**Faraday's law of induction** or **Faraday's law** is a basic law of [electromagnetism](https://en.wikipedia.org/wiki/Electromagnetism) predicting how a [magnetic field](https://en.wikipedia.org/wiki/Magnetic_field) will interact with an [electric circuit](https://en.wikipedia.org/wiki/Electric_circuit) to produce an [electromotive force](https://en.wikipedia.org/wiki/Electromotive_force) (EMF) a phenomenon known as [electromagnetic induction](https://en.wikipedia.org/wiki/Electromagnetic_induction).

It is the fundamental operating principle of [transformers](https://en.wikipedia.org/wiki/Transformer), [inductors](https://en.wikipedia.org/wiki/Inductor), and many types of electrical motors, generators and [solenoids](https://en.wikipedia.org/wiki/Solenoid).

The **Maxwell–Faraday equation** (listed as one of [Maxwell's equations](https://en.wikipedia.org/wiki/Maxwell%27s_equations)) describes the fact that a spatially varying (and also possibly time-varying, depending on how a magnetic field varies in time) electric field always accompanies a time-varying magnetic field, while Faraday's law states that there is EMF (electromotive force, defined as electromagnetic work done on a unit charge when it has traveled one round of a conductive loop) on the conductive loop when the magnetic flux through the surface enclosed by the loop varies in time. The integral form of the Maxwell–Faraday equation describes only the transformer EMF, while the equation of Faraday's law describes both the transformer EMF and the motional EMF.

The most widespread version of Faraday's law states: The electromotive force around a closed path is equal to the negative of the time rate of change of the [magnetic flux](https://en.wikipedia.org/wiki/Magnetic_flux) enclosed by the path.

Faraday's law states that the EMF is also given by the [rate of change](https://en.wikipedia.org/wiki/Time_derivative) of the magnetic flux:

**{\displaystyle {\mathcal {E}}=-{\frac {\mathrm {d} \Phi \_{B}}{\mathrm {d} t}},}**

where {\displaystyle {\mathcal {E}}} is the [electromotive force](https://en.wikipedia.org/wiki/Electromotive_force) (EMF) and Φ*B* is the [magnetic flux](https://en.wikipedia.org/wiki/Magnetic_flux).

The direction of the electromotive force is given by [Lenz's law](https://en.wikipedia.org/wiki/Lenz%27s_law). Faraday's law contains the information about the relationships between both the magnitudes and the directions of its variables. However, the relationships between the directions are not explicit; they are hidden in the mathematical formula.

**Lenz's law**, named after the [physicist](https://en.wikipedia.org/wiki/Physicist) [Emil Lenz](https://en.wikipedia.org/wiki/Emil_Lenz)  who formulated it in 1834, states that the direction of the current induced in a conductor by a changing [magnetic field](https://en.wikipedia.org/wiki/Magnetic_field) is such that the magnetic field created by the induced current opposes the initial changing magnetic field.

It is a qualitative law that specifies the direction of induced current, but states nothing about its magnitude. Lenz's law explains the direction of many effects in [electromagnetism](https://en.wikipedia.org/wiki/Electromagnetism), such as the [direction of voltage induced](https://en.wikipedia.org/wiki/Electromagnetic_induction) in an [inductor](https://en.wikipedia.org/wiki/Inductor) or wire loop by a changing current, or the drag force of [eddy currents](https://en.wikipedia.org/wiki/Eddy_current) exerted on moving objects in a magnetic field.

Lenz's law may be seen as analogous to [Newton's third law](https://en.wikipedia.org/wiki/Newton%27s_laws_of_motion#Newton's_third_law) in classic mechanics.

Lenz's law states that the current induced in a circuit due to a change in a magnetic field is directed to oppose the change in flux and to exert a mechanical force which opposes the motion.

Lenz's law is contained in the rigorous treatment of [Faraday's law of induction](https://en.wikipedia.org/wiki/Faraday%27s_law_of_induction), where it finds expression by the negative sign:

**Self-Inductance and Mutual Inductance**

In [electromagnetism](https://en.wikipedia.org/wiki/Electromagnetism) and [electronics](https://en.wikipedia.org/wiki/Electronics), **inductance** is the tendency of an [electrical conductor](https://en.wikipedia.org/wiki/Electrical_conductor) to oppose a change in the [electric current](https://en.wikipedia.org/wiki/Electric_current) flowing through it. The flow of electric current through a conductor creates a [magnetic field](https://en.wikipedia.org/wiki/Magnetic_field) around the conductor, whose strength depends on the magnitude of the current. A change in current causes a change in the magnetic field. From [Faraday's law of induction](https://en.wikipedia.org/wiki/Faraday%27s_law_of_induction), any change in magnetic field through a circuit induces an [electromotive force](https://en.wikipedia.org/wiki/Electromotive_force) (EMF) ([voltage](https://en.wikipedia.org/wiki/Voltage)) in the conductors; this is known as [electromagnetic induction](https://en.wikipedia.org/wiki/Electromagnetic_induction). So the changing current induces a voltage in the conductor. This induced voltage is in a direction which tends to oppose the change in current (as stated by [Lenz's law](https://en.wikipedia.org/wiki/Lenz%27s_law)), so it is called a [*back EMF*](https://en.wikipedia.org/wiki/Back_EMF). Due to this back EMF, a conductor's inductance opposes any increase or decrease in electric current through it.

