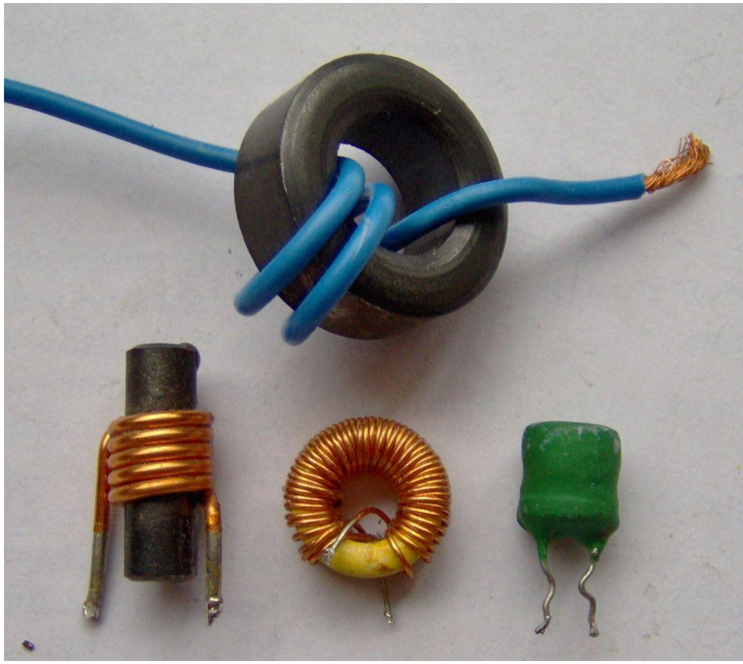
Inductors

An **inductor**, is an electrical component which resists changes in electric current passing through it.

It consists of a conductor such as a wire, usually wound into a coil.

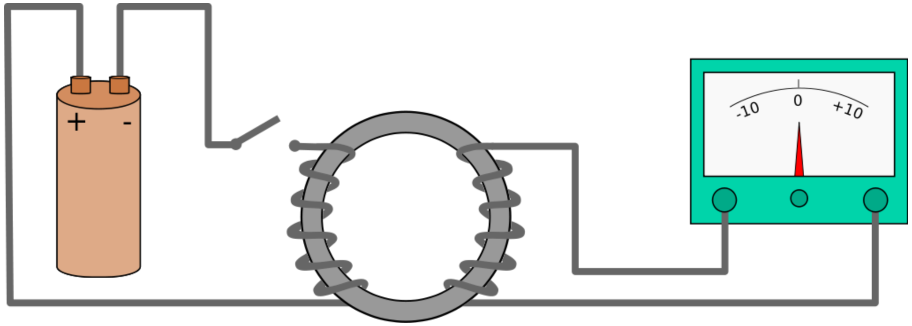
When a current flows through it, **energy** is stored temporarily in a **magnetic field** in the coil.

When the current flowing through an inductor changes, the time-varying magnetic field induces a voltage in the conductor, according to Faraday's law of electromagnetic induction, which opposes the change in current that created it.



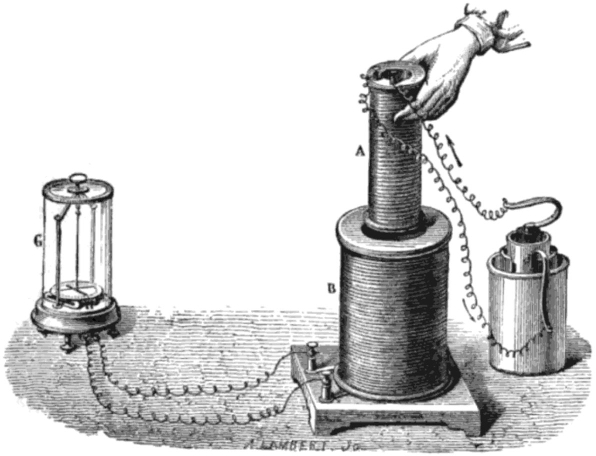
Most references in this presentation are summarized from Wikipedia entry *Inductor*

Michael Faraday (UK)
1791-1867
*Discovered electromagnetic induction
*Invented precursor devices which became electric motors (and generators)
*Major contributions to fields of electromagnetism and electrochemistry

