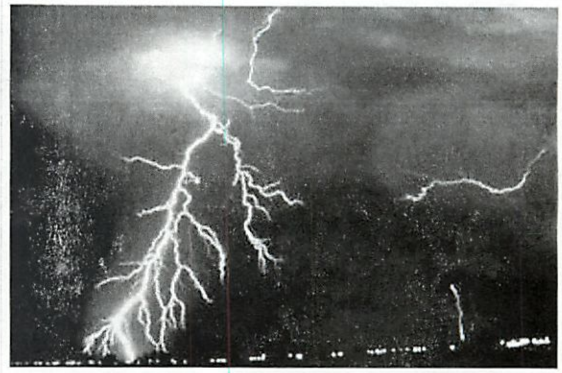
Electricity

From Wikipedia, *the* free encyclopedia

For songs called Electricity, *see Electricity (song title).*



Lightning strikes during a night-time thunderstorm. Energy is radiated as light as the air of Earth's atmosphere is shifted from gas to plasma and back.

Electricity is a property of matter that results from the presence or movement of electric charge. Together with magnetism, it constitutes the fundamental interaction known as electromagnetism. Electricity is responsible for many well-known physical phenomena such as lightning, electric fields and electric currents, and is put to use in industrial applications such as electronics and electric power.

Contents

Concepts in electricity

In casual usage, the term **electricity** is applied to several related concepts that are better identified by more precise terms:

- **Electric charge** - a fundamental conserved property of some subatomic particles, which determines their electromagnetic interactions. Electrically charged matter is influenced by, and produces, electromagnetic fields.
- **Electric field** - an effect produced by an electric charge that exerts a force on charged objects in its vicinity.
- **Electric potential** - the potential energy per unit charge associated with a static electric field (often referred to as voltage).
- **Electric current** - a movement or flow of electrically charged particles.
- **Electrical energy** - the energy made available by the flow of electric charge through a conductor or from the forces between charged particles.

- **Electric power** - the rate at which electric energy is converted to or from another energy form, such as light, heat, or mechanical energy.

History

Ancient

According to Thales of Miletus, writing 600 BC, a form of electricity was known to the Ancient Greeks who found that rubbing fur on various substances, such as amber, would cause a particular attraction between the two. The Greeks noted that the amber buttons could attract light objects such as hair and that if they rubbed the amber for long enough they could even get a spark to jump.

An object found in Iraq in 1938, dated to about 250 BC and called the Baghdad Battery, resembles a galvanic cell and is believed by some to have been used for electroplating.

Modern

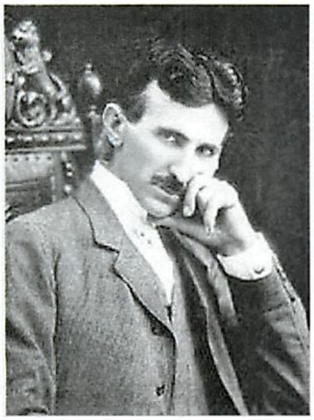
Italian physician Girolamo Cardano returned to the subject of electricity in *De Subtilitate* (1550)[1], distinguishing, perhaps for the first time, between electrical and magnetic forces. In 1600 the English scientist William Gilbert, in *De Magnete*, expanded on Cardano's work and coined the modern Latin word *electricus* from *ηλεκτρον* (*elektron*), the Greek word for "amber", which soon gave rise to the English words *electric* and *electricity*.

Leyden jars, Museum Boerhaave, Leiden [3] (http://www.museumboerhaave.nl/) .

He was followed in 1660 by Otto von Guericke, who invented an early electrostatic generator. Other European pioneers were Robert Boyle, who in 1675 stated that electric attraction and repulsion can act across a vacuum; Stephen Gray, who in 1729 classified materials as conductors and insulators; and C. F. Du Fay, who first identified the two types of electricity that would later be called *positive* and *negative*.

The Leyden jar, a type of capacitor for electrical energy in large quantities, was invented at Leiden University by Pieter van Musschenbroek in 1745. William Watson, experimenting with the Leyden jar, discovered in 1747 that a discharge of static electricity was equivalent to an electric current.

In June, 1752, Benjamin Franklin promoted his investigations of electricity and theories through the famous, though extremely dangerous, experiment of flying a kite during a thunderstorm. Following these experiments he invented a lightning rod and established the link between lightning and electricity. If Franklin did fly a kite in a storm, he did not do it the way it is often described (as it would have been dramatic but fatal). It was either Franklin (more frequently) or Ebenezer Kinnersley of Philadelphia (less frequently) who created the convention of positive and negative electricity.



Nikola Tesla.

Franklin's observations aided later scientists such as Michael Faraday, Luigi Galvani, Alessandro Volta, André-Marie Ampère, and Georg Simon Ohm whose work provided the basis for modern electrical technology. The work of Faraday, Volta, Ampere, and Ohm is honored by society, in that fundamental units of electrical measurement are named after them.

Volta worked with chemicals and discovered that chemical reactions could be used to create positively charged anodes and negatively charged cathodes. When a conductor was attached between these, the difference in the electrical potential (also known as voltage) drives a current between them through the conductor. The potential difference between two points is measured in units of volts in recognition of Volta's work.

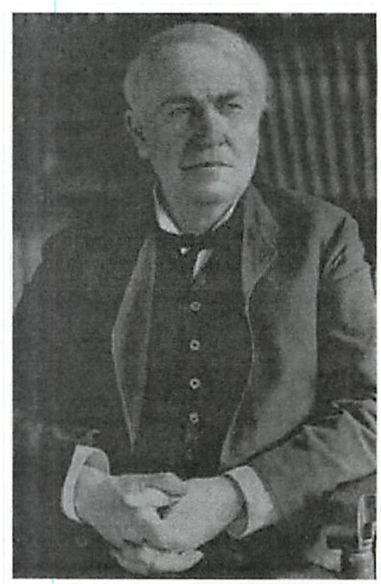
In 1800 Volta constructed the first device that would produce a large flow of electricity, that device was later known as electric battery. Napoleon, noticed of his works, called him in 1801 for a kind of "command performance" of his experiments. He received many medals and decorations, including the Legion of Honor.

The invention of the electric telegraph showed that commercial and practical use could be made of electrical phenomena. By the end of the 19th century electrical engineering became a distinct profession, separate from the physicist or inventor.

This resulted in arrival of some companies that investigating, developing and perfectioning techniques of electricity transmission achieved a great degree of acceptance in goverments all over the world for starting the first worldwide electrical telecomunication network in history: telegraph network. We are talking about pioneers like Werner von Siemens, that founded Siemens in 1847, or Sir John Pender, founder of Cable & Wireless.

The late 19th and early 20th century produced such giants of electrical engineering as Nikola Tesla, inventor of the polyphase induction motor; Samuel Morse, inventor of the telegraph; Antonio Meucci, an inventor of the telephone; Thomas Edison, inventor of the first commercial electrical energy distribution network; George Westinghouse, inventor of the electric locomotive; Charles Steinmetz, theoretician of alternating current; Alexander Graham Bell, another inventor of the telephone and founder of a successful telephone business.

The rapid advance of electrical technology in the latter 19th and early 20th centuries led to commercial rivalries, such as the so-called War of the Currents between Edison's direct-current system and Westinghouse's alternating-current method. Often, concurrent research in widely scattered locations led to multiple claims to the invention of a device or system.



Thomas Alva Edison

Electric charge

Main article: Electric charge

Electric charge is a property of certain subatomic particles (e.g., electrons and protons) which interacts with electromagnetic fields and causes attractive and repulsive forces between them. Electric charge gives rise to one of the four fundamental forces of nature, and is a conserved property of matter that can be quantified. In this sense, the phrase "quantity of electricity" is used interchangeably with the phrases "charge of electricity" and "quantity of charge." There are two types of charge: we call one kind of charge positive and the other negative. Through experimentation, we find that like-charged objects repel and opposite-charged objects attract one another. The magnitude of the force of attraction or repulsion is given by Coulomb's law.

Electric field

Main article: Electric field


Michael Faraday

The concept of electric field was introduced by Michael Faraday. The electrical field force acts between two charges, in the same way that the gravitational field force acts between two masses. However, the electric field is a little bit different. Gravitational force depends on the masses of two bodies, whereas electric force depends on the electric charges of two bodies. While gravity can only pull two masses together, the electric force can be an attractive *or* repulsive force. If both charges are of same sign (e.g. both positive), there will be a repulsive force between the two. If the charges are opposite, there will be an attractive force between the two bodies. The magnitude of the force varies inversely with the square of the distance between the two bodies, and is also proportional to the product of the unsigned magnitudes of the two charges.

Electric potential

Main article: Electric potential

The electric potential difference between two points is defined as the work done per unit charge (against electrical forces) in moving a positive point charge slowly between two points. If one of the points is taken to be a reference point with zero potential, then the electric potential at any point can be defined in terms of the work done per unit charge in moving a positive point charge from that reference point to the point at which the potential is to be determined. For isolated charges, the reference point is usually taken to be infinity. The potential is measured in volts. (1 volt = 1 joule/coulomb) The electric potential is analogous to temperature: there is a different temperature at every point in space, and the temperature gradients indicate the direction of heat flows. Similarly, there is an electric potential at every point in space, and its gradient in the electric field indicates where charges move.

Electric current

Main article: Current (electricity)

An electric current is a flow of electric charge, and its intensity is measured in amperes. Examples of electric currents include metallic conduction, where electrons flow through a conductor such as a metal wire, and electrolysis, where ions (charged atoms) flow through liquids. The particles themselves often move quite slowly, while the electric field that drives them propagates at close to the speed of light. See *electrical conduction* for more information.

Devices that use charge flow principles in materials are called electronic devices.

A direct current (DC) is a unidirectional flow, while an alternating current (AC) reverses direction repeatedly. The time average of an alternating current is zero, but its energy capability (RMS value) is not zero.

Ohm's Law is an important relationship describing the behaviour of electric currents, relating them to voltage.

For historical reasons, electric current is said to flow from the most positive part of a circuit to the most negative part. The electric current thus defined is called *conventional current*. It is now known that, depending on the conditions, an electric current can consist of a flow of charged particles in either direction, or even in both directions at once. The positive-to-negative convention is widely used to simplify this situation. If another definition is used - for example, "electron current" - it should be explicitly stated.

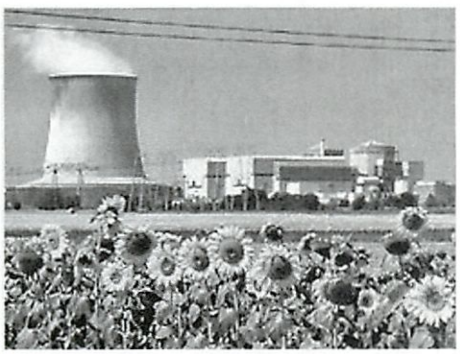
Electrical energy is energy stored in an electric field or transported by an electric current. Energy is defined as the ability to do work, and electrical energy is simply one of the many types of energy. Examples of electrical energy include:

- the energy that is constantly stored in the Earth's atmosphere, and is partly released during a thunderstorm in the form of lightning
- the energy that is stored in the coils of an electrical generator in a power station, and is then transmitted by wires to the consumer; the consumer then pays for each unit of energy he receives
- the energy that is stored in a capacitor, and can be released to drive a current through an electrical circuit

Electric power

Main article: Electric power

Electric power is the rate at which electrical energy is produced or consumed, and is measured in watts (symbol: W).



A nuclear power station.

A fossil-fuel or nuclear power station converts heat to electrical energy, and the faster the station burns fuel, assuming constant efficiency of conversion, the higher its power output. The output of a power station is usually specified in megawatts (millions of watts). The electrical energy is then sent over transmission lines to reach the consumers.

Every consumer uses appliances that convert the electrical energy to other forms of energy, such as heat (in electric arc furnaces and electric heaters), light (in light bulbs and fluorescent lamps), or motion, i.e. kinetic energy (in electric motors). Like the power station, each appliance is also rated in watts, depending on the rate at which it converts electrical energy into another form. The power station must produce electrical energy at the same rate as all the connected appliances consume it.

In electrical engineering, the concepts of apparent power and reactive power are also used. Apparent power is the product of RMS voltage and RMS current, and is measured in volt-amperes (VA). Reactive power is measured in volt-amperes-reactive (VAR).

Non-nuclear electric power is categorized as either green or brown electricity.

Green power is a cleaner alternative energy source in comparison to traditional sources, and is derived from renewable energy resources that do not produce any nuclear waste; examples include energy produced from wind, water, solar, thermal, hydro, combustible renewables and waste.

Electricity from coal, oil, and natural gas is known as traditional power or "brown" electricity.

SI electricity units

SI electromagnetism units				
Symbol	**Name of Quantity**	**Derived Units**	**Unit**	**Base Units**
I	Current	ampere (SI base unit)	A	A = W/V = C/s
q	Electric charge, Quantity of electricity	coulomb	C	A·s

V	Potential difference	volt	V	$J/C = kg{\cdot}m^2{\cdot}s^{-3}{\cdot}A^{-1}$
R, Z, X	Resistance, Impedance, Reactance	ohm	Ω	$V/A = kg{\cdot}m^2{\cdot}s^{-3}{\cdot}A^{-2}$
ρ	Resistivity	ohm metre	Ω·m	$kg{\cdot}m^3{\cdot}s^{-3}{\cdot}A^{-2}$
P	Power, Electrical	watt	W	$V{\cdot}A = kg{\cdot}m^2{\cdot}s^{-3}$
C	Capacitance	farad	F	$C/V = kg^{-1}{\cdot}m^{-2}{\cdot}A^2{\cdot}s^4$
	Elastance	reciprocal farad	F^{-1}	$V/C = kg{\cdot}m^2{\cdot}A^{-2}{\cdot}s^{-4}$
ε	Permittivity	farad per metre	F/m	$kg^{-1}{\cdot}m^{-3}{\cdot}A^2{\cdot}s^4$
χ_e	Electric susceptibility	(dimensionless)	-	-
G, Y, B	Conductance, Admittance, Susceptance	siemens	S	$\Omega^{-1} = kg^{-1}{\cdot}m^{-2}{\cdot}s^3{\cdot}A^2$
σ	Conductivity	siemens per metre	S/m	$kg^{-1}{\cdot}m^{-3}{\cdot}s^3{\cdot}A^2$
H	Magnetic field, magnetic field intensity	ampere per metre	A/m	$A{\cdot}m^{-1}$
Φ_m	Magnetic flux	weber	Wb	$V{\cdot}s = kg{\cdot}m^2{\cdot}s^{-2}{\cdot}A^{-1}$
B	Magnetic flux density, magnetic induction, magnetic field strength	tesla	T	$Wb/m^2 = kg{\cdot}s^{-2}{\cdot}A^{-1}$
	Reluctance	ampere-turns per weber	A/Wb	$kg^{-1}{\cdot}m^{-2}{\cdot}s^2{\cdot}A^2$
L	Inductance	henry	H	$Wb/A = V{\cdot}s/A = kg{\cdot}m^2{\cdot}s^{-2}{\cdot}A^{-2}$
μ	Permeability	henry per metre	H/m	$kg{\cdot}m{\cdot}s^{-2}{\cdot}A^{-2}$
χ_m	Magnetic susceptibility	(dimensionless)	-	-

See also

- Electromagnetism
- Electrical engineering
- Electrical phenomena
- Electrostatics

Devices

- Battery
- Conductor
- Insulator
- Light fixture

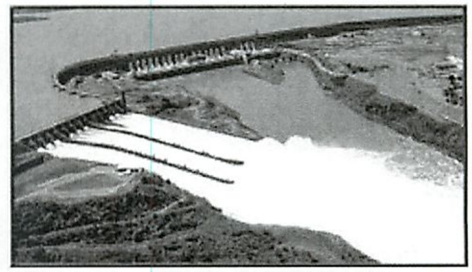
Engineering

- Green electricity
- Electrical wiring

Electricity generation

From Wikipedia, the free encyclopedia

Electricity generation is the first process in the delivery of electricity to consumers. The other three processes are electric power transmission, electricity distribution and electricity retailing.



Itaipu Dam is a hydroelectric generating station

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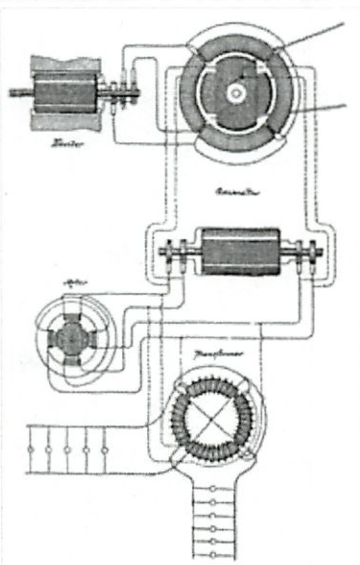
Electricity generation



Nikola Tesla's generation system using AC circuits to transport energy across great distances.

The importance of dependable electricity generation, transmission and distribution was revealed when it became apparent that electricity was useful for providing heat, light and power for human activities. Decentralised power generation became possible when it was recognised that alternating current electric power lines can transport electricity at low costs across great distances by taking advantage of the ability to transform the voltage using power transformers.

Electricity has been generated for the purpose of powering human technologies for at least 120 years from various sources of potential energy. The first power plants were run on wood, while today we rely mainly on petroleum, natural gas, coal, hydroelectric and nuclear power and a small amount from hydrogen, solar energy, tidal harnesses, wind generators, and geothermal sources.

Electricity demand

The demand for electricity can be met in two different ways. The primary method thus far has been for public or private utilities to construct large scale centralized projects to generate and transmit the electricity required to fuel growing economies. Many of these projects have unpleasant environmental effects such as air or radiation pollution and the flooding of large areas of land.

Increasingly, distributed generation is seen as an alternate way to supply the electrical demand close to the users. Smaller, distributed projects can:

1. Protect from blackouts caused by the closure of de-centralised power plants or transmission lines for maintenance, market manipulation or emergency shut downs or detox
2. Reduce pollution
3. Allow smaller players to enter the energy markets

Methods of generating electricity

Methods for transforming other power into electrical power

Rotating turbines attached to electrical generators produce most commercially available electricity. Turbines may be driven by using steam, water, wind or other fluids as an intermediate energy carrier. The most common usage is by steam in fossil fuel power plants or nuclear power plants, and by water in hydroelectric dams. Alternately, turbines can be driven directly by the combustion of natural gas. Combined cycle gas turbine plants offer efficiencies of up to 60%. They generate power by burning natural gas in a gas turbine and use residual heat to generate additional electricity from steam. Wind turbines generate electricity by using the wind. Solar chimneys use wind that is artificially produced inside the chimney by heating it with sunlight. Solar parabolic troughs and solar power towers concentrate sunlight to heat a heat transfer fluid that is used to produce steam to turn a turbine. Small electricity generators are often powered by reciprocating engines burning diesel, biogas or natural gas. Diesel engines are usually used on ships, remote building sites or for emergency standby. Diesel is also used in some peaking power plants, especially as a backup fuel. Biogas is often combusted where it is produced, such as a landfill or wastewater treatment plant, with a reciprocating engine or a microturbine, which is a small gas turbine.

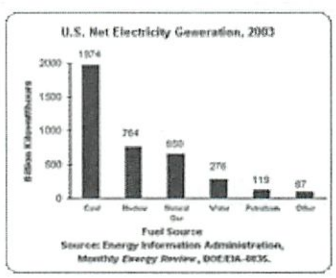
Fuel cells produce electricity using a variety of chemicals and are seen by some people to be the most likely source of power in the long term, especially if hydrogen can be used as the feedstock. However, hydrogen is usually only an energy carrier, and must be formed by some other power source.

Stirling engines produce electricity using a temperature difference. They are used to produce electricity in solar dishes, solar ponds and from low temperature waste heat from power plants and industrial processes. Thermocouples also produce electricity from temperature differences, but they have not been used for commercial electricity generation.

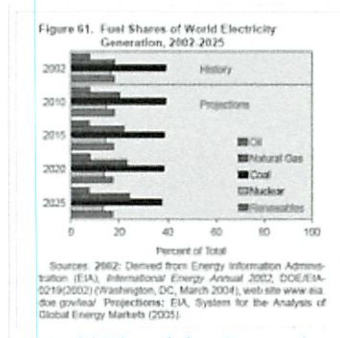
Photovoltaic panels generate electricity directly from sunlight.