Inductance is defined as the ratio of the induced voltage to the rate of change of current causing it. It is a proportionality factor that depends on the geometry of circuit conductors and the [magnetic permeability](https://en.wikipedia.org/wiki/Magnetic_permeability) of nearby materials. An [electronic component](https://en.wikipedia.org/wiki/Electronic_component) designed to add inductance to a circuit is called an [inductor](https://en.wikipedia.org/wiki/Inductor). It typically consists of a [coil](https://en.wikipedia.org/wiki/Electromagnetic_coil) or helix of wire.

The term *inductance* was coined by [Oliver Heaviside](https://en.wikipedia.org/wiki/Oliver_Heaviside) in 1886. It is customary to use the symbol L{\displaystyle L} for inductance, in honour of the physicist [Heinrich Lenz](https://en.wikipedia.org/wiki/Heinrich_Lenz). In the [SI](https://en.wikipedia.org/wiki/International_System_of_Units) system, the unit of inductance is the [henry](https://en.wikipedia.org/wiki/Henry_(unit)) (H), which is the amount of inductance that causes a voltage of one [volt](https://en.wikipedia.org/wiki/Volt), when the current is changing at a rate of one [ampere](https://en.wikipedia.org/wiki/Ampere_(unit)) per second. It is named for [Joseph Henry](https://en.wikipedia.org/wiki/Joseph_Henry), who discovered inductance independently of Faraday.

A current {\displaystyle i}i flowing through a conductor generates a [magnetic field](https://en.wikipedia.org/wiki/Magnetic_field) around the conductor, which is described by [Ampere's circuital law](https://en.wikipedia.org/wiki/Ampere%27s_circuital_law). The total [magnetic flux](https://en.wikipedia.org/wiki/Magnetic_flux) ɸ through a circuit {\displaystyle \Phi } is equal to the product of the perpendicular component the magnetic field and the area of the surface spanning the current path. If the current varies, the [magnetic flux](https://en.wikipedia.org/wiki/Magnetic_flux) ɸ {\displaystyle \Phi } through the circuit changes. By [Faraday's law of induction](https://en.wikipedia.org/wiki/Faraday%27s_law_of_induction), any change in flux through a circuit induces an [electromotive force](https://en.wikipedia.org/wiki/Electromotive_force) (EMF) or voltage **v**{\displaystyle v} in the circuit, proportional to the rate of change of flux.

The negative sign in the equation indicates that the induced voltage is in a direction which opposes the change in current that created it; this is called [Lenz's law](https://en.wikipedia.org/wiki/Lenz%27s_law). The potential is therefore called a [back EMF](https://en.wikipedia.org/wiki/Back_EMF). If the current is increasing, the voltage is positive at the end of the conductor through which the current enters and negative at the end through which it leaves, tending to reduce the current. If the current is decreasing, the voltage is positive at the end through which the current leaves the conductor, tending to maintain the current. Self-inductance, usually just called inductance, L is the ratio between the induced voltage and the rate of change of the current

**{\displaystyle v(t)=L\,{\frac {{\text{d}}i}{{\text{d}}t}}\qquad \qquad \qquad (1)\;}v(t)=L**

Thus, inductance is a property of a conductor or circuit, due to its magnetic field, which tends to oppose changes in current through the circuit. The unit of inductance in the [SI](https://en.wikipedia.org/wiki/Systeme_International) system is the [henry](https://en.wikipedia.org/wiki/Henry_(unit)) (H), named after American scientist [Joseph Henry](https://en.wikipedia.org/wiki/Joseph_Henry), which is the amount of inductance which generates a voltage of one [volt](https://en.wikipedia.org/wiki/Volt_(unit)) when the current is changing at a rate of one [ampere](https://en.wikipedia.org/wiki/Ampere) per second.