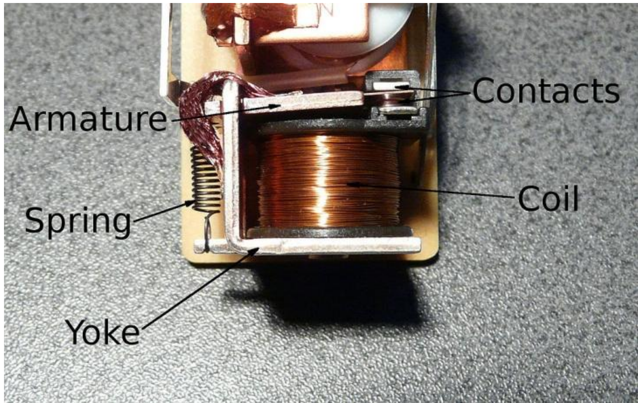


Joseph Henry (US)
1797-1878

*Discovered self inductance
*Invented the electromagnet
*Work on electromagnetic relay basis of the electrical telegraph system



A diagram of Faraday's iron ring-coil apparatus



Mathematical definition of Inductance *L*

$$L = \frac{d\Phi}{dI}$$

magnetic flux linked by coil ($d\Phi$)

current (dI)

voltage induced →

$$V = -\frac{d\Phi}{dt}$$

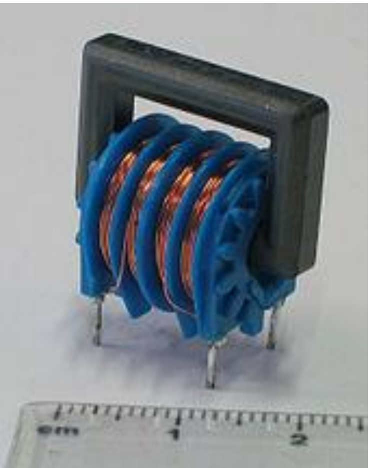
Faraday's (&Lenz's) law of electromagnetic induction

$$V = -\frac{d\Phi}{dI} \times \frac{dI}{dt}$$

chain rule

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

Potential difference across an inductor



A ferrite core inductor with two 47 mH windings.

An inductor with an inductance of 1 Henry produces an EMF of 1 volt when the current through the inductor changes at the rate of 1 ampere per second.

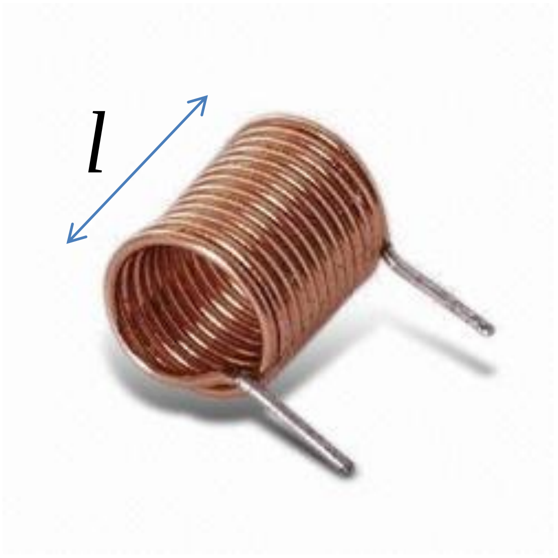
The polarity (direction) of the induced voltage is given by Lenz's law, which states that it will be such as to oppose the change in current.

For example, if the current through an inductor is increasing, the induced voltage will be positive at the terminal through which the current enters and negative at the terminal through which it leaves.

Calculating the Inductance of a coil

$$\mu_0 = 4\pi \times 10^{-7}\ \mathrm{Hm^{-1}}$$

$$L = \mu\mu_0 \frac{KN^2 A}{l}$$



μ_0 Permeability of free space
μ Relative permeability of core material within coil
K Nagaoka coefficient
N Number of coil turns
A Cross sectional area of coil
l Length of coil
L Inductance (in Henries (H) if all other units are SI)

If radius of a (circular) coil is *r*

$$K \approx 1$$

$$l \gg r$$

Material	Relative permeability μ
Air, wood, water, copper	1
Nickel, carbon steel	100
Ferrite (Fe_2O_3, usually combined with Nickel, Zinc...)	> 640
Pure iron	> 5,000

Toroidal inductor

diameter of coil windings

number of coils

$$L \approx 0.007975 \frac{d^2 N^2}{D}$$

diameter of torus

Only valid when

$$d < 0.1D$$

Toroidal inductor in the power supply of a wireless router

Energy stored in the magnetic field of an inductor

The instantaneous power which must be supplied to manifest current I in an inductor is

$$P = IV$$

Where V is the voltage induced by the inductor

$$V = L\frac{dI}{dt}$$

If it takes time *t* to manifest current *I*, the total energy stored in the inductor is