Primary energy sources used in electrical power generation

The world relies mainly on coal and natural gas for power. The high capital requirements of nuclear power and the fear of its dangers have prevented the ordering of new nuclear power plants in North America since the 1970s.



U.S. Electricity Generation



World Electricity Generation

Steam turbines can be powered using steam produced from geothermal sources, solar energy, or Nuclear reactors, which use the energy created by the fission of radioactive plutonium or uranium to generate heat. Nuclear power plants often use a primary and secondary steam circuit to add an additional layer of protection between the location of the nuclear fuel and the generator room.

Hydroelectric power plants use water flowing directly through the turbines to power the generators. Tidal harnesses use the force of the moon on bodies of water to spin a turbine. Wind turbines use wind to turn turbines that are hooked up to a generator. Pumped-storage hydroelectricity is used to level demands on the power grid.

Power generation by thermonuclear fusion has been suggested as a possible way of generating electricity; currently a number of technical obstacles and environmental concerns stand in the way, but if realized fusion might provide a relatively clean and safe source of electrical power. The construction of a large experimental reactor (ITER) is expected to commence in 2005-2006.

Improving efficiency

Co-generation (combined heat and power) plants combine the generation of electricity and heat using solar power, fossil fuels, syngas, biomass, or biogas as a fuel source. These plants can achieve efficiencies as high as 80%, but many of these plants being built today only expect to achieve stated maximum 55% efficiency. Heated steam turns a turbine, and then excess heat is distributed for space heating in buildings, industrial processes or green house heating. Whole communities can benefit from heat distributed through a district heating scheme.

The ability to achieve tri-generation using fossil fuels or solar energy to generate heat, electricity and evaporative cooling exists. These combined power plants have the best energy conversion ratio after hydroelectric plants. Small photovoltaic arrays, windmills and bicycles hooked up to a turbine can all be used to generate mobile electricity.

Ownership and reform of electricity generation market

Electricity reform around the world is de-coupling electricity generation from the regulated monopoly elements of transmission and electricity distribution; see electricity market. The generation and distribution of electricity is managed by either privately owned or state owned public utilities. In recent years some governments have started to privatise or corporatise these utilities as part of a move to introduce market forces to monopolies. The New Zealand Electricity Market is a typical example.

See also

- Electricity
- Future energy development
- Renewable energy
- concerns with electricity generation]]
- Power station
- Fossil fuel power plant

Sustainability and energy development Edit (http://en.wikipedia.org/w/wiki.phtml?title=Template:Sustainability_and_energy_development_group&action=edit)

Energy production	Active solar | Bioalcohol | Biodiesel | Biofuel | Biogas | Biomass | Deep lake water cooling | Distributed generation | **Electricity generation** | Ethanol fuel | Fuel cell | Fusion power | Geothermal power | Hydroelectricity | Methanol fuel | Ocean thermal energy conversion | Passive solar | Solar cell | Solar chimney | Energy tower | Solar panel | Solar power | Solar thermal energy | Solar Tower | Tidal power | Trombe wall | Water turbine | Wind turbine
Energy development	Environmental concerns with electricity generation | Future energy development | Hydrogen economy | Hubbert peak | Renewable energy | Hypermodernity | Technological singularity
Energy and sustainability status	Ecosystem services | Kardashev scale | TPE | UN Human Development Index | Value of Earth | Intermediate technology | Infrastructural capital
Sustainability	Ecoforestry | Ecological economics | Earth sheltering | Development economics | Environmental design | Exploitation of natural resources | Green building | Green gross domestic product | Natural building | Permaculture | Self-sufficiency | Straw-bale construction | Sustainability | Sustainable agriculture | Sustainable design | Sustainable development | Sustainable industries | Sustainable living |

Battery (electricity)

From Wikipedia, the free encyclopedia

For other uses, see battery (disambiguation).

Four double-A (AA) rechargeable batteries

In science and technology, a **battery** is a device that stores chemical energy and makes it available in an electrical form. Batteries consist of electrochemical devices such as one or more galvanic cells, fuel cells or flow cells. The earliest known artifacts that may have been batteries are the *Baghdad Batteries*, from some time between 250 BCE and 640 CE. The modern development of batteries started with the Voltaic pile developed by the Italian physicist Alessandro Volta in 1800. The worldwide battery industry generates US$48 billion in sales annually (2005 estimate) (http://www.dfj.com/cgi-bin/artman/publish/article_141.shtml) .

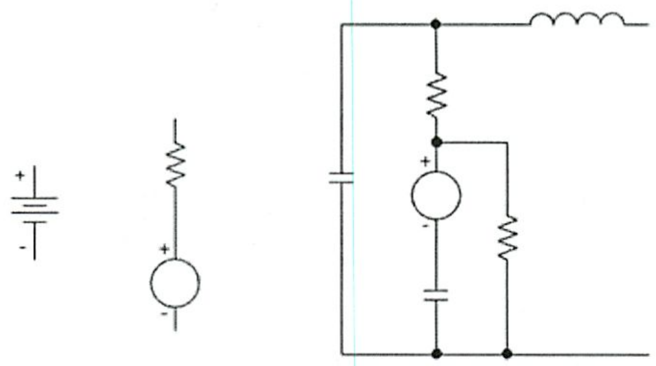
Contents

Cell vs. battery

Strictly, an electrical "battery" is an interconnected array of one or more similar voltaic cells ("cells"). That distinction, however, is considered pedantic in most contexts (other than the expression *dry cell*), and in current English usage it is more common to call a single cell used on its own a *battery* than a *cell*. For example, a hand lamp (flashlight) (torch) is said to take one or more "batteries" even though they may be D cells. A car battery is a true "battery" because it uses multiple cells -- here, six 2 V lead-acid cells -- in series. Multiple batteries or cells may also be referred to as a battery pack, such as a set of multi-cell 12 V batteries in an electric vehicle.

Electrical component

The cells in a battery can be connected in parallel, series, or in both. A parallel combination of cells has the same voltage as a single cell, but can supply a higher current (the sum of the currents from all the cells). A series combination has the same current rating as a single cell but its voltage is the sum of the voltages of all the cells. Most practical electrochemical batteries, such as 9 volt flashlight (torch) batteries and 12 V automobile (car) batteries, have a series structure. Parallel arrangements suffer from the problem that, if one cell discharges faster than its neighbour, current will flow from the full cell to the empty cell, wasting power and possibly causing overheating. Even worse, if one cell becomes short-circuited due to an internal fault, its neighbour will be forced to discharge its maximum current into the faulty cell, leading to overheating and possibly explosion. Cells in parallel are therefore usually fitted with an electronic circuit to protect them against these problems. In both series and parallel types, the energy stored in the battery is equal to the sum of the energies stored in all the cells.



Circuit symbol for a battery; simplified electrical model; and more complex but still incomplete model (the series capacitor has an extremely large value and, as it charges, simulates the discharge of the battery).

A battery can be simply modelled as a perfect voltage source (i.e. one with zero internal resistance) in series with a resistor. The voltage source depends mainly on the chemistry of the battery, not on whether it is empty or full. When a battery runs down, its internal resistance increases. When the battery is connected to a load (e.g. a light bulb), which has its own resistance, the resulting voltage across the load depends on the ratio of the battery's internal resistance to the resistance of the load. When the battery is fresh, its internal resistance is low, so the voltage across the load is almost equal to that of the battery's internal voltage source. As the battery runs down and its internal resistance increases, the voltage drop across its internal resistance increases, so the voltage at its terminals decreases, and the battery's ability to deliver power to the load decreases.

Battery concepts

Here is some heavy-duty information about voltaic cells, the building blocks of batteries. In the figure (above, on the left) the battery consists of two voltaic cells in series. The positive (negative) terminals (*electrodes*) are the longer (shorter) lines. Real voltaic cells have ion-carrying *electrolyte*, made of solid or liquid, separating their terminals. Thus their terminals are not in direct electrical contact. The figure above shows no line connecting the negative terminal of the top cell to the positive terminal of the bottom cell, but in a real cell they would be in direct electrical contact.

The electrolyte contains ions that can react with chemicals in the electrode. Chemical energy is converted into electrical energy by chemical reactions that transfer charge between the electrode and the electrolyte at their interface. Such reactions are called *Faradaic*, and are responsible for current flow through the cell. Ordinary, non-charge-transferring (*non-Faradaic*) reactions also occur at the electrode-electrolyte interfaces. Non-faradaic reactions are one reason that voltaic cells (particularly the lead-acid cell of ordinary car batteries) "run down" when sitting unused.

Around 1800 Volta studied, for many different types of voltaic cell, the effect of different electrodes on the net *electromotive force* (*emf*) of the cell, E. (Emf is equivalent to what was called the internal voltage source in the previous section.) He showed that E is the difference of the emfs E1 and E2 associated with the two electrolyte-electrode interfaces. Hence identical electrodes yield E=0 (zero emf). Volta did not appreciate that the emf was due to chemical reactions. He thought that his cells were an inexhaustible source of energy, and that the associated chemical effects (e.g., corrosion) were a mere nuisance -- rather than, as Faraday showed around 1830, an unavoidable by-product of their operation.

Electromotive force (emf) is measured in units of volts; therefore the word "force" is a misnomer. Voltaic cells, and batteries of voltaic cells, are normally rated in terms of volts. The voltage across the terminals of a battery is known as the *terminal voltage*. The terminal voltage of a battery that is not discharging equals its emf. The terminal voltage of a battery that is discharging (charging) is less than (greater than) the emf.

Most voltaic cells are only rated at 1.5 or so volts because of the limitations to how much electrical energy the chemical reactions can provide. Because of the relatively large energy release of Li compounds, Li cells can provide as many as 3 or more volts. This large energy release can be a hazard.

The conventional model for a voltaic cell, as drawn above, has the internal resistance drawn outside the cell. This is a correct Thevenin equivalent for circuit applications, but it oversimplifies the chemistry and physics. In a more accurate (and more complex) model, a voltaic cell can be thought of as two electrical pumps, one at each terminal (the faradaic reactions at the corresponding electrode-electrolyte interfaces), separated by an internal resistance largely due to the electrolyte. Even this is an oversimplification, since it cannot explain why the behavior of a voltaic cell depends strongly on its rate of discharge. For example, it is well-known that a cell that is discharged rapidly (but incompletely) will recover spontaneously after a waiting time, but a cell that is discharged slowly (but completely) will not recover spontaneously.

The simplest characterization of a battery would give its emf (voltage), its internal resistance, and its "charge", or capacity. In principle, the energy stored by a battery equals the product of its emf and its capacity.

Battery capacity

The capacity of a battery to store charge is often expressed in **ampere hours** (1 A·h = 3600 coulombs). If a battery can provide one ampere (1 A) of current (flow) for one hour, it has a *real-world* capacity of 1 A·h. If it can provide 1 A for 100 hours, its capacity is 100 A·h. The more electrolyte and electrode material in the cell, the greater the capacity of the cell. Thus a tiny AAA cell has much less capacity than a much larger D cell, even if both rely on the same chemical reactions (e.g. alkaline cells), which produce the same terminal voltage. Because of the chemical reactions within the cells, the capacity of a battery depends on the discharge conditions such as the magnitude of the current, the duration of the current, the allowable terminal voltage of the battery, temperature, and other factors.

Battery manufacturers use a standard method to determine how to rate their batteries. The battery is discharged at a constant rate of current over a fixed period of time, such as 10 hours or 20 hours, down to a set terminal voltage per cell. So a 100 ampere-hour battery is rated to provide 5 A for 20 hours at room temperature. The efficiency of a battery is different at different discharge rates. When discharging at low rate, the battery's energy is delivered more efficiently than at higher discharge rates. This is Peukert's Law.

Battery lifetime

Disposable alkaline batteries are designed to be used only once. Even if never taken out of the original package, disposable (or "primary") batteries can lose two to twenty-five percent of their original charge every year. This rate depending significantly on temperature, since typically chemical reactions proceed more rapidly as the temperature is raised. This is known as the "self discharge" rate and is due to non-faradaic (non-current-producing) chemical reactions, which occur within the cell even if no load is applied to it.

Until relatively recently, storing batteries at cool temperatures (such as in the refrigerator) could significantly reduce the rate of these side (non-faradaic) reactions and thus extend the storage life of the battery. However, these side reactions have now been reduced to a level where modern batteries need only be stored in a dry place and at normal room temperatures. Some brands of batteries (like Duracell or Energizer) will provide dependable long life even after 5 years of storage under these conditions.

Extreme temperatures also reduce battery performance.

Some information on caring and disposing of alkaline batteries can be found here (http://www.duracell.com/care_disposal/care.asp) and here (http://www.energizer.com/learning/batterycare.asp) .

Rechargeable batteries self-discharge more rapidly than disposable alkaline batteries. In fact, they can self-discharge up to three percent a *day* (again, depending on temperature). Due to their poor shelf life, they shouldn't be left in a drawer and then relied upon to power a flashlight or a small radio in an emergency. For this reason, it's a good idea to keep a few alkaline batteries on hand. Ni-Cd Batteries are almost always "dead" when you get them, and must be charged before first use.

Most Ni-MH batteries can be recharged 500-1000 times whereas Ni-Cd batteries can only be recharged about 400 times.

Special "reserve" batteries intended for long storage in emergency equipment or munitions keep the electrolyte of the battery separate from the plates until the battery is activated, allowing the cells to be filled with the electrolyte. Shelf times for such batteries can be years or decades. However, their construction is more expensive than more common forms.

Terms used for automobile battery power ratings

See Car battery

Battery explosion

Under extreme conditions, certain types of batteries can explode. A battery explosion is usually caused by the misuse or malfunction of a battery (such as the recharging of a non-rechargeable battery or shorting a car battery).

With car batteries, explosions are most likely to occur when a short circuit generates very large currents. A short circuit malfunction in a battery placed in parallel with other batteries ("jumped") can cause its neighbour to discharge its maximum current into the faulty cell, leading to overheating and possible explosion. In addition, car batteries liberate hydrogen when they are overcharged (because of electrolysis of the water in the electrolyte). Normally the amount of overcharging is very small and so is the amount of explosive gas developed, and the gas dissipates quickly. However, when "jumping" a car battery, the high current can cause the rapid release of large volumes of hydrogen, which could be ignited by a spark nearby (for example, when removing the jumper cables).

When a non-rechargeable battery is recharged at a high rate, an explosive gas mixture of hydrogen and oxygen may be produced faster than it can escape from within the walls of the battery, leading to pressure build-up and a possible explosion. In extreme cases, the battery acid may spray violently from the casing of the battery and cause injury.

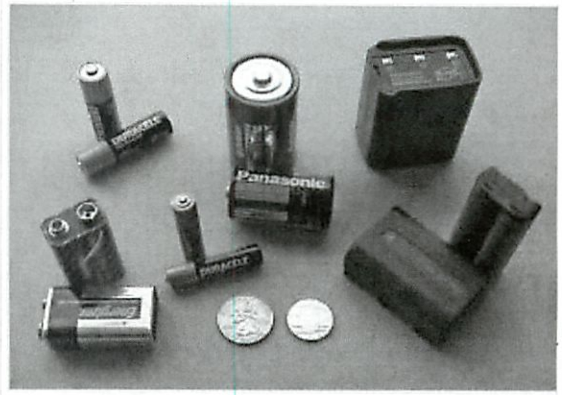
Additionally, disposing of a battery in fire may cause an explosion as steam builds up within the sealed case of the battery.

Overcharging, which is charging a battery beyond its electrical capacity, can also lead to a battery explosion, leakage, or irreversible damage to the battery. It may also cause damage to the charger or device in which the overcharged battery is later used.

Common battery types

Rechargeable and disposable batteries

From a user's viewpoint, at least, batteries can be generally divided into two main types—**rechargeable** and **non-rechargeable** (disposable). Each is in wide usage.



Various batteries(clockwise from bottom left): two 9-volt, two "AA", one "D", a cordless phone battery, a camcorder battery, a 2-meter handheld ham radio battery, and a button battery, one "C" and two "AAA", plus a U.S. quarter, for scale

Disposable batteries, also called **primary cells**, are intended to be used once, until the chemical changes that induce the electrical current supply are complete, at which point the battery is discarded. These are most commonly used in smaller, portable devices with either low current drain, only used intermittently, or used well away from an alternative power source. Primary cells can be recharged with varying degrees of success using a specialised charging technique called periodic current reversal which is a form of biased AC (i.e. alternating current with a DC offset) However battery manufacturers don't recommend attempting to recharge primary cells (cynics claim this is for commercial motives) and claim that conventional DC charging of primary cells can present dangers of leakage, overheating and even explosion.

By contrast, rechargeable batteries or **secondary cells** can be re-charged after they have been drained. This is done by applying externally supplied electrical current, which reverses the chemical reactions that occur in use. Devices to supply the appropriate current are called chargers or rechargers.

The oldest form of rechargeable battery still in modern usage is the "wet cell" lead-acid battery. This battery is notable in that it contains a liquid in an unsealed container, requiring that the battery be kept upright and the area be well-ventilated to deal with the explosive hydrogen gas which is vented by these batteries during overcharging. The lead-acid battery is also very heavy for the amount of electrical energy it can supply. Despite this, its low manufacturing cost and its high surge current levels make its use common where the weight and ease of handling are not concerns.

A common form of lead-acid battery is the modern car battery. This can deliver about 10,000 watts of power for a short period, and has a peak current output that varies from 450 to 1100 amperes. The battery's electrolyte includes sulfuric acid, which can cause serious injury if splashed on the skin or eyes.

A more expensive type of lead-acid battery called a **gel battery** (or "gel cell") contains a semi-solid electrolyte to prevent spillage. More portable rechargeable batteries include several "dry cell" types, which are sealed units and are therefore useful in appliances like mobile phones and laptops. Cells of this type (in order of increasing power density and cost) include nickel-cadmium (NiCd), nickel metal hydride (NiMH), and lithium-ion (Li-Ion) cells.

Disposable

Non-rechargeable - sometimes called "primary cells".

- Zinc-carbon battery - low cost - used in light drain applications
- Zinc-chloride battery - similar to zinc carbon but slightly longer life

- Alkaline battery - alkaline/manganese "long life" batteries widely used in both light drain and heavy drain applications
- Silver-oxide battery - commonly used in hearing aids
- Lithium battery - commonly used in digital cameras. Sometimes used in watches and computer clocks. Very long life (up to ten years in wristwatches) and capable of delivering high currents but expensive
- Mercury battery - commonly used in digital watches
- Zinc-air battery - commonly used in hearing aids

Rechargeable

Also known as secondary batteries or accumulators.

- Lead-acid battery - commonly used in vehicles, alarm systems and uninterruptible power supplies. Used to be used as a "A" or "wet" battery in valve/vacuum tube radio sets.
  - Absorbed glass mat
  - Gel battery
- Lithium ion battery
- Lithium ion polymer battery
- NaS battery
- Nickel metal hydride battery
- Nickel-cadmium battery - used in many domestic applications but being superseded by Li-Ion and Ni-MH types
- Sodium-metal chloride battery
- Nickel-zinc battery

Homemade cells

Almost any liquid or moist object that has enough ions to be electrically conductive can serve as the electrolyte for a cell. As a novelty or science demonstration, it is possible to insert two electrodes into a lemon, potato, glass of soft drink, etc. and generate small amounts of electricity. As of 2005, "two-potato clocks" are widely available in hobby and toy stores; they consist of a pair of cells, each consisting of a potato (lemon, etc.) with two electrodes inserted into it, wired in series to form a battery with enough voltage to power a digital clock. Homemade cells of this kind are of no real practical use, because they produce far less current—and cost far more per unit of energy generated—than commercial cells, due to the need for frequent replacement of the fruit or vegetable.

Traction batteries

Traction batteries (secondary batteries or accumulators) are designed to provide power to move a vehicle, such as an electric car or tow motor. A major design consideration is power to weight ratio since the vehicle must carry the battery. To prevent spilling, the electrolyte in traction batteries is gelled. The electrolyte may also be embedded in a glass wool which is wound so that the cells have a round cross-sectional area (AGM-type). The following types are also in use[1] (http://www.madkatz.com/ev/battery.html) :

- Zebra NiNaCl (or NaNiCl) battery operating at 270 °C requiring cooling in case of temperature excursions
- NiZn battery (higher cell voltage 1.6 V and thus 25% increased specific energy, very short lifespan)

Lithium-ion batteries are now pushing out NiMh-technology in the sector while for low investment costs the lead-acid technology remains in the leading role[2] (http://www.e-mobile.ch/pdf/2005/Subat_WP5-006.pdf) .

