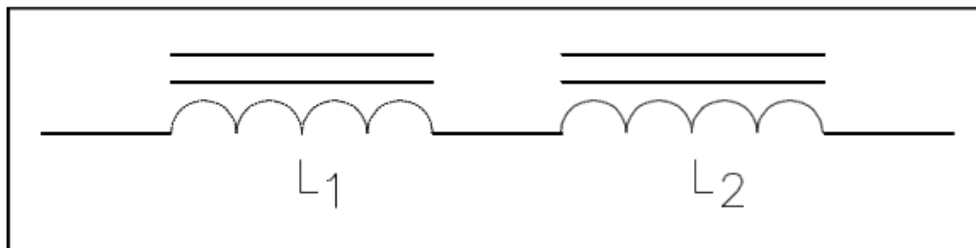
Inductors in series are combined like resistors in series.

**Equation 3-2:**

$$L_{eq} = L_1 + L_2 + \dots + L_n$$

**Where:**

- **$L_{eq}$**  = Equivalent inductance (henries)
- **$L_1, L_2, L_n$**  = Individual inductances (henries)



**Figure 4:** Inductors in Series

Inductors in parallel are combined like resistors in parallel.

**Equation 3-3:**

$$\frac{1}{L_{eq}} = \frac{1}{L_1} + \frac{1}{L_2} + \dots + \frac{1}{L_N}$$

**Where:**

- **Leq** = Equivalent inductance (henries)
- **L1, L2, LN** = Individual inductances (henries)

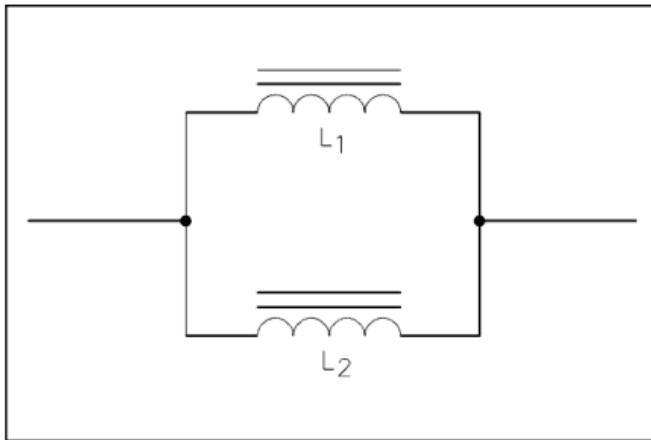
When only two inductors are in parallel, as shown in Figure 5, the calculation may be simplified.

**Equation 3-4:**

$$L_{eq} = \frac{L_1 L_2}{L_1 + L_2}$$

**Where:**

- **Leq** = Equivalent inductance (henries)
- **L1** = Inductance of first parallel inductor (henries)
- **L2** = Inductance of second parallel inductor (henries)



**Figure 5:** Inductors in Parallel

## Inductive Time Constant

Circuits containing inductors exhibit exponential increase and decay of current and voltage.



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