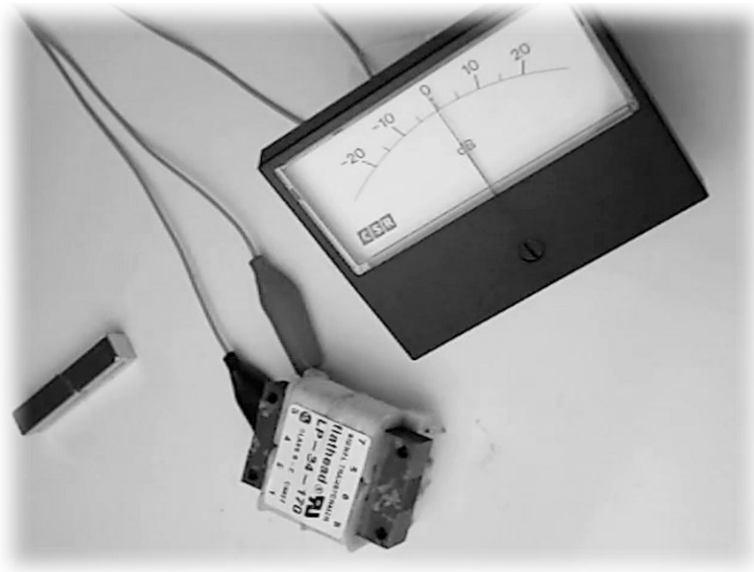
Inductance

In the discussion of magnetism, we wondered …

> *'If current flowing through a conductor gives rise to a magnetic field, would the reverse also be true; would a passing magnetic field induce a current in a conductor?'*

The answer is that indeed it does, and that's part of a very interesting phenomenon called *inductance*.

To prove it, I have a galvanometer hooked up to a transformer, which I am just using as a simple coil. I'm using a coil, instead of a straight piece of wire, because it amplifies the effect to the point where we can easily observe it in this way. When I pass a lodestone over the coil one way and the other, the meter registers current impulses.

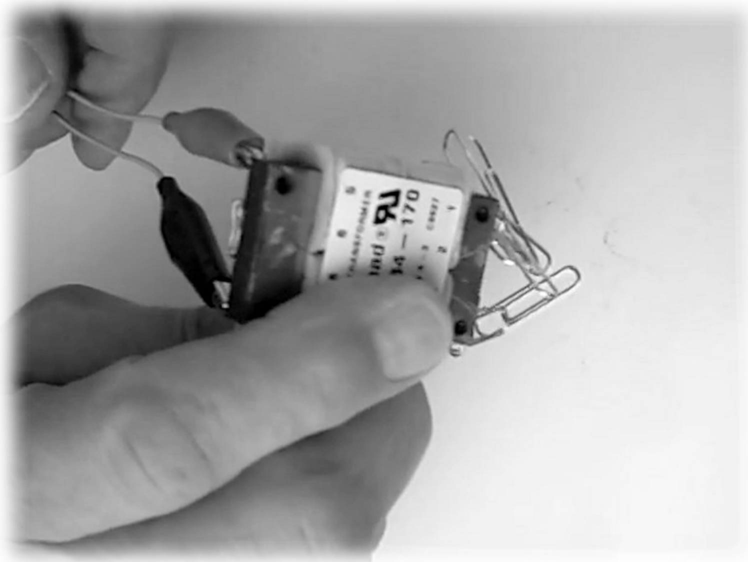


Inductors

As you now already know, current flowing through a conductor gives rise to a magnetic field around the wire.

If a length of wire is wrapped into the form of a coil, the fields around the individual turns combine to form a unified magnetic field around the coil, establishing north and south magnetic poles at its ends.

Using the transformer again, this time as a coil wrapped around a non-magnetized iron core, we can observe this electromagnetic effect. When connected to a DC power source, the magnetic field developed by the coil is transferred, or *induced,* into to the transformer's iron core.



The symbol for inductance is *L* and the unit of inductance is the *henry* — named in honor of an American scientist Joseph Henry, who discovered electromagnetic induction in 1831.

In a coil with an inductance of one henry, a current that is changing at a constant rate of one ampere per second results in the generation of one volt of potential difference across an inductor. Stated mathematically …

$$v_t = -L\frac{\Delta i}{\Delta t}$$

Higher values of $\Delta i/\Delta t$ produce higher voltage impulses — which is the principle by which the spark coil in older car engines generates a high and dangerous voltage.