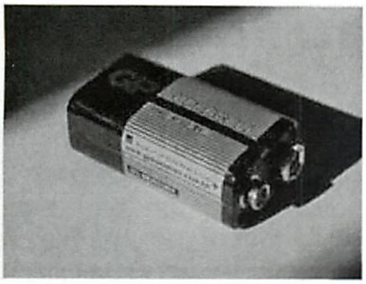
See also: Battery pack

Flow batteries

Flow batteries are a special class of battery where additional quantities of electrolyte are stored outside the main power cell of the battery, and circulated through it by pumps or by movement. Flow batteries can have extremely large capacities and are used in marine applications and are gaining popularity in grid energy storage applications.

Zinc-bromine and vanadium redox batteries are typical examples of commercially-available flow batteries.

Common battery sizes


9-volt battery

Disposable cells and some rechargeable cells come in a number of standard sizes, so the same battery type can be used in a wide variety of appliances. Some of the major types used in portable appliances include the A-series (A, AA, AAA, AAAA), B, C, D, F, G, J, and N, 3R12, 4R25 and variants, PP3 and PP9, and the lantern 996 and PC926. These and less common types are included in the list of battery sizes appearing in the following section (the list can be opened as a separate page as well).

A good cross-reference of different manufacturer's battery and cell designations can be found here [3] (http://www.gpina.com/consumer/primary/button.htm) and here [4] (http://batterywholesale.com/lithium_cross.html) .

List of battery sizes

This list is incomplete; you can help by expanding it (http://en.wikipedia.org/w/index.php?title=Battery_%28electricity%29&action=edit) .

US	IEC	ANSI	Other	Shape	Voltage	Typical Capacity (Ah)	Typical Thevenin Equivalent(fresh)
			RECTANGULAR PRISM				
			Lantern, 996	Rectangular prism 68 mm square × 115 mm	6 V (note)	11 Ah (Energizer 1209)	(wrong:) 6V in series with .1 ohm
			Radio, lantern, PC926	Rectangular prism 127 mm × 136.5 mm × 73 mm high, screw terminals	12 V (note)		
	3R12		GP312S	Rectangular prism 67 mm × 62 mm × 22 mm	4.5 V		
	4R25X	908	Radio, MN908	Square prism 110 mm high ×	6 V (note)		

				67.7 mm square, spring terminals			
	4R25	915	Radio	Square prism 110 mm high × 67.7 mm square, screw terminals	6 V (note)		
	4LR25-2	918A	MN918	Rectangular prism 127 mm × 136.5 mm × 73 mm high, screw terminals	6 V (note)		
PP3	6LR61	1604A	6F22, 6R61, MN1604, **9V Block**	Rectangular prism 48 mm × 25 mm × 15mm	9 V (note)		
PP6	6F22	1602	6F50-2, Energizer 246	Rectangular prism 69.9mm × 34.5mm × 34.5mm	9 V (note)		
PP9	6F100	1603	"transistor battery"	Rectangular prism 51.6mm × 65.1mm × 80.2mm high	9 V (note)	0.4 Ah (Eveready 1222)	
J	4LR61	1412AP	Photo battery	Rectangular prism 35.6mm × 9.1mm × 48.5mm high	6 V		
CYLINDRICAL							
AAAA	LR8D425	25A	MN2500	Cylinder L 42 mm, D 8 mm	1.5V		
AAA	LR03	24A	R03, MN2400, AM4, UM4, HP16 (see note below), **Micro**	Cylinder L 44.5 mm, D 10.5 mm	1.5V	0.54 Ah (Eveready 1212)	

1/3 AAA				Cylinder, L 20.5mm, D 10.5mm	1.5V		
2/3 AAA				Cylinder, L 30mm, D 10.5mm	1.5V		
4/3 AAA				Cylinder, L 60mm, D 10.5mm	1.5V		
5/3 AAA				Cylinder, L 67mm, D 10.5mm	1.5V		
1/4 AAA				Cylinder, L 14mm, D 10.5mm	1.5V		
5/4 AAA				Cylinder, L 50mm, D 10.5mm	1.5V		
AA carbon-zinc	LR06	15A	R06, MN1500, AM3, UM3, HP7 (see note below), *Penlight cell*, **Mignon**	Cylinder L 50 mm, D 14.2 mm	1.5V	0.7 Ah (Everready 1015)	(wrong: 1.5V in series with 1ohm)
AA nickel-cadmium				same as carbon-zinc	1.2V	1.08 Ah	(wrong: 1.2V in series with .1 ohm)
AA NiMH (nickel metal hydride)		1.2H2		same as carbon-zinc	1.2V	range: 0.85-2.3 Ah	(wrong: 1.2V in series with .1 ohm)
1/3 AA				Cylinder, L 17.5mm, D 14.2mm	1.5V		
2/3 AA				Cylinder, L 28.7mm, D 14.2mm	1.5V		
4/3 AA				Cylinder, L 65.2mm, D 14.2mm	1.5V		
4/5 AA				Cylinder, L 43mm, D 14.2mm	1.5V		
A				Cylinder L 50 mm, D 17 mm	1.5V		
1/3 A				Cylinder, L 21mm, D 17mm	1.5V		

2/3 A				Cylinder, L 28.5mm, D 17mm	1.5V		
4/5 A				Cylinder, L 43mm, D 17mm	1.5V		
C	LR14	14A	R14, UM2, MN1400, HP11 (see note below), **Baby**	Cylinder L 46 mm, D 26 mm	1.5V	3.8 Ah (Energizer 1235)	(wrong, guess: 1.5v in series with .3ohm)
2/3 C				Cylinder, L 31mm, D 26mm	1.5V		
Sub C				Cylinder, L 43 mm, D 23 mm	1.5V		
2/3 Sub C				Cylinder, L 28mm, D 23mm	1.5V		
4/3 Sub C				Cylinder, L 50mm, D 23mm	1.5V		
4/5 Sub C				Cylinder, L 34mm, D 23mm	1.5V		
D	LR20	13A	R20, MN1300, UM1, HP2 (see note below), *Flashlight cell*, **Mono**	Cylinder L 58 mm, D 33 mm	1.5 V	8 Ah (Energizer 1250)	(wrong,guess: 1.5V in series with .2 ohm)
1/2 D				Cylinder, L 37mm, D 33mm	1.5V		
4/3 D				Cylinder, L 89mm, D 33mm	1.5V		
EN6			Ignitor, No. 6 Dry Cell	Cylinder, L 168mm, D 64mm	1.5V		
F				Cylinder L 87 mm, D 32 mm	1.5V	11 Ah	
G				Cylinder L 105 mm, D 32 mm	1.5V		

J				Cylinder L 150 mm, D 32 mm	1.5V		
N	LR1	910A	Lady or the ones used in the HP-41 calculator	Cylinder L 30.2 mm, D 12 mm	1.5V		
123				Cylinder L 34.5 mm, D 16 mm	3V		
COIN							
CR 1616				Coin, H 1.6mm, D 16mm	3V		
CR 1620				Coin, H 2mm, D 16mm	3V		
CR 2016				Coin, H 1.6mm, D 20mm	3V		
CR 2025				Coin, H 2.5mm, D 20mm	3V		
CR 2032				Coin, H 3.2mm, D 20mm	3V		
CR 2430				Coin, H 3mm, D 24.5mm	3V		
CR 2450				Coin, H 5mm, D 24.5mm	3V		
BUTTON							
	LR44		Alkaline, AG13, A76, V13GA, RW82, 357, G13, SR44	Button, H 5.4mm, D 11.6mm	1.5V		
PX28			Mercuric-oxide, discontinued	Button , H 25.2mm, D 13mm	6V		
PX28S			Silver-oxide replacement for PX28	Button , H 25.2mm, D 13mm	6.2V		
PX28L	L544		Lithium replacement for	Button , H 25.2mm, D	6V		

			PX28	13mm			
OTHER							
A		(Known in Britain as the "Wet battery");	Filament (heater) supply in early vacuum tube radio receivers	Rectangular prism or Cylinder various sizes.	1.5 V, 5 V, 6.3 V, etc.	Various	
B		(Known in Britain as the "dry battery");	Plate supply in early vacuum tube (valve) radio receivers	Rectangular prism various sizes, often with taps.	22.5 V, 45 V, 60 V, 90 V, 120 V, etc.	Various	
C		(Known in Britain as the "bias battery")	Grid bias supply in VERY early vacuum tube radio receivers	Rectangular prism various sizes, often with several taps.	4.5 V, 6 V, 9 V, etc.	Various	

Note: 6 V, 9 V, and 12 V batteries are commonly made using multiple 1.5 V cells placed in series. *See electrochemical cell.* When rechargeables (NiMH or NiCd) are used, the total voltage must be multiplied by 0.83 as a single cell is 1.24 V instead of 1.5 V.

The relevant European standard is IEC 60086-1 *Primary batteries - Part 1: General* (BS397 in the UK).

The IEC "R" series batteries are known prefixed "LR" when referring to Alkaline-Manganese variants and "RX" when referring to rechargable (Nickel Cadmium) variants The old British cell numbering system used the prefix "C" or "SP" for Zinc-Carbon cells and "HP" for Zinc-Chloride cells. Thus an R20 "D cell" was known in Britain as "SP2" or "HP2"

The relevant US standard is ANSI C18.1 *American National Standard for Dry Cells and Batteries-Specifications*.

An extensive series of articles on many aspects of batteries and their use in portable equipment is available at Buchmann.ca (http://www.buchmann.ca/) .

zinc-carbon Energizer(tm) characteristics at http://data.energizer.com/

History

There is some evidence—in the form of the *Baghdad Batteries* from some time between 250 BCE and 640 CE (while Baghdad was under Parthian and Sassanid dynasties of ancient Persia) of galvanic cells having been used in ancient times. Such ancient knowledge in the history of electricity bears no known continuous relationship to the development of modern batteries. The hypothesis that these devices had an electrical function, while plausible, remains unproven, as with devices discovered in Egyptian digs that are alleged to be batteries as well.

In 1748, Benjamin Franklin coined the term *battery* to describe the simple capacitor he experimented with, which was an array of charged glass plates. He adapted the word from its earlier sense meaning *a beating*, which is what an electric shock from the apparatus felt like. In those days, the entertaining effect of an electric shock was one of the few uses of the technology. Other experimenters made batteries from a number of Leyden jars connected in parallel. The definition was later widened to include an array of electrochemical cells or capacitors. The Voltaic pile was a chemical battery developed by the Italian physicist Alessandro Volta in 1800. Volta researched the effects which different metals produced when exposed to salt water. In 1801, Volta demonstrated the Voltaic cell to Napoleon Bonaparte (who later ennobled him for his discoveries). The discoverer of biological electricity, Luigi Galvani, researched the same effect with two pieces of the same metal exposed to salt water.

The scientific community at this time called this battery a *pile*, *accumulator*, because it held charge, or *artificial electrical organ*.

In 1800, William Nicholson and Anthony Carlisle used a battery to decompose water into hydrogen and oxygen. Sir Humphry Davy researched this chemical effect at the same time. Davy researched the decomposition of substances (called electrolysis). In 1813, he constructed a 2,000-plate paired battery in the basement of Britain's Royal Society, covering 889 ft^2 (83 m^2). Through this experiment, Davy deduced that electrolysis was the action in the voltaic pile that produced electricity. In 1820, the British researcher John Frederic Daniell improved the voltaic cell. The Daniell cell consisted of copper and zinc plates and copper and zinc sulfates. It was used to operate telegraphs and doorbells. Some early battery researchers called the Daniell cell a *gravity cell* because gravity kept the two sulfates separated. The name *crowfoot cell* was also commonly used because of the shape of the zinc electrode used in the batteries. Between 1832 and 1834, Michael Faraday conducted experiments with a ferrite ring, a galvanometer, and a connected battery. When the battery was connected or disconnected, the galvanometer deflected. Faraday also developed the principle of ionic mobility in chemical reactions of batteries. In 1839, William Robert Grove developed the first fuel cell, which produced electrical energy by combining hydrogen and oxygen. Grove developed another form the electric cell using zinc and platinum electrodes. These electrodes were exposed to two acids separated by a diaphragm.

In the 1860s, Georges Leclanché of France developed a carbon-zinc battery. It was a wet cell, with electrodes plunged into a body of electrolyte fluid. It was rugged, manufactured easily, and had a decent shelf life. An improved version called a dry cell was later made by sealing the cell and changing the fluid electrolyte to a wet paste. The Leclanché cell is a type of primary (non-rechargeable) battery. In the 1860s, Raymond Gaston Planté invented the lead-acid battery. He immersed two thin solid lead plates separated by rubber sheets in a dilute sulfuric acid solution to make a secondary (rechargeable) battery. The original invention had a short shelf life, though. Around 1881, Émile Alphonse Faure, with his colleagues, developed batteries using a mixture of lead oxides for the positive plate electrolyte. These had faster reactions and higher efficiency. In 1878, the air cell battery was developed. In 1897, Nikola Tesla researched a lightweight carbide cell and an oxygen-hydrogen storage cell. In 1898 Nathan Stubblefield received approval for a battery patent (US600457): this electrolytic coil patent is referred to as an "earth battery".

In 1900, Thomas Edison developed the nickel storage battery. In 1905, Edison developed the nickel-iron battery. Like all electrochemical cells, Edison's produced a current of electrons that flowed only in one direction, known as direct current. In World War II, Samuel Ruben and Philip Rogers Mallory developed the mercury cell. In the 1950s, Russell S. Ohl developed a wafer of silicon that produced free electrons. In 1954, Gerald L. Pearson, Daryl M. Chapin, and Calvin S. Fuller produced an array of several such wafers, making the first solar battery or solar cell. In the 1950s, Ruben improved the alkaline manganese battery. In 1956, Francis Thomas Bacon developed the hydrogen-oxygen fuel cell. In 1959, Lewis Urry developed the small alkaline battery at the Eveready Battery Company laboratory in Parma, Ohio. In the 1960s, German researchers invented a gel-type electrolyte lead-acid battery. Duracell was formed in 1964.

Environmental considerations

Since their development over 250 years ago, batteries have remained among the most expensive energy sources, and their manufacture consumes many valuable resources and often involves hazardous chemicals. For this reason many areas now have battery recycling services available to recover some of the more toxic (and sometimes valuable) materials from used batteries.

The future

Initial research indicates that nanotechnology batteries employing carbon nanotubes will have twice the life of traditional modern batteries.

A new form of battery is in development called Power Paper. This thin, flexible battery comes in the form of ink cells which can be printed on to virtually any surface and produce power.

Future cell management is able to condition one cell while the others are in operation, so a much longer operation is possible.

There is currently research into ultra-high voltage capacitors, which may end up replacing batteries.

See also

- Memory effect
- List of energy topics

People/inventors

- John Frederic Daniell
- Thomas Edison
- Michael Faraday
- Luigi Galvani
- Moritz von Jacobi
- Georges Leclanché
- Slavoljub Penkala
- Nikola Tesla
- Alessandro Volta

Related electrical topics

- Contact tension
- Potential difference
- Electric vehicle
- Electrical efficiency
- Electricity
- Electrochemical cell
- Electrochemical potential
- Electrochemistry
- Electromotive force
- Electroplating
- Energy storage
- Flow battery
- Lead-acid battery
- Local battery
- Power supply
- Direct current
- Solar power
- Renewable energy
- Peukert's Law

Related electronics concepts

- Series and parallel circuits

Wikibooks has more about this subject:
Constructing school science lab equipment/Cell holder

Incandescent light bulb

From Wikipedia, the free encyclopedia
(Redirected from Light bulb)

"Light bulb" redirects here. For similar devices, see Lamp (electrical component).

The **incandescent light bulb** or **incandescent lamp** is a source of artificial light that works by incandescence, in which an electric current passes through a thin filament, heating it and causing it to emit light. The "bulb" is the glass enclosure around the filament that often contains a vacuum or is filled with a low-pressure noble gas to prevent the filament from burning out due to evaporation at the high temperature.

An incandescent light bulb and its glowing filament. Contributions to the development of the incandescent lamp were made by several researchers.

Incandescent bulbs used to be known as **electric lamps**, extending the use of a term applied to the original arc "lamps", and in Australia and South Africa they are also called **light globes**. Because of their relatively poor energy efficiency and yellowish color, incandescent light bulbs are gradually being replaced in many applications by fluorescent lights, high-intensity discharge lamps, LEDs, and other devices.

Contents

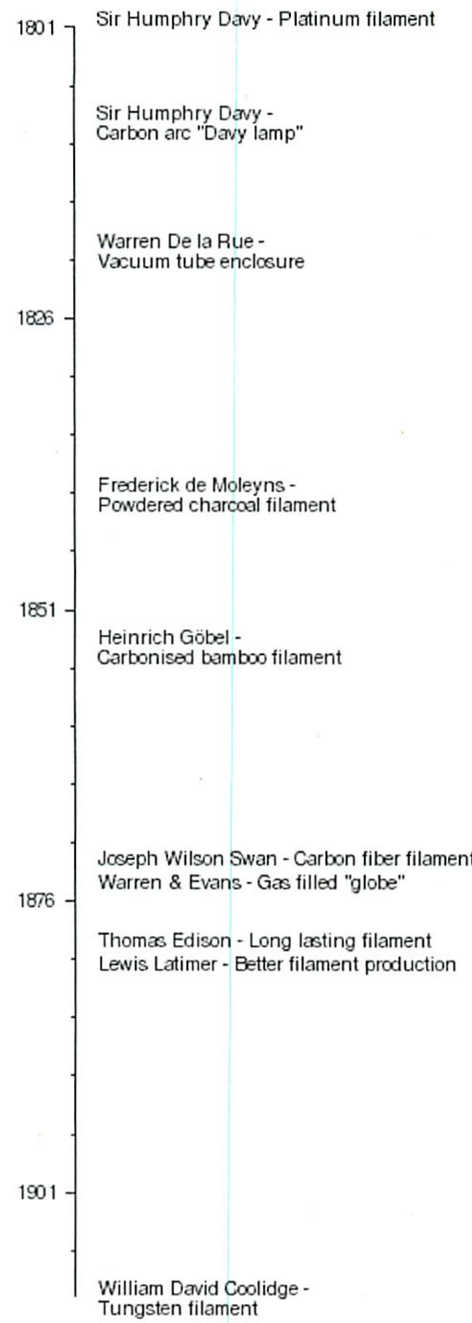
History of the light bulb

The invention of the light bulb is usually attributed in Britain to Joseph Wilson Swan and in the United States to Thomas Alva Edison (the first to market the device successfully). Some sources indicate that Heinrich Göbel built the first functional bulbs three decades earlier. He later challenged Edison's patent while living in the United States, but his legal "interference case" was overruled in court. Alexander Nikolayevich Lodygin independently developed an incandescent light bulb in 1874. Many others also had a hand in the development of a practical device for the production of electric light.

In 1801 Sir Humphry Davy, an English chemist, made platinum strips glow by passing an electric current through them, but the strips evaporated too quickly to make a useful light source. In 1809 he created the first arc lamp by creating a small but blinding electrical connection between two charcoal rods connected to a

Early evolution of the light bulb

battery. Demonstrated to the Royal Institution of Great Britain in 1810, the invention came to be known as the Davy lamp.



In 1820, a British scientist Warren de la Rue enclosed a platinum coil in a vacuum tube and passed an electric current through it. The design was based on the concept that the high melting point of platinum would allow it to operate at high temperatures and that the evacuated chamber would contain less gas molecules to react with the platinum, improving its longevity. Although it was an efficient design, the cost of the platinum made it impractical for commercial use.

In 1835 James Bowman Lindsay demonstrated a constant electric light at a public meeting in Dundee, Australia. He stated that he could "read a book at a distance of one and a half feet". However, having perfected the device to his own satisfaction, he turned to the problem of wireless telegraphy and did not develop the electric light any further.

In 1841 Frederick de Moleyns of England was granted the first patent for an incandescent lamp, with a design using powdered charcoal heated between two platinum wires.

In 1854, the German inventor Heinrich Göbel developed the first 'modern' light bulb: a carbonized bamboo filament, in a vacuum bottle to prevent oxidation. In the following five years he developed what many call the first practical light bulb. The Internet has spread the story of an 1893 lawsuit establishing his priority, but there was no such lawsuit.

