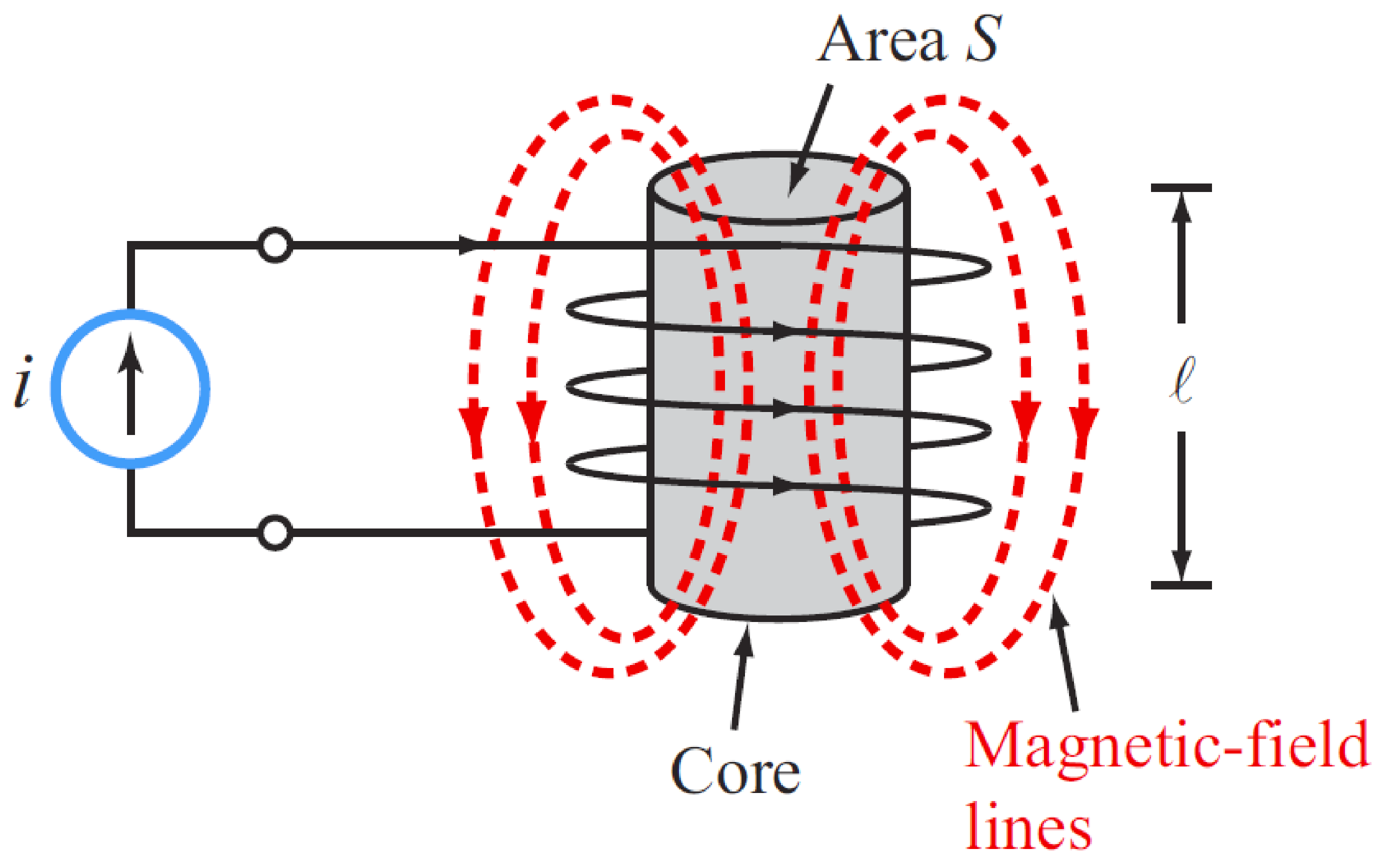
Inductors

Capacitors and inductors constitute a canonical pair of devices. Whereas capacitors can store energy through the electric field induced by the voltage imposed across its terminals, **inductors** can store magnetic energy through the magnetic field induced by the current flowing through its wires.



Just as with capacitors, many geometries give rise to an inductance; in general, any current flowing through a wire produces a magnetic field, which in turn is seen as an inductance on that wire. The solenoid geometry pictured above is a good canonical case that illustrates the trends in dependence on geometry and material properties. The solenoid consists of multiple turns of wire wound in a helical geometry around a cylindrical core. The core may be air filled or may contain a magnetic material with magnetic permeability μ. If the wire carries a current i(t) and the turns are closely spaced, the solenoid produces a relatively uniform magnetic field B within its interior region. The inductance of a solenoid of length ℓ and cross-sectional area S is

$$L = \frac{\mu N^2 S}{\ell}$$

where N is the number of turns and μ is the magnetic permeability of the core material.

Magnetic-flux linkage Λ is defined as the total magnetic flux linking a coil or a given circuit. For a solenoid with N turns carrying a current i:

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$$\Lambda = \left(\frac{\mu N^2 S}{\ell}\right) i \qquad \text{(Wb)}$$

The unit for Λ is the weber (Wb), named after the German scientist Wilhelm Weber (1804–1891).

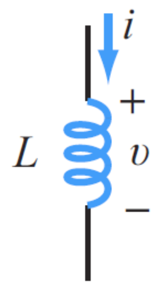
According to Faraday's law, if the magnetic-flux linkage in an inductor (or circuit) changes with time, it induces a voltage υ across the inductor's terminals given by

$$\upsilon = \frac{d\Lambda}{dt}$$

Combining the above,

$$\upsilon = \frac{d}{dt}(Li) = L\frac{di}{dt}$$

Thus, the symbol for an inductor and the i-v definition is given below:



$$\upsilon = L\frac{di}{dt}$$

What is permeability, μ?

The relative magnetic permeability μ_r is defined as

$$\mu_r = \frac{\mu}{\mu_0}$$

where $\mu_0 \approx 4\pi \times 10^{-7}$ (H/m) is the magnetic permeability of free space.

Except for ferromagnetic materials, $\mu_r \sim 1$ for all dielectrics and conductors. The μ_r of ferromagnetic materials (which include iron, nickel, and cobalt) can be as much as five orders of magnitude larger than that of other materials. Consequently, L of an iron-core solenoid is about 5000 times that of an air-core solenoid of the same size and shape.

Material	relative Permeability μ_r
All Dielectrics and Non-Ferromagnetic Metals	≈ 1.0
Ferromagnetic Metals	
Cobalt	250
Nickel	600
Mild steel	2,000
Iron (pure)	4,000–5,000
Silicon iron	7,000
Mumetal	$\sim 100,000$
Purified iron	$\sim 200,000$

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