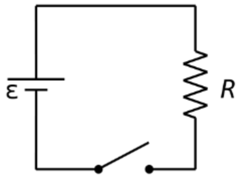
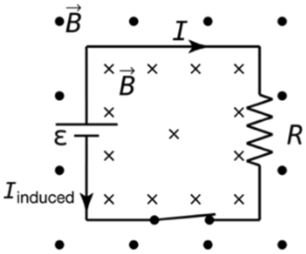
Flipping Physics Lecture Notes:
Inductance
http://www.flippingphysics.com/inductance.html



Let's look at a basic circuit. Before time t = 0, the switch in the circuit is open and zero current flows through the open loop. At time t = 0, the switch is closed and remains closed. From this perspective, a clockwise current, I, is now in the circuit. Up to this point we have assumed the current appears instantaneously in the circuit. You should realize that, in the real world, nothing changes instantaneously. So, let's look at what really happens when the switch closes.



According to the alternate right-hand rule, the clockwise current, I, in the circuit causes a magnetic field which is out of the page outside the loop and a magnetic field which is into the page inside the loop. In other words, this circuit is a loop which initially, before time t = 0, has zero magnetic flux in it and, as soon as the switch is closed, the loop has magnetic flux in it. We know, according to Faraday's law, that a changing magnetic flux induces an emf and can induce a current. We can use Lenz' law to determine the direction the induced current would be in the loop:

$$\varepsilon_{induced} = -N\frac{d\Phi_B}{dt}$$

- Initially, there is zero magnetic flux.
- Finally, there is a B field which is into the page inside the loop.
    - Note: Only the magnetic field inside the loop causes a magnetic flux inside the loop.
- Therefore, the magnetic flux is increasing.
- Lenz's law states that an induced magnetic field is created to counteract the change in magnetic flux.
- Therefore, the induced magnetic field is out of the page.
- According to the alternate right-hand rule, an induced current would be counterclockwise in the loop from this perspective.
- This means the current in the circuit does not instantly change from 0 to I. The current in the circuit takes time to transition from 0 to I, because, the circuit itself opposes the change in current.
- This opposition of a circuit to a change in current in that same circuit is called *self-inductance*.
- In general, opposition to a change in current in a conductor is called *inductance*.

To get to the equation for inductance, we need to return to the simple circuit example and the basic concept of Faraday's law.

- Induced emf is proportional to change in magnetic flux with respect to time.

$$\varepsilon_{induced} \propto \frac{d\Phi_B}{dt}$$

- The magnitude of magnetic flux equals the magnetic field times the area of the loop times the cosine of the angle between the direction of the magnetic field and the direction of the area.

$$\Phi_B = BA\cos\theta$$

- Assuming the area and angle are not changing with respect to time, the induced emf is proportional to the change in the magnetic field with respect to time.

$$\varepsilon_{induced} \propto \frac{dB}{dt}$$

- An example of a magnetic field around a current carrying wire is the one which surrounds an infinitely long current carrying wire which we have derived previously.
    - "a" is the straight-line distance perpendicular out from the wire to the location of the B field.

$$B = \frac{\mu_0 I}{2\pi a}$$

- This means the induced emf in a conductor is proportional to change in current in the conductor with respect to time.

$$\varepsilon_{induced} \propto \frac{dI}{dt}$$

An inductor is a circuit element with a known inductance.
The equation for the inductance of an inductor is:

$$\varepsilon_L = -L\frac{dI}{dt}$$

- "L" is the inductance of the inductor.
- The simplest version of an inductor is a small, ideal solenoid. Because a solenoid is in the shape of a coil, the symbol for an inductor looks like the coils of a miniature solenoid.
- The units for inductance are henrys, H.
    - $\varepsilon_L = -L\frac{dI}{dt} \Rightarrow L = -\frac{\varepsilon_L}{dI/dt} \Rightarrow \frac{V}{A/s} \Rightarrow \text{henry}, H = \frac{V\cdot s}{A}$