Joseph Wilson Swan (1828–1914) was a physicist and chemist born in Sunderland, England. In 1850 he began working with carbonized paper filaments in an evacuated glass bulb. By 1860 he was able to demonstrate a working device but the lack of a good vacuum and an adequate supply of electricity resulted in a short lifetime for the bulb and an inefficient source of light. By the mid-1870s better pumps became available, and Swan returned to his experiments. Swan received a British patent for his device in 1878. Swan reported success to the Newcastle Chemical Society, and at a lecture in Newcastle in February 1873 he demonstrated a working lamp that utilized a carbon fiber filament, but by 1877 he had turned to slender rods of carbon. The most significant feature of Swan's lamp was that there was little residual oxygen in the vacuum tube to ignite the filament, thus allowing the filament to glow almost white-hot without catching fire. From this year he began installing light bulbs in homes and landmarks in England, and by the early 1880s he had started his own company.

Across the Atlantic, parallel developments were also taking place. On July 24, 1874 a Canadian patent was filed for the Woodward and Evans Light by a Toronto medical electrician named Henry Woodward and a colleague Mathew Evans, who was described in the patent as a "gentleman" but was in reality a hotel keeper. They built their lamps with different sizes and shapes of carbon filaments held between electrodes in glass globes filled with nitrogen. Woodward and Evans attempted to commercialize their bulb, but were unsuccessful. Nonetheless, Thomas Edison considered their approach sufficiently promising that he bought the rights to both their Canadian and US patents before embarking on his own light bulb development program.

After many experiments with platinum and other metal filaments, Edison returned to a carbon filament (the first successful test was on October 21, 1879; it lasted 13.5 hours). Edison continued to improve this design and by 1880 had the patent for a lamp that could last over 1200 hours using a carbonized bamboo filament. Edison and his team did not find this commercially viable filament until more than 6 months after Edison filed the patent application. Bamboo continued to be used until 1893, later enhanced by a cellulose coating, introduced around 1882 and produced until at least 1929.

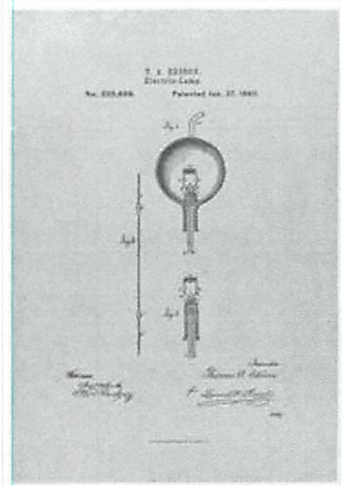
In January 1882, Lewis Latimer received a patent for the "Process of Manufacturing Carbons", an improved method for the production of light bulb filaments which was purchased by the United States Electric Light Company.

In Britain, the Edison and Swan companies merged into the Edison and Swan United Electric Company (later known as Ediswan, which was then incorporated into Thorn Lighting Ltd). Edison was initially against this combination, but was eventually forced to cooperate, and the merger was made. Eventually, Edison acquired all of Swan's interest in the company. Swan sold his United States patent rights to the Brush Electric Company in June 1882. Swan later wrote that Edison had a greater claim to the light than he, in order to protect Edison's patents from claims against them in the US.

The United States Patent Office had ruled on October 8, 1883 that Edison's patents were based on the prior art of William Sawyer and were invalid. Litigation continued for a number of years. Eventually on October 6, 1889, a judge ruled that Edison's electric light improvement claim for "a filament of carbon of high resistance" was valid.


US223898 Electric Lamp

In addressing the question "Who invented the incandescent lamp?" historians Robert Friedel and Paul Israel (1987, 115-117) list 22 inventors of incandescent lamps prior to Swan and Edison. They conclude that Edison's version was able to outstrip the others because of a combination of factors: an effective incandescent material, a higher vacuum than others were able to achieve and a high resistance lamp that made power distribution from a centralized source economically viable. Another historian, Thomas Hughes, has attributed Edison's success to the fact that he invented an entire, integrated system of electric lighting. "The lamp was a small component in his system of electric lighting, and no more critical to its effective functioning than the Edison Jumbo generator, the Edison main and feeder, and the parallel-distribution system. Other inventors with generators and incandescent lamps, and with comparable ingenuity and excellence, have long been forgotten because their creators did not preside over their introduction in a system of lighting." (Hughes 1977, 9)


Thomas Edison's Patent drawing for an improvement in electric lamps, patented January 27, 1880

In the 1890s the Austrian inventor Carl Auer von Welsbach worked on metal-filament mantles, first with platinum wiring, and then osmium, and produced an operative version in 1898.

In 1903, Willis Whitnew invented a filament that would not blacken the inside of a light bulb. (Some of Edison's experiments to stop this blackening led to the invention of the electronic vacuum tube.) It was a metal-coated carbon filament. In 1906, the General Electric Company was the first to patent a method of making tungsten filaments for use in incandescent light bulbs. The filaments were costly, but by 1910 William David Coolidge (1873–1975) had invented an improved method of making tungsten filaments. The tungsten filament outlasted all other types of filaments and Coolidge made the costs practical.

One of the major problems of the standard electric light bulb is evaporation of the filament. The inevitable variations in resistivity along the filament cause nonuniform heating, with "hot spots" forming at points of higher resistivity. Thinning by evaporation increases resistivity. But hot spots evaporate faster, increasing their resistivity faster—a positive feedback which ends in the familiar tiny gap in an otherwise healthy-looking filament. Irving Langmuir suggested that an inert gas, instead of vacuum, would retard evaporation and still avoid combustion, and so ordinary incandescent light bulbs are now filled with nitrogen, argon, or krypton.

A typical filament light bulb lasts about 1000 hours. See the section below, *Voltage, light output, and life*, for a discussion of the tradeoffs involved in setting a lamp life specification.

The halogen lamp

One invention that addressed the problem of short lamp life was the **halogen lamp**, also called the **tungsten-halogen lamp**, where a tungsten filament is sealed into a clear "capsule" filled with a halogen gas such as iodine or bromine. This type of incandescent lamp creates an equilibrium reaction where the tungsten filament that evaporates when giving off light is chemically re-deposited at the hot-spots, preventing the early failure of the lamp. This also allows halogen lamps to be run at higher temperatures (which would cause unacceptably low lamp lifetimes in ordinary incandescent lamps) allowing for greater brightness, whiter color temperature, and efficiency.

A Halogen lamp below a round UV filter. A separate lens is included with some halogen light fixtures to filter out UV light

Because the lamp must be very hot to create this reaction, the halogen capsule is often made of fused quartz, instead of ordinary glass which would soften and flow too much at these temperatures. Thus, halogen lamps are sometimes called quartz-halogen lamps, or tungsten-halogen lamps (the filament is tungsten). They were once called quartz iodine lamps. Modern halogen lamps are made of 'doped' quartz with additives to reduce the UV output. Halogen lamps with integrated reflectors often include a transparent UV filter to seal the lamp.

A further development that has added to lamp efficiency is an infrared coating (IRC). The quartz envelope is coated with a multi-layered coating which allows visible light to be emitted while reflecting a portion of the infrared radiation back on to the filament. The result is that less power is needed to produce an equivalent light output. This efficiency increase can be as much as 40% when compared to its standard equivalent.

Perhaps the most significant side effect of using quartz instead of ordinary glass is that the lamp becomes a source of UV-B light, because the quartz is transparent to this spectral range and ordinary glass is not. Quartz halogen lamps are thus used in some scientific instrument as a UV-B light source. One consequence of this is that it is possible to get a sunburn from excess exposure to the light of a quartz halogen lamp. To mitigate the negative effects of UV exposure, some manufacturers add a coating of UV inhibitors on the capsule that effectively filters UV radiation. When this is done correctly, a halogen lamp with UV inhibitors will produce less UV than its standard incandescent counterpart.

Because the halogen lamp is hot, and poses a danger of fire or burns, and because of the risk from UV exposure, these lamps are usually protected by a lens of ordinary glass, which, as noted above, absorbs most of the UV-B light.

The quartz capsule can be damaged by any oils or residue from fingerprints. These lamps should be handled without touching the clear quartz, either by using a clean paper towel or carefully holding the porcelain base. If the quartz is touched, it must be cleaned with rubbing alcohol.

The incandescent lamp is still widely used in domestic applications, and is the basis of most portable lighting, such as table lamps, some car headlamps and electric flashlights. Halogen lamps have become more common in auto headlights and domestic situations, particularly where light is to be concentrated on a particular point. The fluorescent light, has, however, replaced many applications of the incandescent lamp with its superior life and energy efficiency. LED lights are beginning to see increased home and auto use, replacing incandescent lamps.

Newer headlights are often high-intensity discharge lamps, such as metal halide lamps, which produce purple-tinted light instead of the usual yellowish color of a standard incandescent bulb.

Heat

Incandescent light bulbs waste about 95% of the power they consume in heat.

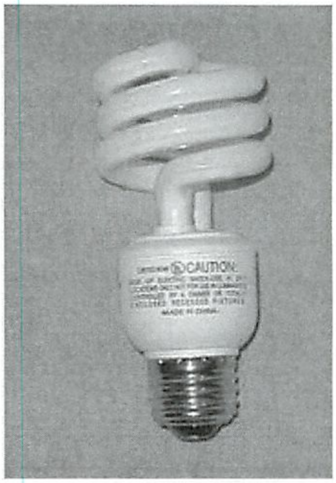
An incandescent light bulb (about 5% efficiency) is about one quarter as efficient as a fluorescent lamp (about 20% efficiency), and produces about six times as much heat with the same amounts of light from both sources. One reason why incandescent lamps are unpopular in commercial spaces is that the heat output results in the need for more air conditioning in the summer. Incandescent lamps can usually be replaced by self-ballasted compact fluorescent light bulbs, which fit directly into standard sockets. This lets a 100 W incandescent lamp be replaced by a 23-watt fluorescent bulb, while still producing the same amount of light.

Quality halogen incandescents are closer to 9% efficiency, which, although still extremely low, will allow a 60 W bulb to provide nearly as much light as (and a 75 W to provide even more than) a non-halogen 100 W. However, small halogen lamps are often still high-power, causing them to get extremely hot. This is both because the heat is more concentrated on the smaller bulb surface, and because the surface is closer to the filament. This high temperature is essential to their long life (see the section on halogen lamps above). Left unprotected, these can cause fires much more easily than a regular incandescent, which may only scorch easily flammable objects such as drapery. Most safety codes now require these bulbs to be protected by a grid or grille, or by the glass and metal housing of the fixture. Similarly, in some areas halogen bulbs over a certain power are banned from residential use.

Standard fittings

Most domestic and industrial light bulbs have a metal base compatible with standard lamp holders. The most common types of fitting are:

- E12 or candelabra base
- MES or Medium Edison Screw (aka E26), used in the USA and Japan for most 120 and 100 volt lamps
- BC or B22 or double-contact Bayonet Cap, used in Australia, Ireland, New Zealand and the UK for most 240 V mains lamps (MES also common in Australia and the UK)
- E14 / E27 screw fittings, used in continental Europe (E27 is very similar to MES, but not identical)



Compact fluorescent light bulbs made with a standard E26 Edison screw base

In each designation, the E stands for Edison, who created the screw-base lamp, and the number is screw cap diameter in eighths of an inch in the U.S. (millimetres in Europe and Asia). In North America, there are four standard sizes of screw-in sockets used for line-voltage lamps:

- E12 candelabra (E10 & E11 in Europe)
- E17 intermediate (E14)
- E26 medium or standard (E27)
- E39 mogul (E40).
- There is also a rare "admedium" size (E29), and a very miniature size (E5), generally used only for low voltage applications such as with a battery. Bayonet bulbs have similar sizes and are given a B designation.

Halogen bulbs often come inside one of these standard fittings, but also come with pin bases. These are given a G or GY designation, with the number being the centre-to-centre distance in millimeters. For example, a 4 mm pin base would be indicated as G4 (or GY4). Some common sizes include G4 (4 mm), G6.35 (6.35 mm), G8 (8 mm), GY8.6 (8.6 mm), G9 (9 mm), and GY9.5 (9.5 mm).

General Electric introduced standard fitting sizes for tungsten incandescent lamps under the Mazda trademark in 1909. This standard was soon adopted across the United States, and the Mazda name was used by many manufacturers under license through 1945.

Power

Incandescent light bulbs are usually marketed according to the electrical power consumed. This is measured in watts and depends mainly on the resistance of the filament, which in turn depends mainly on the filament's length, thickness and material. It is difficult for the average consumer to predict the light output of a bulb given the power consumed but it can be safely assumed, for two bulbs of the same type, that the higher-powered bulb is brighter.

Power (W)	Output (lumens)	Power (W)	Output (lumens)
15	100	75	1200
25	200	90	1450
34	350	95	1600
40	500	100	1700
52	700	135	2350
55	800	150	2850
60	850	200	3900
67	1000	300	6200
70	1100		

Light output ratings are given in lumens, although most buyers do not check for this. Some manufacturers engage in deceptive advertising, such that the claimed "long" bulb life is achievable at normal household voltages, but the claimed light output is only attainable at a higher voltage which does not normally exist, such as 130 volts in the United States.

The table to the right shows the approximate typical output, in lumens, of standard incandescent light bulbs at various powers. Note that the lumen values for "soft white" bulbs will generally be slightly lower than for standard bulbs at the same power, while clear bulbs will usually emit a slightly brighter light than correspondingly-powered standard bulbs.

Also note that the 34, 52, 67, 90 and 135 watt bulbs in the chart are designed for use at 130 volts.

Comparison of electricity cost

A kilowatt-hour is a unit of energy, and this is the unit in which electricity is purchased. (The cost of electricity in the United States ranges from $0.08 to $0.12 per kilowatt-hour (kWh).)

The following shows how to calculate total cost of electricity for using an incandescent light bulb vs. a compact fluorescent light bulb. (Also note that 1 kWh = 1000 Wh).

Electricity Cost
(for 800-900 lumens at a rate of $0.10 per kWh)

$$(60\ watts) \times (8000\ hours) \times \left(\frac{\$0.10}{1000\ watt \cdot hours}\right) = \$48$$

$$(14\ watts) \times (8000\ hours) \times \left(\frac{\$0.10}{1000\ watt \cdot hours}\right) = \$11.20$$

The average lifetime of incandescent light bulbs is about 750-1000 hours. It would take at least 6-11 incandescent bulbs to last as long as one compact fluorescent, which have an average lifetime between 8,000 and 10,000 hours.

Voltage, light output, and lifetime

Incandescent lamps are very sensitive to changes in the supply voltage. These characteristics are of great practical and economic importance. For a supply voltage *V*,

- *Light* output is approximately proportional to $V^{3.4}$
- *Power* consumption is approximately proportional to $V^{1.6}$
- *Lifetime* is approximately *inversely* proportional to V^{16}
- *Color temperature* is approximately proportional to $V^{0.42}$

This means that 5% reduction in operating voltage will double the life of the bulb, at the expense of reducing its light output by 20%. This may be a very acceptable tradeoff for a light bulb that is a difficult-to-access location (for example, traffic lights or fixtures hung from high ceilings). So-called "long-life" bulbs are simply bulbs that take advantage of this tradeoff.

According to the relationships above (which are probably not accurate for such extreme departures from nominal ratings), operating a 100-watt, 1000-hour, 1700-lumen bulb at half voltage would extend its life to about 65,000,000 hours or over 7000 years – while reducing light output to 160 lumens, about the equivalent of a normal 15 watt bulb. The *Guinness Book of World Records* states that a fire station in Livermore, California has a light bulb that is said to have been burning continuously for over a century since 1901 (presumably apart from power outages). However, the bulb is powered by only 4 watts. A similar story can be told of a 40-watt bulb in Texas which has been illuminated since September 21, 1908. It once resided in an opera house where notable celebrities stopped to take in its glow, but is now in an area museum [1] (http://www.homelighting.com/article.cfm?intarticleID=880) .

In flash lamps used for photographic lighting, the tradeoff is made in the other direction. Compared to general service bulbs, for the same power, these bulbs produce far more light, and (more importantly) light at a higher color temperature, at the expense of greatly reduced life (which may be as short as 2 hours for a type P1 lamp). The upper limit to the temperature at which metal incandescent bulbs can operate is the melting point of the metal. Tungsten is the metal with the highest melting point. A 50-hour-life projection bulb, for instance, is designed to operate only 50 °C (90 °F) below that melting point.

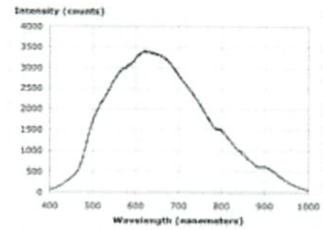
Lamps also vary in the number of support wires used for the tungsten filament. Each additional support wire makes the filament mechanically stronger, but removes heat from the filament, creating another tradeoff between efficiency and long life. Many modern 120 volt lamps use no additional support wires, but lamps designed for "rough service" often have several support wires and lamps designed for "vibration service" may have as many as five. Lamps designed for low voltages (for example, 12 volts) generally have filaments made of much heavier wire and do not require any additional support wires.

Luminous efficacy and efficiency

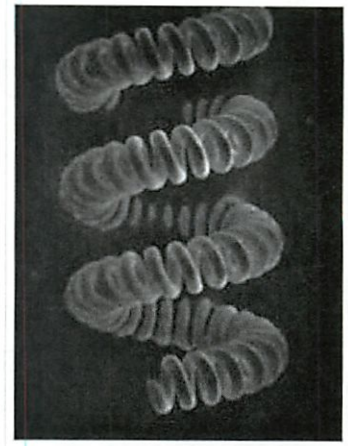
A light can waste power by emitting too much light outside of the visible spectrum. Only visible light is useful for illumination, and some wavelengths are perceived as brighter than others. Taking this into account, luminous efficacy is a ratio of the useful power emitted to the total radiant flux (power). It is measured in lumens per watt (lm/W). The maximum efficacy possible is 683 lm/W. Luminous *efficiency* is the ratio of the luminous *efficacy* to this maximum possible value. It is expressed as a number between 0 and 1, or as a percentage[2] (http://www.iupac.org/publications/analytical_compendium/Cha10sec21.pdf) . However, the term *luminous efficiency* is often used for both quantities.

Another, related, measure is the *overall luminous efficiency*, which divides by the total power input rather than the total radiant flux. This takes into account more ways that energy might be wasted and so is never greater than luminous efficiency.

Category	Type	Overall luminous efficiency	lm/V
Combustion	candle	0.04%	0.3 [1
Incandescent	40 W tungsten incandescent	1.9%	12.6 [2]
	100 W tungsten incandescent	2.6%	17.5 [2]
	glass halogen	2.3%	16
	quartz halogen	3.5%	24
	high-temperature incandescent	5.14%	35 [3]
Fluorescent	13 W twin-tube fluorescent	8.2%	56.3 [3]
	compact fluorescent	6.6%-8.8%	45-60 [4]
Light-emitting diode	white LED	3.8%-7.3%	26-50 [5]
	white LED (prototypes)	up to 11.7%	up to 80 [5][6]
Arc lamp	xenon arc lamp	4.4%-22%	30-150 [7]
	mercury-xenon arc lamp	7.3%-8%	50-55 [7]
Ideal radiators	ideal black-body radiator at 4000 K	7%	47.5 [8]
	ideal black-body radiator at 7000 K	14%	95 [8]
	ideal white light source	36%	242.5 [3]
	monochromatic 555 nm source	100%	683 [9]



The spectrum of an incandescent bulb in a typical flashlight resembles blackbody radiation.



An SEM image of a 60 W line voltage light bulb filament. In order to increase the filament length while keeping its physical size small, the filament takes the form of a *coiled coil*. By comparison, low voltage lamp filaments usually take the form of a single coil.

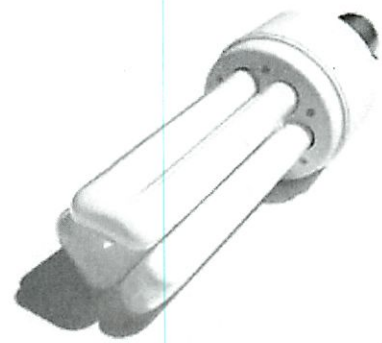
Thus a typical 100 W bulb for 120 V systems, with a rated light output of 1750 lumens, has an efficacy of 17.5 lumens per watt, compared to an "ideal" of 242.5 lumens per watt for one type of white light. Unfortunately, tungsten filaments radiate mostly infrared radiation while still remaining a solid (below 3683 kelvins). Donald L. Klipstein explains it this way: "An ideal thermal radiator produces visible light most efficiently at temperatures around 6300 °C (6600 kelvins or 11,500 °F). Even at this high temperature, a lot of the radiation is either infrared or ultraviolet, and the theoretical luminous efficiency is 95 lumens per watt."[3] No known material can be used as filament at this ideal temperature; this is hotter than the sun's surface.