$$E = \int_0^t P dt$$

$$E = \int_0^t LI\frac{dI}{dt}dt = L\int_0^I IdI$$

$$E = \tfrac{1}{2}LI^2$$

$$E = \tfrac{1}{2}LI^2$$

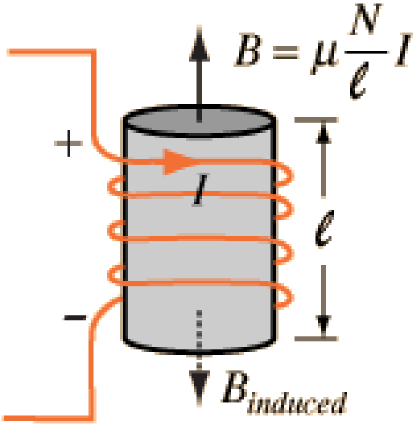
By considering the magnetic field strength *B* in a **solenoid** of *N* turns length *l* and cross section *A*, this energy expression allows us to derive a more general result for the **energy per unit volume stored in a magnetic field** *u*

$$B = \mu\mu_0\frac{NI}{l}$$ magnetic field of a solenoid

$$L = \frac{\mu\mu_0 N^2 A}{l}$$ coil inductance

$$u = \frac{\frac{1}{2}LI^2}{Al}$$ energy per unit volume

$$u = \tfrac{1}{2}\frac{B^2}{\mu\mu_0}$$

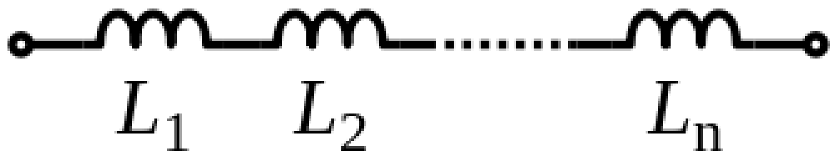


ref

Combining inductors in series

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

So *L* is proportional to potential difference *V*

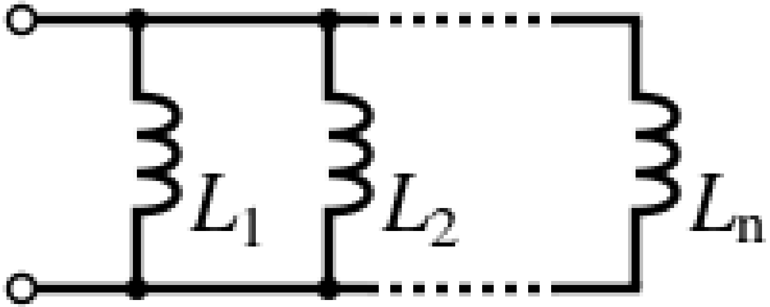


The current through inductors in series stays the same, but the voltage across each inductor can be different. The sum of the potential differences (voltage) is equal to the total voltage.

$$L = L_1 + L_2 + \ldots + L_n$$

True only when there is no mutual coupling of magnetic fields between individual inductors

Combining inductors in parallel



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

So *L* is proportional to potential difference *V*

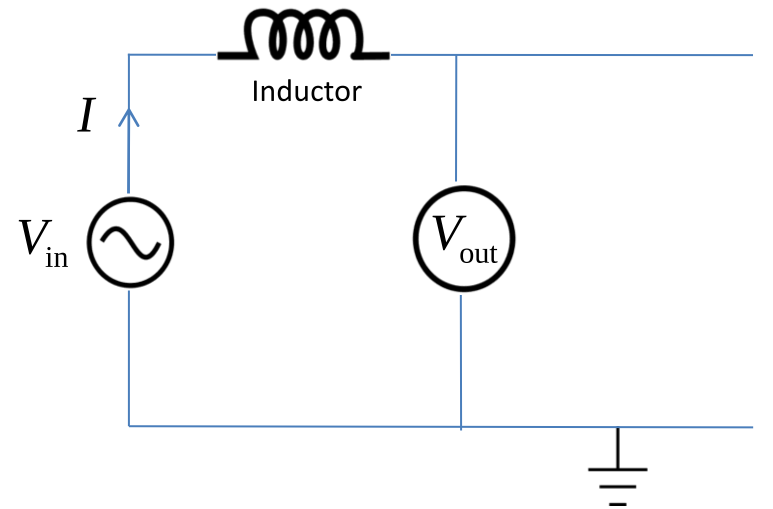
Inductors in a parallel configuration each have the same potential difference (voltage).

$$L = \frac{1}{\frac{1}{L_1} + \frac{1}{L_2} + \ldots + \frac{1}{L_n}}$$

True only when there is no mutual coupling of magnetic fields between individual inductors

Signal filtering using inductors

In this configuration, the inductor blocks AC current, while allowing DC current to pass.



In this configuration, the inductor decouples DC current, while allowing AC current to pass.