All conductors have some inductance, which may have either desirable or detrimental effects in practical electrical devices. The inductance of a circuit depends on the geometry of the current path, and on the [magnetic permeability](https://en.wikipedia.org/wiki/Magnetic_permeability) of nearby materials; [ferromagnetic](https://en.wikipedia.org/wiki/Ferromagnetic) materials with a higher permeability like [iron](https://en.wikipedia.org/wiki/Iron) near a conductor tend to increase the magnetic field and inductance. Any alteration to a circuit which increases the flux (total magnetic field) through the circuit produced by a given current increases the inductance, because inductance is also equal to the ratio of [magnetic flux](https://en.wikipedia.org/wiki/Magnetic_flux) to current.

**L={\displaystyle L={\Phi (i) \over i}}**

An [inductor](https://en.wikipedia.org/wiki/Inductor) is an [electrical component](https://en.wikipedia.org/wiki/Electrical_component) consisting of a conductor shaped to increase the magnetic flux, to add inductance to a circuit. Typically it consists of a wire wound into a [coil](https://en.wikipedia.org/wiki/Electromagnetic_coil) or [helix](https://en.wikipedia.org/wiki/Helix). A coiled wire has a higher inductance than a straight wire of the same length, because the magnetic field lines pass through the circuit multiple times, it has multiple [flux linkages](https://en.wikipedia.org/wiki/Flux_linkage). The inductance is proportional to the square of the number of turns in the coil.

The inductance of a coil can be increased by placing a [magnetic core](https://en.wikipedia.org/wiki/Magnetic_core) of [ferromagnetic](https://en.wikipedia.org/wiki/Ferromagnetic) material in the hole in the center. The magnetic field of the coil magnetizes the material of the core, aligning its [magnetic domains](https://en.wikipedia.org/wiki/Magnetic_domain), and the magnetic field of the core adds to that of the coil, increasing the flux through the coil. This is called a [ferromagnetic core inductor](https://en.wikipedia.org/wiki/Inductor#ferromagnetic_core_inductor). A magnetic core can increase the inductance of a coil by thousands of times.

If multiple [electric circuits](https://en.wikipedia.org/wiki/Electric_circuit) are located close to each other, the magnetic field of one can pass through the other; in this case the circuits are said to be [*inductively coupled*](https://en.wikipedia.org/wiki/Inductive_coupling). Due to [Faraday's law of induction](https://en.wikipedia.org/wiki/Faraday%27s_law_of_induction), a change in current in one circuit can cause a change in magnetic flux in another circuit and thus induce a voltage in another circuit. The concept of inductance can be generalized in this case by defining the [mutual inductance](https://en.wikipedia.org/wiki/Mutual_inductance) {\displaystyle M\_{k,\ell }} of circuit {\displaystyle k} and circuit {\displaystyle \ell } as the ratio of voltage induced in circuit {\displaystyle \ell } to the rate of change of current in circuit{\displaystyle k}. This is the principle behind a [*transformer*](https://en.wikipedia.org/wiki/Transformer).

The property describing the effect of one conductor on itself is more precisely called *self-inductance*, and the properties describing the effects of one conductor with changing current on nearby conductors is called *mutual inductance*.

**Energy stored in Magnetic Field**

If the current through a conductor with inductance is increasing, a voltage **{\displaystyle v(t)}v(t)** will be induced across the conductor with a polarity which opposes the current, as described above (this is in addition to any voltage drop caused by the conductor's resistance). The charges flowing through the circuit lose potential energy moving from the higher voltage to the lower voltage end. The energy from the external circuit required to overcome this "potential hill" is being stored in the increased magnetic field around the conductor. Therefore, any inductance with a current through it stores energy in its magnetic field. At any given time **{\displaystyle t}t** the power **p(t)**{\displaystyle p(t)} flowing into the magnetic field, which is equal to the rate of change of the stored energy **U**, is the product of the current **{\displaystyle i(t)}i(t)** and voltage **v(t)**{\displaystyle v(t)} across the conductor.

**p(t)**

Substituting **{\displaystyle v(t)=L\,{\frac {{\text{d}}i}{{\text{d}}t}}\qquad \qquad \qquad (1)\;}v(t)=L**  in above equation we get

**L**

**Or dU= L {\displaystyle U}**

When there is no current, there is no magnetic field and the stored energy is zero. Neglecting resistive losses, the [energy](https://en.wikipedia.org/wiki/Energy)**{\displaystyle U}U** (measured in [joules](https://en.wikipedia.org/wiki/Joule), in [SI](https://en.wikipedia.org/wiki/SI)) stored by an inductance with a current **{\displaystyle I}i** through it is equal to the amount of work required to establish the current through the inductance from zero, and therefore the magnetic field. This is given by:

**U=L**

**U =**

So therefore inductance is also proportional to how much energy is stored in the magnetic field for a given current. This energy is stored as long as the current remains constant. If the current decreases, the magnetic field will decrease, inducing a voltage in the conductor in the opposite direction, negative at the end through which current enters and positive at the end through which it leaves. This will return stored magnetic energy to the external circuit.