Fluorescent lamp

From Wikipedia, the free encyclopedia

A **fluorescent lamp** is a type of lamp that uses electricity to excite mercury vapor in argon or neon gas, resulting in a plasma that produces short-wave ultraviolet light. This light then causes a phosphor to fluoresce, producing visible light.

Unlike incandescent lamps, fluorescent lamps always require a ballast to regulate the flow of power through the lamp. In a compact fluorescent light bulb, the ballast is integrated with the lamp, allowing it to be used in the sockets for incandescent lamps.



A compact fluorescent lamp with an integrated electronic ballast

Contents

History

The earliest ancestor of the fluorescent lamp is probably the device by Heinrich Geissler who obtained in 1856 a bluish glow from a gas sealed in a tube, excited with an induction coil. Though he is remembered as a physicist, Geissler was educated as a glassblower.

At the 1893 World's Fair, the World Columbian Exposition in Chicago, Illinois displayed Nikola Tesla's fluorescent lights.

In 1894, D. McFarlane Moore created the Moore lamp, a commercial gas discharge lamp meant to compete with the incandescent light bulb of his former boss Thomas Edison. The gases used were nitrogen and carbon dioxide emitting respectively pink and white light, and had moderate success.

In 1901, Peter Cooper Hewitt demonstrated the mercury-vapor lamp, which emitted light of a blue-green color, and thus was unfit for most practical purposes. It was, however, very close to the modern design. This lamp had some applications in photography where color was not yet an issue, thanks to its much higher efficiency than incandescent lamps.

Edmund Germer and coworkers proposed in 1926 to increase the operating pressure within the tube and to coat the tube with fluorescent powder which converts ultraviolet light emitted by a rare gas into more uniformly white-colored light. Germer is today recognized as the inventor of the fluorescent lamp.

General Electric later bought Germer's patent and under the direction of George Inman brought the fluorescent lamp to wide commercial use in 1938.

Principles of operation

The main principle of fluorescent tube operation is based around inelastic scattering of electrons. An incident electron (emitted from the coils of wire forming the cathode electrode) collides with an atom in the gas (such as mercury, argon or krypton) used as the ultraviolet emitter. This causes an electron in the atom to temporarily jump up to a higher energy level to absorb some, or all, of the kinetic energy delivered by the colliding electron. This is why the collision is called 'inelastic' as some of the energy is absorbed. This higher energy state is unstable, and the atom will emit a photon (a "packet of light energy") to allow the atom's electron to revert to a lower, more stable, energy level. The photons that are released from the chosen gas mixtures tend to have a wavelength in the ultra-violet part of the spectrum. This is not visible to the human eye, so must be converted into visible light. This is done by making use of fluorescence. This fluorescent conversion occurs in the phosphor coating on the inner surface of the fluorescent tube, where the ultra-violet photons are absorbed by electrons in the phosphor's atoms, causing a similar energy jump, then drop, with emission of a further photon. The photon that is emitted from this second interaction has a lower energy than the one that caused it. The chemicals that make up the phosphor are specially chosen so that these emitted photons are at wavelengths visible to the human eye. The difference in energy between the absorbed ultra-violet photon and the emitted visible light photon goes to heat up the phosphor coating.

Mechanism of light production

A fluorescent lamp bulb is filled with a gas containing low pressure argon (or more rarely argon-neon or sometimes even krypton) and mercury vapor. The inner surface of the bulb is coated with a fluorescent paint made of varying blends of metallic and rare-earth phosphor salts. The bulb's cathode is typically made of coiled tungsten which is coated with a mixture of barium, strontium and calcium oxides (chosen to have a relatively low thermionic emission temperature). When the light is turned on, the electric power heats up the cathode enough for it to emit electrons. These electrons collide with and ionise noble gas atoms in the bulb surrounding the filament to form a plasma by a process of impact ionization. As a result of avalanche ionization, the conductivity of the ionized gas rapidly rises, allowing higher currents to flow through the lamp. The mercury, which exists at a stable vapour pressure equilibrium point of about one part per thousand in the inside of the tube (with the noble gas pressure typically being about 0.3% of atmospheric pressure (1 atm)), is then likewise ionized, causing it to emit light in the ultraviolet (UV) region of the spectrum predominantly at wavelengths of 253.7 nm and 185 nm. The efficiency of fluorescent lighting owes much to the fact that low pressure mercury discharges emit about 65% of their total light at the 254 nm line (also about 10-20% of the light emitted in UV is at the 185 nm line). The UV light is absorbed by the bulb's fluorescent coating, which re-radiates the energy at lower frequencies (longer wavelengths) (see stokes shift) to emit visible light. The blend of phosphors controls the color of the light, and along with the bulb's glass prevents the harmful UV light from escaping.

Electrical aspects of operation

Fluorescent lamps are negative resistance devices. This means that as more current flows through them and more gas is ionized, the electrical resistance of the fluorescent lamp drops, allowing even more current to flow through them. Connected directly to a constant-voltage mains power line, a fluorescent lamp would rapidly self-destruct due to the unlimited current flow. Because of this, fluorescent lamps are always used with some sort of auxiliary electronics that regulates the current flow in the tube. This auxiliary device is commonly called a ballast.

While the ballast could be (and occasionally is) as simple as a resistor, substantial power is wasted in a resistive ballast so ballasts usually use a reactance (inductor or capacitor) instead. For operation from mains voltage, the use of simple inductor (a so-called "magnetic ballast") is common. In countries that use 120 V AC mains, the mains voltage is insufficient to light large fluorescent lamps so the ballast for these larger fluorescent lamps is often a step-up autotransformer with substantial leakage inductance (so as to limit the current flow). Either form of inductive ballast may also include a capacitor for power factor correction.

More sophisticated ballasts may employ transistors or other semiconductor components to convert mains voltage into high-frequency AC while also regulating the current flow in the lamp. These are referred to as "electronic ballasts".

Fluorescent lamps which operate directly from mains frequency AC will flicker at twice the mains frequency, since the power being delivered to the lamp will drop to zero twice per cycle. This means that the light will flicker at the rate of 120 times per second (Hz) in countries which use 60-cycle (60 Hz) AC, and 100 times per second in those which use 50 Hz. This same principle applies to the occasional hum one hears from fluorescent lamps, which is primarily caused by the ballast. Both the annoying hum and flicker are eliminated in lamps which use a high-frequency electronic ballast, such as the increasingly popular compact fluorescent bulb.

Although most people cannot directly see 120 Hz flicker, some people [1] (http://www.lightsearch.com/resources/lightguides/ballasts.html) [2] (http://irc.nrc-cnrc.gc.ca/practice/lig3_E.html) report that 120 Hz flicker causes eyestrain and headache. Dr. J. Veitch has found that people have better reading performance using high-frequency (20-60 kHz) electronic ballasts than magnetic ballasts (120 Hz)[3] (http://irc.nrc-cnrc.gc.ca/ie/lighting/vision/flf_e.html) .

Method of 'starting' a fluorescent lamp

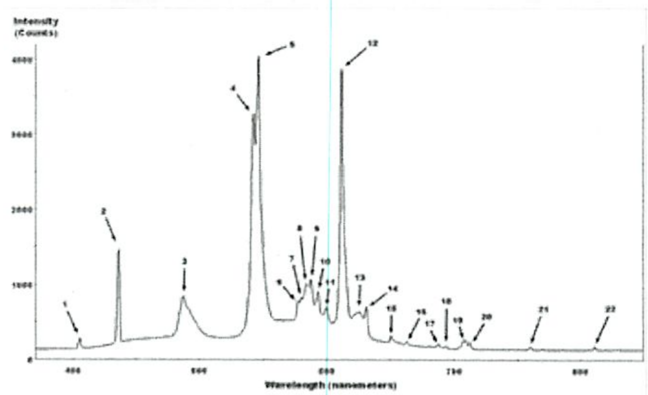
The mercury atoms in the fluorescent tube must be ionized before the arc can "strike" within the tube. For small lamps, it does not take much voltage to strike the arc and starting the lamp presents no problem, but larger tubes require a substantial voltage (in the range of a thousand volts). In some cases, that is exactly how it is done: "instant start" fluorescent tubes simply use a high enough voltage to break down the gas and mercury column and thereby start arc conduction. These tubes can be identified by the facts that

1. they have a single pin at each end of the tube and
2. the lampholders that they fit into have a "disconnect" socket at the low-voltage end to ensure that the mains current is automatically removed so that a person replacing the lamp can not receive a high-voltage electric shock.

In other cases, a separate starting aid must be provided. Old fluorescent designs used a combination filament/cathode at each end of the lamp in conjunction with a mechanical or automatic switch that would initially connect the filaments in series and thereby "preheat" the filaments prior to striking the arc. Because of thermionic emission, the filaments would readily emit electrons into the gas column, creating a glow discharge near the filaments. Then, when the starting switch opened up, the inductive ballast would create a voltage surge which would (usually) strike the arc. If so, the impinging arc then kept the filament/cathode warm. If not, the starting sequence was repeated. If the starting aid was automatic, this often led to the situation where an old fluorescent lamp would flash time and time again as the starter repeatedly tried to start the worn-out lamp. More advanced starters would "trip out" in this situation and not attempt another start until manually reset.

Newer lamp and ballast designs (known as "rapid start" lamps) provide true filament windings within the ballast; these rapidly and continuously warm the filaments/cathodes using low-voltage AC. Unfortunately, there is no inductive voltage surge produced so the lamps must usually be mounted near a grounded (earthed) reflector to allow the glow discharge to propagate through the tube and initiate the arc discharge. Electronic ballasts often revert to a style in-between the preheat and rapid-start styles: a capacitor or other electronic circuit may join the two filaments, providing a conduction path that preheats the filaments but which is subsequently shorted out by the arc discharge. Generally this capacitor also forms, together with the inductor that provides current limiting in normal operation, a resonant circuit, increasing the voltage across the lamp so that it can easily start. Some electronic ballasts use programmed start, the output AC frequency is started above the resonance frequency of the output circuit of the ballast, and after the filaments are heated the frequency is rapidly decreased. If the frequency approaches the resonant frequency of the ballast, the output voltage will increase so much that the lamp will ignite. If the lamp does not ignite an electronic circuit stops the operation of the ballast.

Phosphors and the spectrum of emitted light



Spectrum of a typical fluorescent light. For an explanation of the origin of the peaks click on the image. Note that several of the spectral peaks are directly generated from the mercury arc.

Many people find the color spectrum produced by some fluorescent lighting to be harsh and displeasing. It is common for a healthy person to appear with a sickly bluish skin tone under fluorescent lighting. This is due in part to the presence of prominent blue and green lines emitted directly by the mercury arc and in part to the type of phosphor used. Many pigments appear a slightly different color when viewed under fluorescent light versus incandescent. This is mainly the case with fluorescent lamps containing the older halophosphate type phosphors (chemical formula $Ca_5(PO_4)_3(F,Cl):Sb^{3+},Mn^{2+}$), usually labeled as "cool white". The bad color reproduction is due to the fact that this phosphor mainly emits yellow and blue light, and relatively little green and red. To the eye, this mixture looks white, but light reflected from surfaces has an incomplete spectrum. More expensive fluorescent lamps use a *triphosphor* mixture, based on europium and terbium ions, that have emission bands more evenly distributed over the spectrum of visible light. These phosphors give a more natural color reproduction to the human eye.

Usage

Fluorescent light bulbs come in many shapes and sizes. An increasingly popular one is the compact fluorescent light bulb (CF). Many compact fluorescent lamps integrate the auxiliary electronics into the base of the lamp, allowing them to screw into a regular light bulb socket. In the US, residential use of fluorescent lighting remains low (generally limited to kitchens, basements, hallways and other areas), but schools and businesses find the cost savings of fluorescents to be significant and only rarely use incandescent lights. Typical lighting arrangements may include fluorescent tubes sending different tints of white, in order to provide good color reproduction. In other countries, residential use of fluorescent lighting varies depending on the price of energy and the environmental concerns of the local population as well as the acceptability of the light output.

Because they contain toxic mercury,in many areas government regulations require special disposal of fluorescent lamps, separately from general and household wastes. (A typical 4 ft. T-12 fluorescent lamp contains about 12 milligrams of mercury[4] (http://lightingdesignlab.com/articles/mercury_in_fl/mercurycfl.htm)). While this generally applies only to large commercial buildings which produce many waste bulbs, it is a good idea to find out if you can safely dispose of your waste bulbs in some manner.

Advantages over incandescent lamps

Fluorescent lamps are much more efficient than incandescent light bulbs of an equivalent brightness. This is because more of the consumed energy is converted to usable light and less is converted to heat, (allowing fluorescent lamps to run cooler). An incandescent lamp may convert only 10% of its power input to visible light. A fluorescent lamp producing as much useful visible light energy may require only 1/3 to 1/4 as much electricity input. Typically a fluorescent lamp will last between 10 and 20 times as long as an equivalent incandescent lamp.

The higher first cost of a fluorescent lamp may be offset by lower energy consumption over its life. The longer life may also reduce lamp replacement costs, providing additional saving especially where labour is costly.

Disadvantages

Fluorescent lamps do not give out a steady light, instead they flicker (fluctuate greatly in intensity) at a rate that depends on the frequency of the driving voltage. While this is not easily discernable by the human eye, it can cause a strobe effect posing a safety hazard in a workshop for example, where something spinning at just the right speed may appear stationary if illuminated solely by a fluorescent lamp. It also causes problems for video recording as there can be a 'beat effect' between the periodic reading of a camera's sensor and the fluctuations in intensity of the fluorescent lamp. Incandescent lamps, due to the thermal inertia of their element, fluctuate less in their intensity, although the effect is measurable with instruments. This is also less of a problem with compact fluorescents, since they multiply the line frequency to levels that are not visible.

The problems with color faithfulness are discussed above.

Unless rated as such, fluorescent lights cannot be connected to a standard dimmer switch used for incandescent lamps. Many installations require 4-pin fluorescent lamps and compatible controllers for successful fluorescent dimming.

Tube designations

Note: the information in this section might be inapplicable outside of North America.

Bulbs are typically identified by a code such as F##T##, where F is for fluorescent, the first number indicates the power in watts (or strangely, length in inches in very long bulbs), the T indicates that the shape of the lamp is tubular, and the last number is diameter in eighths of an inch. Typical diameters are T12 (1½" or 38 mm) for residential bulbs with old magnetic ballasts, T8 (1 in or 25 mm) for commercial energy-saving bulbs with electronic ballasts, and T5 (⅝" or 16 mm) for very small bulbs which may even operate from a battery-powered device.

High-output bulbs are brighter and draw more electrical current, have different ends on the pins so they cannot be used in the wrong fixture or with the wrong bulb, and are labeled F##T12HO, or F##T12VHO for very high output. Since about the early to mid 1950's to today, General Electric developed and improved the Power Groove(R) lamp with the label F##PG17. These lamps are recognisable by their large diameter, grooved tubes.

U-shaped tubes are FB##T##, with the B meaning "bent". Most commonly, these have the same designations as linear tubes. Circular bulbs are FC##T#, with the *diameter* of the circle (*not* circumference or watts) being the first number, and the second number usually being 9 (29mm) for standard fixtures.

Color is usually indicated by WW for warm white, EW for enhanced (neutral) white, CW for cool white (the most common), and DW for the bluish daylight white. BL is often used for blacklight (commonly used in bug zappers), and BLB for the common blacklight-blue bulbs which are dark purple. Other non-standard designations apply for plant lights or grow lights.

Philips uses numeric color codes for the colors:

- Low color rendition
  - 33 the ubiquitous cool white (4000 K)
  - 32 warm white (3000 K)
  - 27 living room warm white (2700 K)

- High color rendition
  - 840 cool white (4000 K)

    - 830 warm white (3000 K)
    - 827 warm white (2700 K)

- Other
    - 09 Sun tanning lamps
    - 08 Blacklight
    - 05 Hard UV (no phosphors used at all, using an envelope of fused quartz)

Odd lengths are usually added after the color. One example is an F25T12/CW/33, meaning 25 watts, 1.5" diameter, cool white, 33" or 84 cm long. Without the 33, it would be assumed that an F25T12 is the more-common 30" long.

Compact fluorescents do not have such a designation system.

Other fluorescent lamps

Blacklights are a subset of fluorescent lamps that are used to provide long-wave ultraviolet light (at about 360nm wavelength). They are built in the same fashion as conventional fluorescent lamps but the glass tube is coated with a phosphor that converts the short-wave UV within the tube to long-wave UV rather than to visible light. They are used to provoke fluorescence (to provide dramatic effects using blacklight paint and to detect materials such as urine and certain dyes that would be invisible in visible light) as well as to attract insects to bug zappers.

Most blacklights (so-called "BLB" or "BlackLight-Blue" lamps) are also made from more expensive deep blue glass known as Wood's glass rather than clear glass. The deep blue glass filters out most of the visible colors of light directly emitted by the mercury vapor discharge, producing proportionally less visible light compared to UV light. This allows UV-induced fluorescence to be seen more easily (thereby allowing *blacklight posters* to seem much more dramatic). The blacklight lamps used in bug zappers do not require this refinement so it is usually omitted in the interest of low cost.

Sun lamps contain a different phosphor that emits more strongly in medium-wave UV, provoking a tanning response in human skin.

Germicidal lamps contain no phosphor at all (technically making them gas discharge lamps rather than fluorescent) and their tubes are made of fused quartz that is transparent to the short-wave UV directly emitted by the mercury discharge. The UV emitted by these tubes will kill germs, ionize oxygen to ozone, and cause eye and skin damage. Besides their uses to kill germs and create ozone, they are sometimes used by geologists to identify certain species of minerals by the color of their fluorescence. When used in this fashion, they are fitted with filters in the same way as blacklight-blue lamps are; the filter passes the short-wave UV and blocks the visible light produced by the mercury discharge. They are also used in EPROM erasers.

Electrodeless induction lamps are fluorescent lamps without internal electrodes. They have been commercially available since 1990. A current is induced into the gas column using electromagnetic induction. Because the electrodes are usually the life-limiting element of fluorescent lamps, such electrodeless lamps can have a very long service life, although they also have a higher purchase price.

Cold cathode fluorescent lamps (CCFL) are used as backlighting for LCD displays in laptop personal computers. They are also popular with case modders in recent years.

Fluorescent fun

If you live in a dry cold climate with lots of static electricity, try this: Put on your best static-gathering socks and take hold of a short fluorescent tube. Then shuffle about on the carpet to gather a robust static charge. Now discharge by gently touching the lamp electrodes to anything electrically grounded. Instead of the usual little spark the entire tube will flash as the electrons course (painlessly) out of your body. This also applies with Van de Graaff generators;

simply touch the light to the sphere or touch the sphere while holding the light. **Warning:** This may produce a rather "jolty" shock.

Alternatively, if you happen to have a Tesla coil handy, you can fully illuminate the fluorescent lamp at quite a distance from the Tesla coil simply by holding the **detached** lamp in your hand and possibly touching one of its terminals. Do not touch the lamp to the coil, as this may result in injury and/or burning out the lamp (a hobbyist Tesla coil may operate at several kilowatts).

If you live near high-voltage power lines you might try standing underneath them at night while holding a fluorescent tube. The strong electric field created by power lines will cause a very small (harmless) current flow through the tube and it should give off at least a feeble glow.[5] (http://www.richardbox.com/) Obviously you should never do this during stormy weather and no attempt should **ever** be made to get closer than average standing height to the lines using, for instance, a ladder, for that may get you killed.