The factors that determine the inductance of a coil are …

- the number of turns *(N)*
- the type of core *(μ)*
- the spacing of the turns,
- the winding method,
- the diameter of the coil, and
- its diameter/length ratio *(A)(l)*

… or basically …

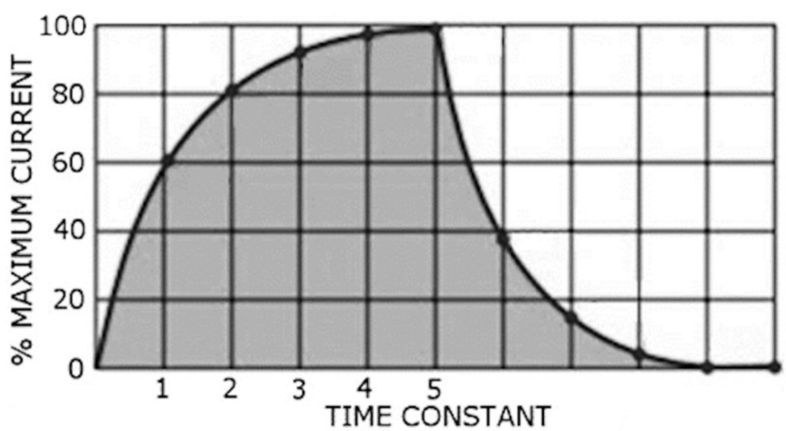
$$L = \frac{\mu N^2 A}{l}$$

Impedance

An *inductor*, also called a *coil* or *reactor*, can be defined as *a passive two-terminal electrical component which resists changes in electric current passing through it.*

When a DC voltage is connected to a coil, the current in the circuit will depend only on the resistance of the wire.

But while the full applied potential will appear across the coil immediately, the current will rise to its maximum *I=E/R* value exponentially — meaning in a nonlinear way …



This happens as a result of interactions within the coil as the electromagnetic field develops. As the field expands it induces complex patterns of emf within parts of the windings, that tend to oppose the primary direction of current flow — an imaginary potential called *back emf*.

When the voltage applied to the coil is subsequently decreased to zero, the reverse occurs, the collapsing field again inducing counter emfs that oppose the changing current.

For continuously varying voltages, such as 50/60Hz AC, or even high-frequency signals, this opposition to changes in coil current has an effect very similar to resistance.

In this case, it is called *impedance*. Just like resistance, the unit of impedance is the ohm. An impedance of one ohm limits the flow of alternating current to one ampere when the applied AC potential is one volt.

In the case of coils, impedance is also referred to as *inductive reactance*, the symbol for which is X_L.

If the AC current and voltage are known …

$$X_L = \frac{E}{I}$$

Otherwise, the inductive reactance of a coil, in ohms, can be calculated using …

$$X_L = 2\pi f L$$

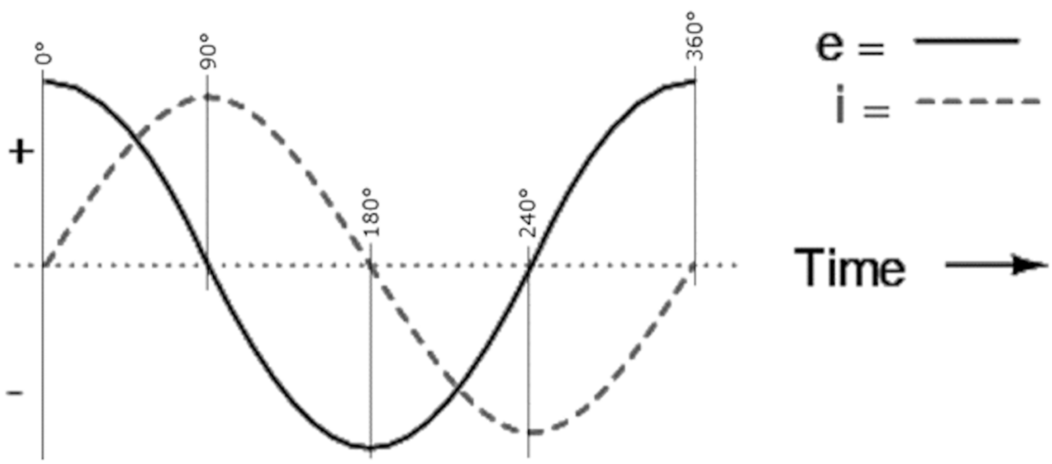
… where *f* is the frequency of the alternating current in Hz, *L* is the inductance of the coil in henries, and π, of course, is equal to 3.1416.

From this formula you can see that the impedance of a coil is proportional to its inductance, and the frequency of the signal applied to it.

Inductive Phase Shift

As a result of an inductor's resistance to changes in current flow, in an inductive circuit with an alternating current, the voltage across the inductor leads the current by 90-degrees.

Thus, when connected in series with some sort of linear resistance, the voltage drop across a coil will be 90° out of phase with the voltage drop across the resistance.



Having said all this, the reality is that, in electronics at least, coils have become pretty much obsolete as circuit components, and are seldom encountered. The main reason for this is that they are not amenable to the requirements for miniaturization. Engineers have therefore had to develop other techniques for implementing functions formerly achieved by the use of inductors.

One special inductive device that hasn’t shared that fate is the venerable old transformer.

We’ll talk about this very important component next!