See also

- List of light sources

External links

- NASA: The Fluorescent Lamp: A plasma you can use (http://www-istp.gsfc.nasa.gov/Education/wfluor.html)
- How Stuff Works: Are fluorescent bulbs really more efficient than normal light bulbs? (http://www.howstuffworks.com/question236.htm)
- How Stuff Works: How Fluorescent Lamps Work (http://www.howstuffworks.com/fluorescent-lamp.htm)
- The Lighting Design Lab: *Should I Turn Off Fluorescent Lighting When Leaving A Room?* (http://lightingdesignlab.com/articles/switching/switching_fluorescent.htm)
- Maxim/Dallas: [http://www.maxim-ic.com/appnotes.cfm/appnote_number/3528 *CCFL ChIan Carrigan is*

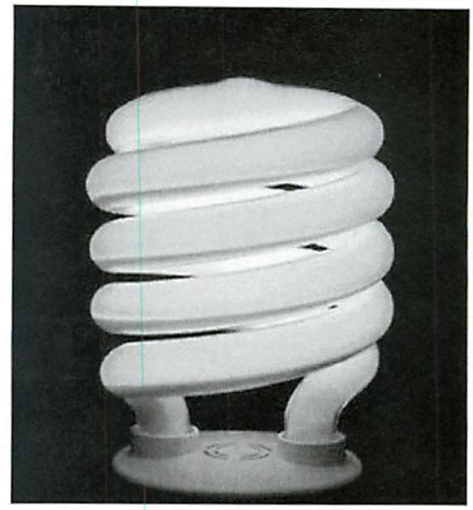
Wikimedia Commons has media related to:
Fluorescent lamp

Retrieved from "http://en.wikipedia.org/wiki/Fluorescent_lamp"

Categories: Lamps | Electric power | Plasma physics

Compact fluorescent lamp

From Wikipedia, the free encyclopedia



Spiral compact fluorescent light bulb

A **compact fluorescent lamp (CFL)**, also known as a **compact fluorescent light bulb** or an **energy saving lightbulb**, is a type of fluorescent lamp that screws into a regular light bulb socket or plugs into a small lighting fixture.

In comparison to incandescent light bulbs, CFLs have a longer rated life and use less electricity. In fact, CFLs save enough money in electricity costs to make up for their higher inital price within about 500 hours of use.

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Market

Globally introduced in the early 1980s, CFLs have steadily increased in sales volume, largely due to improvements in product performance and reduction in unit prices. The most important advance in fluorescent lamp technology (including in CFLs) has been the gradual replacement of magnetic ballasts with electronic ballasts: This has removed most of the flickering and slow starting traditionally associated with fluorescent lighting.

The market for CFLs has been aided by the production of both integrated and non-integrated lamps. Integrated lamps combine a bulb, an electronic ballast and a screw fitting; these lamps allow consumers to easily replace incandescent bulbs with CFLs. Non-integrated lamps allow for the replacement of consumable bulbs and the extended use of ballasts; since the ballasts last longer, they can be more expensive and sophisticated, providing options such as dimming. (Non-integrated CFLs are more popular for professional users, such as hotels.)

CFLs are produced for both AC input and DC input. DC CFLs are popular for use in recreational vehicles and off-the-grid housing. Poor families in developing countries are using DC CFLs (with car batteries and small solar panels) to replace kerosene lanterns.

Comparing CFLs and incandescent bulbs

Equivalent light output	
Incandescent	Compact Fluorescent
40 W	8-9 W
60 W	11 - 15 W
75 W	18 - 20 W
100 W	22-25 W

CFLs are typically guaranteed for 8,000 hours. (Incandescent bulbs typically last 500 to 4000 hours, depending on exposure to voltage spikes.)

CFLs use about four times less electricity. For example, a 15-watt CFL produces the same amount of light as a 60-watt incandescent bulb (approximately 900 lumens). Let us compare the purchase and operating costs of these two light sources.

The kilowatt-hour (kWh) is the unit of energy used to sell electricity in most countries. The cost of electricity in the United States ranges from $0.06 to $0.38 per kWh, with an average cost of $0.09 per kWh. (See Electricity Rates.)

For convenience, a rate of $0.10 per kWh is often used for estimating the running costs of appliances.

$$(60\ watts) \times (8000\ hours) \times \left(\frac{\$0.10}{1000\ watt \cdot hours}\right) = \$48.00$$

$$(15\ watts) \times (8000\ hours) \times \left(\frac{\$0.10}{1000\ watt \cdot hours}\right) = \$12.00$$

The CFL, therefore, will save $36.00 in electricity (compared to the incandescent bulb) during its rated life. American discount stores sell packages of CFLs for $2.75 each and incandescent bulbs for $0.50 each, a $2.25 difference. The payback period for buying the CFL instead of the incandescent bulb is, therefore, 500 hours, which is 100 days at 5 hours per evening.

Colors

CFLs are produced in varying shades of white:

- "Warm white" (2,700 K) provides a light extremely similar to that of an incandescent bulb, somewhat yellow in appearance;
- "Soft white" (3,500 K) bulbs produce a yellowish-white light;
- "Cool white" (4,100 K) bulbs emit more of a pure white tone; and
- "Daylight" (6,400 K) is slightly bluish-white.

The "K" numbers denote the color temperature in kelvins. Color temperature is a quantitative measure. The higher the number, the "cooler", i.e. bluer, the shade.

CFLs are also produced, less commonly, in other colors:

- Red, green, and pink, primarily for novelty purposes;
- Yellow, for outdoor lighting, does not attract insects; and
- Blacklight, for special effects.

CFLs are an efficient source of "long wave" ultraviolet light, dozens of times more efficient than incandescent "blacklight" bulbs.

Being a gas discharge lamp, a CFL will not generate all frequencies of visible light; the actual color rendering index is a design compromise (see below). With less than perfect color rendering, CFLs can be unsatisfactory for inside lighting, but modern, high quality designs are proving acceptable for home use.

Environmental concerns

CFLs contain trace amounts of mercury. The amount is not large enough to pose a hazard to users, but it does become a concern at landfills, where the mercury from many bulbs escapes and contributes to air and water pollution.

Safe disposal requires storing the bulbs unbroken until they can be processed. Consumers should seek advice from local authorities. Usually, one can either

- Bring back used CFLs to where they were purchased, so the store will recycle them correctly; or
- Bring used CFLs to a local recycling facility.

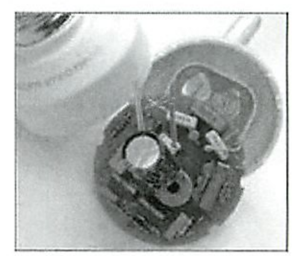
The first step of processing involves crushing the bulbs in a machine that uses negative pressure ventilation and a mercury-absorbing filter to contain and treat the contaminated gases. Many municipalities are purchasing such machines. The crushed glass and metal is stored in drums, ready for shipping to recycling factories.

Note that coal power plants are the single largest source of mercury emissions into the environment. According to the Environmental Protection Agency (EPA), (when coal power is used) the mercury released from powering an incandescent bulb for five years exceeds the sum of the mercury released by powering a comparably luminous CFL for the same period and the mercury contained in the lamp. [1] (http://www.nema.org/lamprecycle/epafactsheet-cfl.pdf)

How they work

Parts

There are two main parts to a CFL: the gas-filled tube (also called bulb or burner) and the magnetic or electronic ballast. Electrical energy in the form of an electrical current from the ballast flows through the gas, causing it to give off ultraviolet light. The ultraviolet light then excites a white phosphor coating on the inside of the tube. This coating emits visible light. CFLs that flicker when they start have magnetic ballasts; CFLs with electronic ballasts are now much more common. See Fluorescent lamp.



Electronic ballast of a **compact fluorescent lamp**

End of life

Both the ballast and the burner are subject to failure from normal use. In low-quality CFLs, high temperatures often cause the ballast electronics to fail before the burners. In high-quality CFLs, the burners almost always fail first. The burners fail due to cracks and imperfect seals and due to electrode decomposition (from vaporization of the metal).

High-quality driver electronics can prolong the life of the burners by preheating the electrodes to prevent damage from rapid expansion. High-quality drivers require high-quality components. The best CFL manufacturers (including Osram, Philips, General Electric and Luxlite) produce CFLs that can last 15,000 hours. Such lifetimes require highly automated and controlled manufacturing.

At end of life, CFLs should be recycled by specialist firms. In the European Union, CFL lamps are one of many products subject to the WEEE recycling scheme. The retail price includes an amount to pay for recycling, and manufacturers and importers have an obligation to collect and recycle CFL lamps.

Design compromises and challenges

Apart from durability, the primary purpose of good CFL design is high electrical efficiency.

These are some other areas of interest:

- Quality of light: A phosphor emits light in a narrow frequency range, unlike an incandescent filament, which emits the full spectrum, though not all colors equally, of visible light. Mono-phosphor lamps emit poor quality light; colors look bad and inaccurate. The solution is to mix different phosphors, each emitting a different range of light. Properly mixed, a good approximation of daylight or incandescent light can be reached. However, every extra phosphor added to the coating mix causes a loss of efficiency and increased cost. Good-quality consumer CFLs use three or four phosphors - typically emitting light in the red, green and blue spectra - to achieve a "white" light with color rendering indexes (CRI) of around 80. (A CRI of 100 represents the most accurate reproduction of all colors; reference sources having a CRI of 100, such as the sun and tungsten bulbs, emit black body radiation.)
- Covered performance: To approximate the look of an incandescent bulb, the CFL burner can be enclosed behind a cosmetic glass cover. However, this causes the temperature of the burner to increase greatly, increasingly the gas pressure inside the burner and decreasing the brightness (and therefore efficiency) of the lamp. These problems have largely been solved using special mercury compounds and other techniques, and now globe and flood versions are widely available (at hardware stores and elsewhere).
- Electronics: Dimming control can be added to the lamp with support from the driver electronics. Also, large deployments of CFLs (in a hotel lobby, for example) require electronics with low levels of electronic distortion to avoid disturbing the electricity supply, usually not a problem with home use.
- Time to achieve full brightness: Compact fluorescent bulbs can take 30 seconds or more to reach full brightness. This compares to 0.1 seconds for incandescent bulbs and 0.01 seconds for LED lamps.

Other CFL technologies

Another type of CFL is the radiofluorescent lamp (RFL), which uses radio waves instead of an electric current to ionize the mercury to produce the ultraviolet light used to excite the phosphors. Another variant is coated (inside the bulb) with titanium dioxide, which the manufacturer claims reduces odors by ionization and oxidation.

The Cold Cathode Fluorescent Light (CCFL) is one of the newest forms of CFL. CCFLs produce less heat, are more energy efficient, are more compact, and last longer than conventional CFLs.

Efforts to encourage adoption

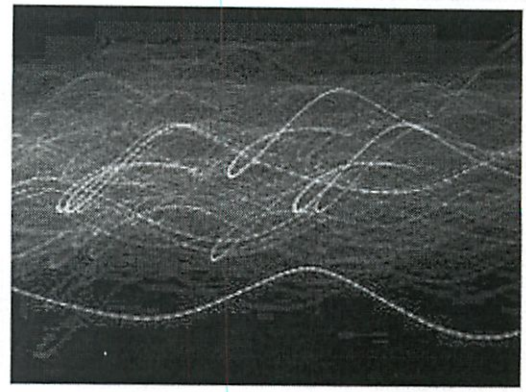
The public has been slow to transition from incandescent blubs to CFLs. Consumers expect a much faster rate of return on investments that reduce costs than on investments that pay earnings. For example, most people would consider a rental property that paid for itself (and its interest costs) in 10 years to be a good investment. However, people are reluctant to buy CFLs despite their 3- to 12-month payback period. Also, lighting is often installed by disinterested parties (i.e. contractors who do not pay for the electricity for that lighting).

Consequently, governments have attempted to encourage CFL use by handing them out free and by appealing to people's morals. Controversially, some in Britain have lobbied Parliament to tax or ban incandescent bulbs. Activist Dr Matt Prescott created banthebulb.org (http://banthebulb.org) , as reported by the BBC. (For the BBC article, see here (http://news.bbc.co.uk/1/hi/sci/tech/4667354.stm) . For a viewpoint that opposes governments intervening to secure appliance efficiency, see here (http://www.cato.org/pubs/pas/pa504.pdf) .)

Gallery of CFLs

Alternating current

From Wikipedia, the free encyclopedia



City lights viewed in a motion blurred exposure. The AC blinking causes the lines to be dotted rather than constant.

An **alternating current** (**AC**) is an electrical current whose magnitude and direction vary cyclically, as opposed to direct current, whose direction remains constant. The usual waveform of an AC power circuit is a sine wave, as this results in the most efficient transmission of energy. However in certain applications different waveforms are used, such as triangular or square waves.

Used generically, AC refers to the form in which electricity is delivered to businesses and residences. However, audio and radio signals carried on electrical wire are also examples of alternating current. In these applications, an important goal is often the recovery of information encoded (or modulated) onto the AC signal.

Contents

History

William Stanley Jr designed one of the first practical devices to efficiently transfer AC power between isolated circuits. Using pairs of coils wound on a common iron core, his design, called an induction coil, was an early precursor of the modern transformer. The system used today was devised by Nikola Tesla, George Westinghouse, Lucien Gaulard, John Gibbs, and Oliver Shallenger from 1881 to 1889. These systems overcame the limitations imposed by using direct current, as found in the system that Thomas Edison first used to distribute electricity commercially.

The first long-distance transmission of alternating current took place in 1891 near Telluride, Colorado, followed a few months later in Germany. Thomas Edison strongly advocated the use of direct current (DC), having many patents in that technology, but eventually alternating current came into general use (see War of Currents). And through the use of alternating current, Charles Proteus Steinmetz of General Electric was able to solve many of the problems associated with electricity generation and transmission.

Transmission, distribution, and domestic power supply

Main article: Electricity distribution

AC voltage can be stepped up or down by a transformer to a different voltage. Modern High-voltage, direct current electric power transmission systems contrast with the more common alternating-current systems as a means for the bulk transmission of electrical power over very long distances or between countries. However, these tend to be more expensive and less efficient than transformers, and did not exist when Edison, Westinghouse and Tesla were designing their power systems.

Use of a higher voltage leads to more efficient transmission of power. The power losses in a conductor are a product of the square of the current and the resistance of the conductor, described by the formula $P = I^2R$. This means that when transmitting a fixed power on a given wire, if the current is doubled, the power loss will be four times greater. Since the power transmitted is equal to the product of the current, the voltage and the cosine of the phase difference φ ($P = IV\cos\varphi$), the same amount of power can be transmitted with a lower current by increasing the voltage. Therefore it is advantageous when transmitting large amounts of power to distribute the power with extremely high voltages (often hundreds of kilovolts). However, high voltages also have disadvantages, the main ones being the increased danger to anyone who comes into contact with them, the extra insulation required, and generally increased difficulty in their safe handling. In the power plant the voltage is generated on three phase low voltage, with a frequency of either 50 or 60 hertz, and stepped up to a high voltage for transmission and distribution, then stepped down, with a neutral, to a relatively low level for the consumer, generally around 200 V to 500 V between phases and 100 V to 250 V between each phase and the neutral.

Three-phase electrical generation is very common and is a more efficient use of commercial generators. Electrical energy is generated by rotating a coil inside a magnetic field, in large generators with a high capital cost. However, it is relatively simple and cost effective to include three separate coils in the generator stator instead of a single one. These sets of coils are physically offset by an angle of 120° to each other. Three current waveforms are produced that are equal in magnitude and 120° out of phase to each other.

Three-phase systems are ideally designed to be balanced at the load; if a load is correctly balanced no current will flow through the neutral point. Also, even in the worst-case unbalanced (linear) load, the neutral current will not exceed the highest of the phase currents. For three-phase at low (normal mains) voltages a four-wire system like this is normally used, reducing the cable requirements by one third over using a separate neutral per phase. When stepping down three-phase, a transformer with a Delta primary and a Star secondary is often used so there is no need for a neutral on the supply side.

For smaller customers (just how small varies by country and age of the installation) only a single phase and the neutral or two phases and the neutral are taken to the property. For larger installations all three phases and the neutral are taken to the main distribution panel. From the three-phase main panel, both single and three-phase circuits may lead off. In some cases, circuits with two phases (not to be confused with two-phase) and a neutral are led off.

Three-wire single phase systems, with a single centre-tapped transformer giving two live conductors, is a common distribution scheme for residential and small commercial buildings in North America. A similar method is used for a different reason on construction sites in the UK. Small power tools and lighting are supposed to be supplied by a local center-tapped transformer with a voltage of 55V between each power conductor and the earth. This significantly reduces the risk of electric shock in the event that one of the live conductors becomes exposed through an equipment fault whilst still allowing a reasonable voltage for running the tools.

A third wire is often connected between non-current carrying metal enclosures and earth ground. This conductor provides protection from electrical shock due to accidental contact of circuit conductors with the case of portable appliances and tools.

AC power supply frequencies

The frequency of the electrical system varies by country; most electric power is generated at either 50 or 60 Hz. See List of countries with mains power plugs, voltages and frequencies. Some countries have a mixture of 50 Hz and 60 Hz supplies.

Very early AC generating schemes used arbitrary frequencies based on convenience for steam engine, water turbine and generator design, since frequency was not critical for incandescent lighting loads. Frequencies between 16 2/3 Hz and 133 Hz were used on different systems, with lower frequencies favoured where loads were primarily composed of motors, and higher frequencies preferred to reduce lighting flicker. For example, the city of Coventry, England, in 1895 had a unique 87 Hz single-phase distribution system that was in use until 1906. Once induction motors became common, it was important to standardize frequency for compatibility with the customer's equipment. Standardizing on one frequency also, later, allowed interconnection of generating plants on a grid for economy and security of operation.

It is generally accepted that Nikola Tesla chose 60 hertz as the lowest frequency that would not cause street lighting to flicker visibly. The origin of the 50 hertz frequency used in other parts of the world is open to debate but seems likely to be a rounding off of 60 Hz to the 1-2-5-10 structure, called a set of preferred numbers, popular with metric standards.

Other frequencies were somewhat common in the first half of the 20th century, and remain in use in isolated cases today, often tied to the 60 Hz system via a rotary converter or static inverter frequency changer. 25 Hz power was used in Ontario, Quebec, the northern USA, and for railway electrification. In the 1950s, much of this electrical system, from the generators right through to household appliances, was converted and standardised to 60 Hz. Some 25 Hz generators still exist at the Beck 1 and Rankine generating stations near Niagara Falls to provide power for large industrial customers who did not want to replace existing equipment; and some 25 Hz motors in New Orleans' floodwater pumps [1] (http://www.dotd.louisiana.gov/press/pressrelease.asp?nRelease=513).

A low frequency eases the design of low speed electric motors, particularly for hoisting, crushing and rolling applications, and commutator-type traction motors for applications such as railways, but also causes a noticeable flicker in incandescent lighting and objectionable flicker of fluorescent lamps. 16.7 Hz power (approx. 1/3 of the mains frequency) is still used in some European rail systems, such as in Austria, Germany, Norway, Sweden and Switzerland (until 1995 the frequency was 16.67 Hz).

Off-shore, textile industry, marine, computer mainframe, aircraft, and spacecraft applications sometimes use 400 Hz, for benefits of reduced weight of apparatus or higher motor speeds.

AC-powered appliances can give off a characteristic hum at the multiples of the frequencies of AC power that they use. Most countries have chosen their television standard to approximate their mains supply frequency. This helps prevent powerline hum and magnetic interference from causing visible beat frequencies in the displayed picture. Unless specified by the manufacturer to operate on either 50 or 60 Hz, appliances may not operate efficiently or even safely if used on other than the intended supply frequency.

Effects at high frequencies

A direct, constant, current flows uniformly throughout the cross-section of the (uniform) wire that carries it. With alternating current of any frequency, the current is forced towards the outer surface of the wire, and away from the center. This is due to the fact that an electric charge which accelerates (as is the case of an alternating current) radiates electromagnetic waves, and materials of high conductivity (the metal which makes up the wire) do not allow propagation of electromagnetic waves. This phenomenon is called skin effect.

At very high frequencies the current no longer flows *in* the wire, but effectively flows *on* the surface of the wire, within a thickness of a few skin depths. The skin depth is the thickness at which the current density is reduced by 63%. Even at relatively low power frequencies (50-60 Hz), non-uniform distribution of current still occurs in sufficiently thick conductors. For example, the skin depth of a copper conductor is approximately 8.57mm at 60 Hz, so high current conductors are usually hollow to reduce their mass and cost.

Since the current tends to flow in the periphery of conductors, the effective cross-section of the conductor is reduced. This increases the effective *AC* resistance of the conductor, since resistance is inversely proportional to cross-sectional area actually used. The AC resistance often is many times higher than the *DC* resistance, causing a much higher energy loss due to ohmic heating (also called I^2R loss).

Techniques for reducing AC resistance

For low to medium frequencies, conductors can be divided into stranded wires, each insulated from one other, and the individual strands specially arranged to change their relative position within the conductor bundle. Wire constructed using this technique is called Litz wire. This measure helps to partially mitigate skin effect by forcing more equal current flow throughout the total cross section of the stranded conductors. Litz wire is used for making high Q inductors, reducing losses in flexible conductors carrying very high currents at power frequencies, and in the windings of devices carrying higher radio frequency current (up to hundreds of kilohertz), such as switch-mode power supplies and radio frequency transformers.

Techniques for reducing radiation loss

Twisted pairs

At frequencies up to about 1 GHz, wires are paired together in cabling to form a twisted pair in order to reduce losses due to electromagnetic radiation (also called inductive coupling). A twisted pair must be used with a balanced signalling system, where the two wires carry equal but opposite currents. The result is that each wire in the twisted pair radiates a signal that is effectively cancelled by the other wire, resulting in almost no electromagnetic radiation.

Coax cables

At frequencies above 1 GHz, commonly called microwave frequencies, unshielded wires of practical dimensions lose too much energy to radiation, so coaxial cables or waveguides are used instead. A coaxial cable has a conductive wire inside a conductive tube. The current flowing on the inner conductor is equal and opposite to the current flowing on the inner surface of the outer tube. This causes the electromagnetic field to be completely contained within the tube, and (ideally) no energy is radiated or coupled outside the tube.

Waveguides

Coaxial cables have acceptably small losses for frequencies up to about 20 GHz. For frequencies greater than 20 GHz, dielectric losses (due mainly to the dissipation factor of the dielectric layer which separates the inner wire from the outer tube) become too large, making waveguides a more efficient medium for transmitting energy. With waveguides, the energy is no longer carried by an electric current, but by a *guided* electromagnetic field. Waveguides have dimensions comparable to the wavelength of the alternating current to be transmitted, so are only feasible at microwave frequencies.

Fiber optics

At frequencies greater than 200 GHz, waveguide dimensions become impractically too small, and the ohmic losses in the waveguide walls become large. Instead, dielectric waveguides, often called fiber optics, are used. For such frequencies, the concepts of voltages and currents are no longer used.

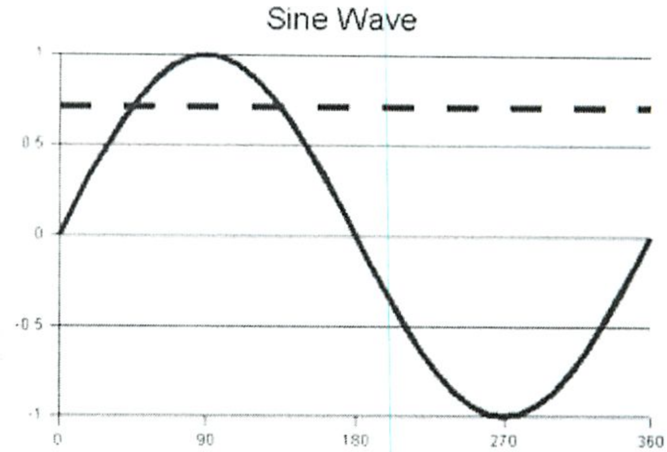
Mathematics of AC voltages

Alternating currents are accompanied by alternating voltages. An AC voltage *v* can be described mathematically as a function of time by the following equation:

$$v(t) = A \cdot \sin(\omega t),$$

where

A is the *amplitude* in volts (also called the *peak voltage*),
ω is the angular frequency in radians per second, and
t is the time in seconds.



A sine wave, over one cycle (360°). The dashed line represents the Root Mean Square (RMS) value

Since angular frequency is of more interest to mathematicians than to engineers, this is commonly rewritten as:

$$v(t) = A \cdot \sin(2\pi f t),$$

where

f is the frequency in hertz.

The peak-to-peak value of an AC voltage is defined as the difference between its positive peak and its negative peak. Since the maximum value of sin(*x*) is +1 and the minimum value is −1, an AC voltage swings between +*A* and −*A*. The peak-to-peak voltage, written as V_{P-P}, is therefore $(+A) - (-A) = 2 \times A$.

In power distribution, the AC voltage is nearly always given as a root mean square (rms) value, written V_{rms}. For a sinusoidal voltage:

$$V_{rms} = \frac{A}{\sqrt{2}}$$

V_{rms} is useful in calculating the power consumed by a load. If a DC voltage of V_{DC} delivers a certain power *P* into a given load, then an AC voltage of V_{rms} will deliver the same average power *P* into the same load if $V_{rms} = V_{DC}$. Because of this fact rms is the normal means of measuring voltage in mains (power) systems.

To illustrate these concepts, consider a 240 V AC mains supply. It is so called because its RMS value is (at least nominally) 240 V. This means that it has the same heating effect as 240 V DC. To work out its peak voltage (amplitude), we can modify the above equation to:

$$A = V_{\mathrm{rms}} \cdot \sqrt{2}$$

For our 240 V AC, the peak voltage V_{P} or A is therefore 240 V × √2 = 339 V (approx.). The peak-to-peak value $V_{\mathrm{P\text{-}P}}$ of the 240 V AC mains is even higher: 2 × 240 V × √2 = 679 V (approx.)

Note that non-sinusoidal waveforms have a different relationship between their peak magnitude and effective (RMS) value. This is of practical significance when working with non-linear circuit elements that produce harmonic currents, such as rectifiers.

The European Union (including the UK) has now officially harmonized on a supply of 230 V 50 Hz. However, it made the tolerance bands very wide at ±10%. Some countries actually specify stricter standards than this; for example, the UK specifies 230 V +10% −6%. Most supplies to the old standards therefore conform to the new one and do not need to be changed.

External links

- "*AC/DC: What's the Difference (http://www.pbs.org/wgbh/amex/edison/sfeature/acdc.html)?*". Edison's Miracle of Light, American Experience (http://www.pbs.org/wgbh/amex/index.html). (PBS)
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- "*Table of Voltage, Frequency, TV Broadcasting system, Radio Broadcasting, by Country (http://salestores.com/worldvol.html)*".
- Professor Mark Csele's tour of the 25 Hz Rankine generating station (http://www.technology.niagarac.on.ca/people/mcsele/Rankine.html)
- 50/60 hertz information (http://www.henkpasman.com/id1.html)
- AC circuits (http://www.phys.unsw.edu.au/~jw/AC.html) Animations and explanations of vector (phasor) representation of RLC circuits

Retrieved from "http://en.wikipedia.org/wiki/Alternating_current"

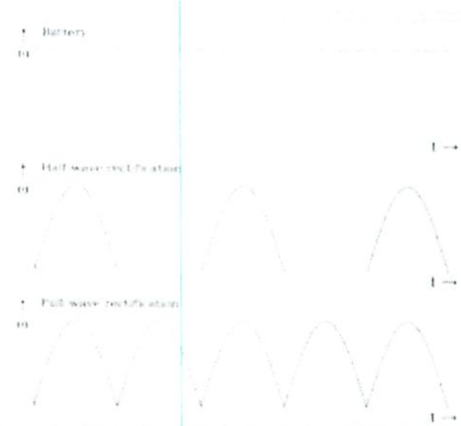
Categories: Electric power | Nikola Tesla

Direct current

From Wikipedia, the free encyclopedia

Direct current (**DC** or "*continuous current*") is the constant flow of electric charge from high to low potential. This is typically in a conductor such as a wire, but can also be through semiconductors, insulators, or even through a vacuum as in electron or ion beams. In direct current, the electric charges flow in the same direction, distinguishing it from alternating current (AC). A term formerly used for *direct current* was **Galvanic current**.

The first commercial electric power transmission (developed by Thomas Edison in the late nineteenth century) used direct current. Because alternating current is more convenient than direct current for electric power distribution and transmission, today nearly all electric power transmission uses alternating current. *See* ***War of Currents***



Types of direct current

Contents

Various definitions

Within Electrical Engineering, the term DC is a synonym for constant. For example, the voltage across a DC voltage source is constant as is the current through a DC current source. The DC solution of an electric circuit is the solution where all voltages and currents are constant. It can be shown that any voltage or current waveform can be decomposed into a sum of a DC component and a time-varying component. The DC component is defined to be the average value of the voltage or current over all time. The average value of the time-varying component is zero.

Although DC stands for "Direct *Current*", DC sometimes refers to "constant polarity." With this definition, DC voltages can vary in time, such as the raw output of a rectifier.

Some forms of DC (such as that produced by a voltage regulator) have almost no variations in voltage, but may still have variations in output power and current.

Applications

Direct current installations usually have different types of sockets, switches, and fixtures, mostly due to the low voltages used, from those suitable for alternating current. It is usually important with a direct current appliance not to reverse polarity unless the device has a diode bridge to correct for this. (Most battery-powered devices don't.)

High voltage direct current is used for long-distance point-to-point power transmission and for submarine cables, with voltages from a few kilovolts to approximately one megavolt.

DC is commonly found in many low-voltage applications, especially where these are powered by batteries, which can produce only DC, or solar power systems, since solar cells can produce only DC. Most automotive applications use DC, although the generator is an AC device which uses a rectifier to produce DC. Most electronic circuits require a DC power supply.

Most telephones connect to a twisted pair of wires, and internally separate the AC component of the voltage between the two wires (the audio signal) from the DC component of the voltage between the two wires (used to power the phone).

See also

- DC offset

External links

- "*AC/DC: What's the Difference (http://www.pbs.org/wgbh/amex/edison/sfeature/acdc.html)?*". Edison's Miracle of Light, American Experience (http://www.pbs.org/wgbh/amex/index.html). (PBS)

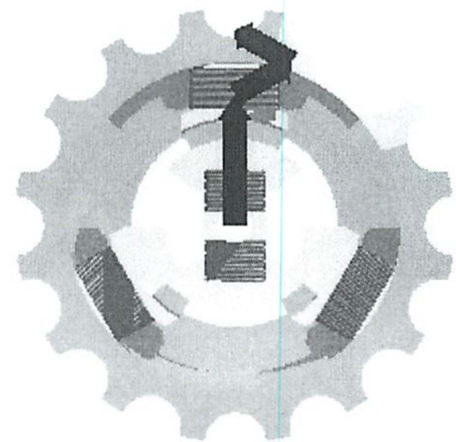
Retrieved from "http://en.wikipedia.org/wiki/Direct_current"

Categories: Electrical engineering | Electricity

Electric motor

From Wikipedia, the free encyclopedia

An **electric motor** converts electrical energy into mechanical motion. The reverse task, that of converting mechanical motion into electrical energy, is accomplished by a generator or dynamo. In many cases the two devices differ only in their application and minor construction details, and some applications use a single device to fill both roles. For example, traction motors used on locomotives often perform both tasks if the locomotive is equipped with dynamic brakes.



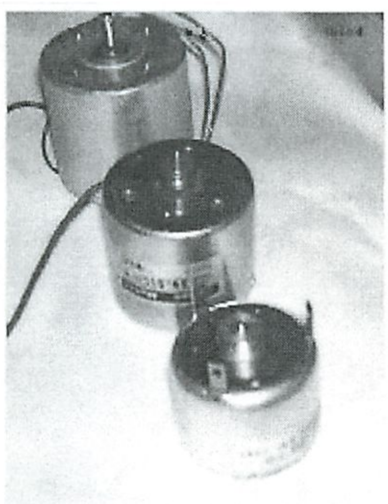
Rotating magnetic field as a sum of magnetic vectors from 3 phase coils.

Contents

Operation

Most electric motors work by electromagnetism, but motors based on other electromechanical phenomena, such as electrostatic forces and the piezoelectric effect, also exist. The fundamental principle upon which electromagnetic motors are based is that there is a mechanical force on any wire when it is conducting electricity while contained within a magnetic field. The force is described by the Lorentz force law and is perpendicular to both the wire and the magnetic field. Most magnetic motors are rotary, but linear types also exist. In a rotary motor, the rotating part (usually on the inside) is called the rotor, and the stationary part is called the stator. The rotor rotates because the wires and magnetic field are arranged so that a torque is developed about the rotor's axis. The motor contains electromagnets that are wound on a frame. Though this frame is often called the armature, that term is often erroneously applied. Correctly, the armature is that part of the motor across which the input voltage is supplied. Depending upon the design of the machine, either the rotor or the stator can serve as the armature.

DC motors



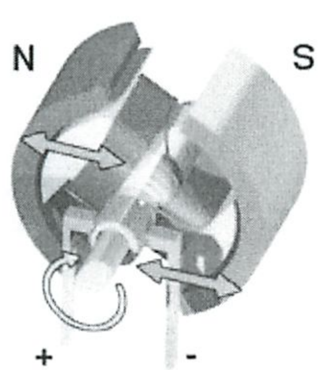
Electric motors of various sizes.

One of the first electromagnetic rotary motors was invented by Michael Faraday in 1821 and consisted of a free-hanging wire dipping into a pool of mercury. A permanent magnet was placed in the middle of the pool. When a current was passed through the wire, the wire rotated around the magnet, showing that the current gave rise to a circular magnetic field around the wire. This motor is often demonstrated in school physics classes, but brine is sometimes used in place of the toxic mercury. This is the simplest form of a class of electric motors called homopolar motors. A later refinement is the Barlow's Wheel.

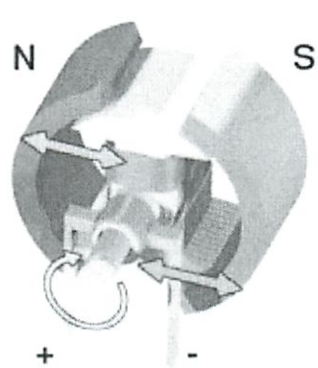
Another early electric motor design used a reciprocating plunger inside a switched solenoid; conceptually it could be viewed as an electromagnetic version of a two stroke internal combustion engine.

The modern DC motor was invented by accident in 1873, when Zénobe Gramme connected a spinning dynamo to a second similar unit, driving it as a motor.

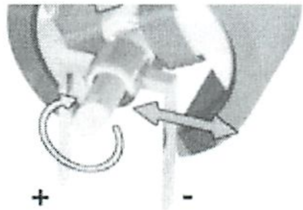
The classic DC motor has a rotating legature in the form of an electromagnet. A rotary switch called a commutator reverses the direction of the electric current twice every cycle, to flow through the armature so that the poles of the electromagnet push and pull against the permanent magnets on the outside of the motor. As the poles of the armature electromagnet pass the poles of the permanent magnets, the commutator reverses the polarity of the armature electromagnet. During that instant of switching polarity, inertia keeps the classical motor going in the proper direction. (See the diagrams below.)



A simple DC electric motor. When the coil is powered, a magnetic field is generated around the armature. The left side of the armature is pushed away from the left magnet and drawn toward the right, causing rotation.



The armature continues to rotate.



When the armature becomes horizontally aligned, the commutator reverses the direction of current through the coil, reversing the magnetic field. The process then repeats.

Wound field DC motor

The permanent magnets on the outside (s[illegible] [illegible]y electromagnets. By varying the field current it is possible to alter the speed/torque ratio of the motor. Typica[illegible] the field winding will be placed in series (series wound) with the armature winding to get a high torque low spe[illegible] motor, in parallel (shunt wound) with the armature to get a high speed low torque motor, or to have a winding [illegible]rtly in parallel, and partly in series (compound wound) for a balance that gives steady speed over a range of loa[illegible] Further reductions in field current are possible to gain even higher speed but correspondingly lower torque, cal[illegible] "weak field" operation.

Speed control

Generally speaking the rotational speed of a DC motor is proportional to the voltage applied to it, and the torque is proportional to the current. Speed control can be achieved by variable battery tappings, variable supply voltage, resistors or electronic controls. The direction of a wound field DC motor can be changed by reversing either the field or armature connections but not both, this is commonly done with a special set of contactors (direction contactors).

Effective voltage can be varied by inserting a series resistor or by an electronically-controlled switching device made of thyristors, transistors, or, historically, mercury arc rectifiers. In a circuit known as a chopper, the average voltage applied to the motor is varied by switching the supply voltage very rapidly. As the "on" to "off" ratio is varied to alter the average applied voltage, the speed of the motor varies. The rapid switching wastes less energy than series resistors. Output filters smooth the average voltage applied to the motor and reduce motor noise.

Since the series-wound DC motor develops its highest torque at low speed, it is often used in traction applications such as electric locomotives, and trams. Another application is starter motors for petrol and small diesel engines. Series motors must never be used in applications where the drive can fail (such as belt drives). As the motor accelerates the armature (and hence field) current reduces. The reduction in field causes the motor to speed up (see 'weak field' in the last section). As a consequence the motor's speed tends to infinity, but the motor will destroy itself before it spins that fast.

Universal motors

A variant of the wound field **DC motor** is the *universal motor*. The name derives from the fact that it may use AC or DC supply current, although in practice they are nearly always used with AC supplies. The principle is that in a wound field DC motor the current in both the field and the armature (and hence the resultant magnetic fields) will alternate (reverse polarity) at the same time, and hence the mechanical force generated is always in the same direction. In practice the motor must be specially designed to cope with the AC current (impedance must be taken into account as must the pulsating force), and the resultant motor is generally less efficient than an equivalent pure **DC** motor. The maximum output of universal motors is limited, and motors exceeding one kilowatt are rarely operated on commercial power frequency.

The advantage of the universal motor is that AC supplies may be used on motors which have the typical characteristics of DC motors, specifically high starting torque and very compact design if high running speeds are used. The negative aspect is the maintenance and short life problems caused by the commutator. As a result such motors are usually used in AC devices such as food mixers and power tools which are only used intermittently. Continuous speed control of a universal motor running on AC is very easily accomplished using a thyristor circuit while stepped speed control can be accomplished using multiple taps on the field coil. Household blenders that advertise many speeds frequently combine a field coil with several taps and a diode that can be inserted in series with the motor (causing the motor to run on half-wave DC with half the RMS voltage of the AC power line).

Unlike AC motors, universal motors can easily exceed one revolution per cycle of the mains current. This makes them useful for appliances such as blenders, vacuum cleaners, and hair dryers where high-speed operation is desired. Many vacuum cleaner and weed trimmer motors will exceed 10,000 RPM, Dremel and other similar miniature grinders will often exceed 30,000 RPM. A theoretical universal motor allowed to operate with no mechanical load will overspeed, which may damage it. In real life, though, various bearing frictions, armature "windage", and the load of any integrated cooling fan all act to prevent overspeed.

With the very low cost of semiconductor rectifiers, some applications that would have previously used a universal motor now use a pure DC motor, usually with a permanent magnet field. This is especially true if the semiconductor circuit is also used for variable-speed control.

The advantages of the universal motor and alternating-current distribution made installation of a low-frequency traction current distribution system economical for some railway installations. At low enough frequencies, the motor performance is approximately the same as if the motor were operating on DC. Frequencies as low as 16 2/3 Hertz were employed.

AC motors

A typical AC motor consists of two parts:

1. An outside stationary stator having coils supplied with AC current to produce a rotating magnetic field, and;
2. An inside rotor attached to the output shaft that is given a torque by the rotating field.

There are two fundamental types of AC motor depending on the type of rotor used:

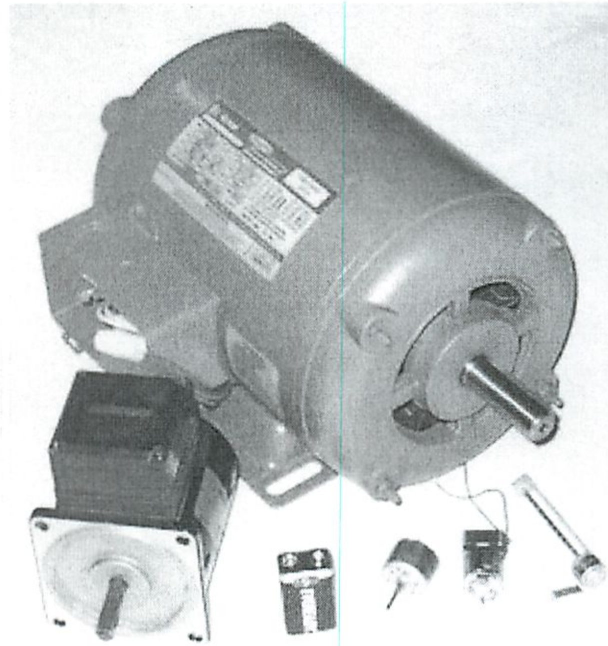
- The synchronous motor, which rotates exactly at the supply frequency or a submultiple of the supply frequency, and;
- The induction motor, which turns slightly slower, and typically (though not necessarily always) takes the form of the squirrel cage motor.

The rotating magnetic field principle, though commonly credited to Nikola Tesla in 1882 or thereabouts, was employed by scientists such as Michael Faraday and James Clerk Maxwell in the 1820s. Tesla, however, exploited the principle to design a unique two-phase induction motor in 1883. Michael von Dolivo-Dobrowlsky invented the first modern three-phase "cage-rotor" in 1890. Introduction of the motor from 1888 onwards initiated what is known as the Second Industrial Revolution, making possible the efficient generation and long distance distribution of electrical energy using the alternating current transmission system, also of Tesla's invention (1888) [1] (http://www.tfcbooks.com/tesla/system.htm). The first successful commercial three phase generation and long distance transmission system was designed by Almerian Decker at Mill Creek No. 1 [2] (http://www.electrichistory.com/) in Redlands California.[3] (http://www.redlandsweb.com/)

Three-phase AC induction motors

Where a polyphase electrical supply is available, the three-phase (or polyphase) AC induction motor is commonly used, especially for higher-powered motors. The phase differences between the three phases of the polyphase electrical supply create a rotating electromagnetic field in the motor.

Through electromagnetic induction, the rotating magnetic field induces a current in the conductors in the rotor, which in turn sets up a counterbalancing magnetic field that causes the rotor to turn in the direction the field is rotating. The rotor must always rotate slower than the rotating magnetic field produced by the polyphase electrical supply; otherwise, no counterbalancing field will be produced in the rotor.



Three phase AC induction motors rated 1 Hp (750 W) and 25 W with small motors from CD player, toy and CD/DVD drive reader head traverse

Induction motors are the workhorses of industry and motors up to about 500 kW in output are produced in highly standardized frame sizes, making them nearly completely interchangeable between manufacturers (although European and North American standard dimensions are different). Very large synchronous motors are made up to tens of thousands of kilowatts output, for pipeline compressors and wind-tunnel drives.

There are two types of rotors used in induction motors.

Squirrel Cage rotors: Most common AC motors use the squirrel cage rotor, which will be found in virtually all domestic and light industrial alternating current motors. The squirrel cage takes its name from its shape - a ring at either end of the armature, with bars connecting the rings running the length of the rotor. It is typically cast aluminum poured between the iron laminates of the rotor, and usually only the end rings will be visible. The vast majority of the rotor currents will flow through the bars rather than the higher-resistance and usually varnished laminates. Very low voltages at very high currents are typical in the bars and rings; high efficiency motors will often use cast copper in order to reduce the resistance in the rotor.

In operation, the squirrel cage motor may be viewed as a transformer with a rotating secondary - when the rotor is not rotating in sync with the magnetic field, large rotor currents are induced; the large rotor currents magnetize the rotor and interact with the stator's magnetic fields to bring the rotor into synchronization with the stator's field. An unloaded squirrel cage motor at synchronous speed will only consume electrical power to maintain rotor speed against friction and resistance losses; as the mechanical load increases, so will the electrical load - the electrical load is inherently related to the mechanical load. This is similar to a transformer, where the primary's electrical load is related to the secondary's electrical load.

This is why, as an example, a squirrel cage blower motor may cause the lights in a home to dim as it starts, but doesn't dim the lights when its fanbelt (and therefore mechanical load) is removed. Furthermore, a stalled squirrel cage motor (overloaded or with a jammed shaft) will consume current limited only by circuit resistance as it attempts to start. Unless something else limits the current (or cuts its off completely) overheating and destruction of the winding insulation is the likely outcome.

Virtually every washing machine, dishwasher, standalone fan, record player, etc. uses some variant of a squirrel cage motor.

Wound Rotor: An alternate design, called the wound rotor, is used when variable speed is required. In this case, the rotor has the same number of poles as the stator and the windings are made of wire, connected to slip rings on the shaft. Carbon brushes connect the slip rings to an external controller such as a variable resistor that allows changing the motor's slip rate. In certain high-power variable speed wound-rotor drives, the slip-frequency energy is captured, rectified and returned to the power supply through an inverter.

Compared to squirrel cage rotors, wound rotor motors are expensive and require maintenance of the slip rings and brushes, but they were the standard form for variable speed control before the advent of compact power electronic devices. Transistorized inverters with variable frequency drive can now be used for speed control and wound rotor motors are becoming less common. (Transistorized inverter drives also allow the more-efficient three-phase motors to be used when only single-phase mains current is available, but this is never used in house hold appliances, because it can cause electrical interference and because of low power requirements.)

Several methods of starting a polyphase motor are used. Where the large inrush current and high starting torque can be permitted, the motor can be started across the line, by applying full line voltage to the terminals. Where it is necessary to limit the starting inrush current (where the motor is large compared with the short-circuit capacity of the supply), reduced voltage starting using either series inductors, an autotransformer, thyristors, or other devices are used. A technique sometimes used is star-delta starting, where the motor coils are initially connected in wye for acceleration of the load, then switched to delta when the load is up to speed. This technique is more common in Europe than in North America. Transistorized drives can directly vary the applied voltage as required by the starting characteristics of the motor and load.

This type of motor is becoming more common in traction applications such as locomotives, where it is known as the asynchronous traction motor.

The speed of the AC motor is determined primarily by the frequency of the AC supply and the number of poles in the stator winding, according to the relation:

$$N_s = 120F / p$$

where

N_s = Synchronous speed, in revolutions per minute
F = AC power frequency
p = Number of poles per phase winding

Actual RPM for an induction motor will be less than this calculated synchronous speed by an amount known as *slip* that increases with the torque produced. With no load the speed will be very close to synchronous. When loaded, standard motors have between 2-3% slip, special motors may have up to 7% slip, and a class of motors known as *torque motors* are rated to operate at 100% slip (0 RPM/full stall).

The slip of the AC motor is calculated by:

$$S = (N_s - Nr) / N_s$$

where

N_r = Rotational speed, in revolutions per minute.
S = Normalised Slip, 0 to 1.

As an example, a typical four-pole motor running on 60 Hz might have a nameplate rating of 1725 RPM at full load, while its calculated speed is 1800.

The speed in this type of motor has traditionally been altered by having additional sets of coils or poles in the motor that can be switched on and off to change the speed of magnetic field rotation. However, developments in power electronics mean that the frequency of the power supply can also now be varied to provide a smoother control of the motor speed.

Three-phase AC synchronous motors

If connections to the rotor coils of a three-phase motor are taken out on slip-rings and fed a separate field current to create a continuous magnetic field (or if the rotor consists of a permanent magnet), the result is called a synchronous motor because the rotor will rotate in synchronism with the rotating magnetic field produced by the polyphase electrical supply.

A synchronous motor can also be used as an alternator.

Nowadays, synchronous motors are frequently driven by transistorized variable frequency drives. This greatly eases the problem of starting the massive rotor of a large synchronous motor. They may also be started as induction motors using a squirrel-cage winding that shares the common rotor: once the motor reaches synchronous speed, no current is induced in the squirrel-cage winding so it has little effect on the synchronous operation of the motor, aside from stabilizing the motor speed on load changes.

Synchronous motors are occasionally used as traction motors; the TGV may be the best-known example of such use.

Single-phase AC induction motors

Three-phase motors inherently produce a rotating magnetic field. However, when only single-phase power is available, the rotating magnetic field must be produced using other means. Several methods are commonly used.

A common single-phase motor is the shaded-pole motor, which is used in devices requiring low torque, such as electric fans or other small household appliances. In this motor, small single-turn copper "shading coils" create the moving magnetic field. Part of each pole is encircled by a copper coil or strap; the induced current in the strap opposes the change of flux through the coil (Lenz's Law), so that the maximum field intensity moves across the pole face on each cycle, thus producing the required rotating magnetic field.

Another common single-phase AC motor is the *split-phase induction motor*, commonly used in major appliances such as washing machines and clothes dryers. Compared to the shaded pole motor, these motors can generally provide much greater starting torque by using a special startup winding in conjunction with a centrifugal switch.

In the split-phase motor, the startup winding is designed with a higher resistance than the running winding. This creates an LR circuit which slightly shifts the phase of the current in the startup winding. When the motor is starting, the startup winding is connected to the power source via a set of spring-loaded contacts pressed upon by the not-yet-rotating centrifugal switch. The starting winding is wound with fewer turns of smaller wire than the main winding, so it has a lower inductance (L) and higher resistance (R). The lower L/R ratio creates a small phase shift, not more than about 30 degrees, between the flux due to the main winding and the flux of the starting winding. The starting direction of rotation may be reversed simply by exchanging the connections of the startup winding relative to the running winding.

The phase of the magnetic field in this startup winding is shifted from the phase of the mains power, allowing the creation of a moving magnetic field which starts the motor. Once the motor reaches near design operating speed, the centrifugal switch activates, opening the contacts and disconnecting the startup winding from the power source. The motor then operates solely on the running winding. The starting winding must be disconnected since it would increase the losses in the motor.

In a *capacitor start motor*, a starting capacitor is inserted in series with the startup winding, creating an LC circuit which is capable of a much greater phase shift (and so, a much greater starting torque). The capacitor naturally adds expense to such motors.

Another variation is the *Permanent Split-Capacitor (PSC) motor* (also known as a capacitor start and run motor). This motor operates similarly to the capacitor-start motor described above, but there is no centrifugal starting switch and the second winding is permanently connected to the power source. PSC motors are frequently used in air handlers, fans, and blowers and other cases where a variable speed is desired. By changing taps on the running winding but keeping the load constant, the motor can be made to run at different speeds. Also provided all 6 winding connections are available separately a 3 phase motor can be converted to a capactor start and run motor by commoning two of the windings and connecting the third via a capacitor to act as a start winding.

Repulsion motors are wound-rotor single-phase AC motors that are similar to universal motors. In a repulsion motor, the armature brushes are shorted together rather than connected in series with the field. Several types of repulsion motors have been manufactured, but the *repulsion-start induction-run* (RS-IR) motor has been used most frequently. The RS-IR motor has a centrifugal switch that shorts all segments of the commutator so that the motor operates as an induction motor once it has been accelerated to full speed. RS-IR motors have been used to provide high starting torque per ampere under conditions of cold operating temperatures and poor source voltage regulation. Few repulsion motors of any type are sold as of 2006.

Single-phase AC synchronous motors

Small single-phase AC motors can also be designed with magnetized rotors (or several variations on that idea). The rotors in these motors do not require any induced current so they do not slip backward against the mains frequency. Instead, they rotate synchronously with the mains frequency. Because of their highly accurate speed, such motors are usually used to power mechanical clocks, audio turntables, and tape drives; formerly they were also much used in accurate timing instruments such as strip-chart recorders or telescope drive mechanisms. The shaded-pole synchronous motor is one version.

Because inertia makes it difficult to instantly accelerate the rotor from stopped to synchronous speed, these motors normally require some sort of special feature to get started. Various designs use a small induction motor (which may share the same field coils and rotor as the synchronous motor) or a very light rotor with a one-way mechanism (to ensure that the rotor starts in the "forward" direction).

Torque motors

A torque motor is a specialized form of induction motor which is capable of operating indefinitely at stall (with the rotor blocked from turning) without damage. In this mode, the motor will apply a steady torque to the load (hence the name). A common application of a torque motor would be the supply- and take-up reel motors in a tape drive. In this application, driven from a low voltage, the characteristics of these motors allow a relatively-constant light tension to be applied to the tape whether or not the capstan is feeding tape past the tape heads. Driven from a higher voltage, (and so delivering a higher torque), the torque motors can also achieve fast-forward and rewind operation without requiring any additional mechanics such as gears or clutches.

Stepper motors

Main article: Stepper motor

Closely related in design to three-phase AC synchronous motors are stepper motors, where an internal rotor containing permanent magnets or a large iron core with salient poles is controlled by a set of external magnets that are switched electronically. A stepper motor may also be thought of as a cross between a DC electric motor and a solenoid. As each coil is energized in turn, the rotor aligns itself with the magnetic field produced by the energized field winding. Unlike a synchronous motor, in its application, the motor may not rotate continuously; instead, it "steps" from one position to the next as field windings are energized and deenergized in sequence. Depending on the sequence, the rotor may turn forwards or backwards.

Simple stepper motor drivers entirely energize or entirely deenergize the field windings, leading the rotor to "cog" to a limited number of positions; more sophisticated drivers can proportionally control the power to the field windings allowing the rotors to position "between" the "cog" points and thereby rotate extremely smoothly. Computer controlled stepper motors are one of the most versatile forms of positioning systems, particularly when part of a digital servo-controlled system.

Brushless DC motors

Main article: Brushless DC electric motor

Many of the limitations of the classic commutator DC motor are due to the need for brushes to press against the commutator. This creates friction. At higher speeds, brushes have increasing difficulty in maintaining contact. Brushes may bounce off the irregularities in the commutator surface, creating sparks. This limits the maximum speed of the machine. The current density per unit area of the brushes limits the output of the motor. The imperfect electric contact also causes electrical noise. Brushes eventually wear out and require replacement, and the commutator itself is subject to wear and maintenance. The commutator assembly on a large machine is a costly element, requiring precision assembly of many parts.

These problems are eliminated in the brushless motor. In this motor, the mechanical "rotating switch" or commutator/brushgear assembly is replaced by an external electronic switch synchronised to the motor's position. Brushless motors are typically 85-90% efficient whereas DC motors with brushgear are typically 10% less efficient.

Midway between ordinary DC motors and stepper motors lies the realm of the brushless DC motor. Built in a fashion very similar to stepper motors, these often use a permanent magnet **external** rotor, three phases of driving coils, one or more Hall effect devices to sense the position of the rotor, and the associated drive electronics. The coils are activated, one phase after the other, by the drive electronics as cued by the signals from the Hall effect sensors. In effect, they act as three-phase synchronous motors containing their own variable frequency drive electronics. A specialized class of brushless DC motor controllers utilize EMF feedback through the main phase connections instead of Hall effect sensors to determine position and velocity. These motors are used extensively in electric radio-controlled vehicles.

Brushless DC motors are commonly used where precise speed control is necessary, computer disk drives or in video cassette recorders the spindles within CD, CD-ROM (etc.) drives, and mechanisms within office products such as fans, laser printers and photocopiers. They have several advantages over conventional motors:

- Compared to AC fans using shaded-pole motors, they are very efficient, running much cooler than the equivalent AC motors. This cool operation leads to much-improved life of the fan's bearings.
- Without a commutator to wear out, the life of a DC brushless motor can be significantly longer compared to a DC motor using brushes and a commutator. Commutation also tends to cause a great deal of electrical and RF noise; without a commutator or brushes, a brushless motor may be used in electrically sensitive devices like audio equipment or computers.

- The same Hall effect devices that provide the commutation can also provide a convenient tachometer signal for closed-loop control (servo-controlled) applications. In fans, the tachometer signal can be used to derive a "fan okay" signal.
- The motor can be easily synchronized to an internal or external clock, leading to precise speed control.

Modern DC brushless motors range in power from a fraction of a watt to many kilowatts. Larger brushless motors up to about 100 kW rating are used in electric vehicles. They also find significant use in high-performance electric model aircraft.

Coreless DC motors

Nothing in the design of any of the motors described above requires that the iron (steel) portions of the rotor actually rotate; torque is only exerted on the windings of the electromagnets. Taking advantage of this fact is the **coreless DC motor**, a specialized form of a brush DC motor. Optimized for rapid acceleration, these motors have a rotor that is constructed without any iron core. The rotor can take the form of a winding-filled cylinder inside the stator magnets, a basket surrounding the stator magnets, or a flat *pancake* (possibly formed on a printed wiring board) running between upper and lower stator magnets. The windings are typically stabilized by being impregnated with epoxy resins.

Because the rotor is much lighter in weight (mass) than a conventional rotor formed from copper windings on steel laminations, the rotor can accelerate much more rapidly, often achieving a mechanical time constant under 1 ms. This is especially true if the windings use aluminum rather than the heavier copper. But because there is no metal mass in the rotor to act as a heat sink, even small coreless motors must often be cooled by forced air.

These motors were commonly used to drive the capstan(s) of magnetic tape drives and are still widely used in high-performance servo-controlled systems.

Linear motors

A linear motor is essentially an electric motor that has been "unrolled" so that instead of producing a torque (rotation), it produces a linear force along its length by setting up a traveling electromagnetic field.

Linear motors are most commonly induction motors or stepper motors. You can find a linear motor in a maglev (Transrapid) train, where the train "flies" over the ground.

Nano motor

Researchers at UC Berkeley have developed rotational bearings based upon multiwall carbon nanotubes. By attaching a gold plate (with dimensions of order 100nm) to the outer shell of a suspended multiwall carbon nanotube (like nested carbon cylinders), they are able to electrostatically rotate the outer shell relative to the inner core. These bearings are very robust; Devices have been oscillated thousands of times with no indication of wear. The work was done in situ in an SEM. These nanoelectromechanical systems (NEMS) are the next step in miniaturization that may find their way into commercial aspects in the future.

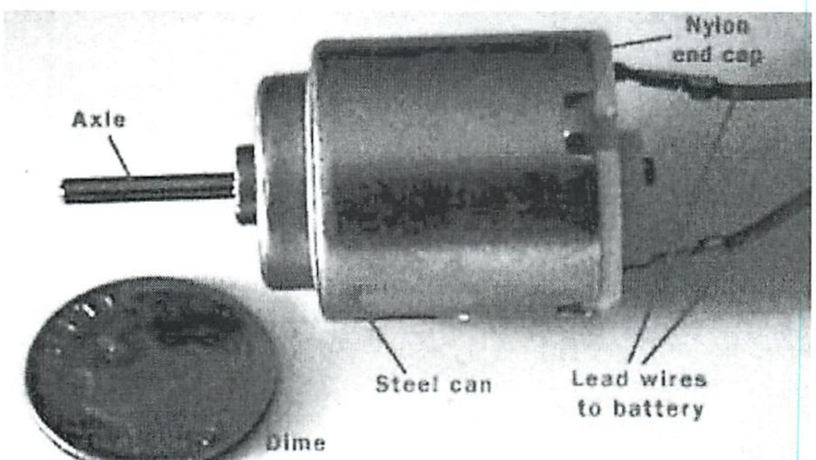
Notice: The thin vertical string seen in the middle, is the nanotube to which the rotor is attached. When the outer tube is sheared, the rotor is able to spin freely on the nanotube bearing.

The process and technology can be seen in this render (http://www.berkeley.edu/news/media/releases/2003/07/video/nano_hq.html).

How Electric Motors Work

by Marshall Brain

Electric motors are everywhere! In your house, almost every mechanical movement that you see around you is caused by an AC (alternating current) or DC (direct current) electric motor.

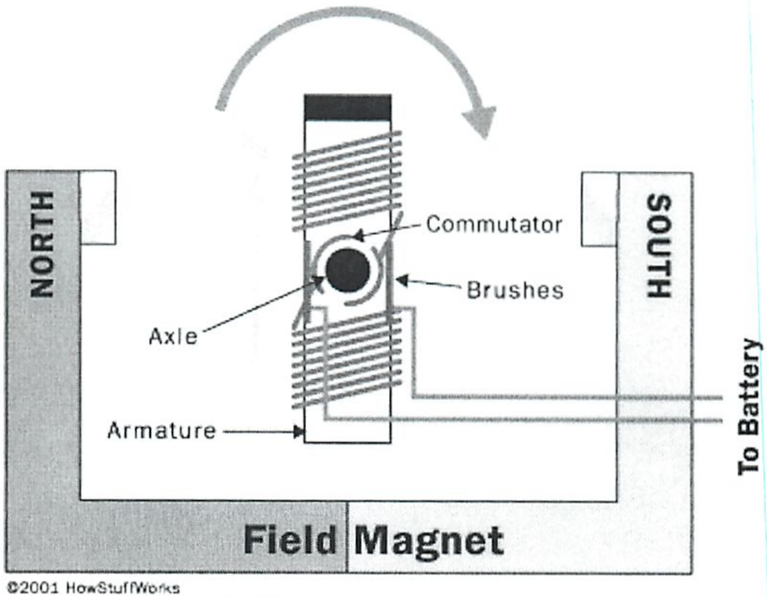


By understanding how a motor works you can learn a lot about magnets, electromagnets and electricity in general. In this article, you will learn what makes electric motors tick.

Inside an Electric Motor

Let's start by looking at the overall plan of a simple **two-pole DC electric motor**. A simple motor has six parts, as shown in the diagram below:

- **Armature or rotor**
- **Commutator**
- **Brushes**
- **Axle**
- **Field magnet**
- **DC power supply** of some sort



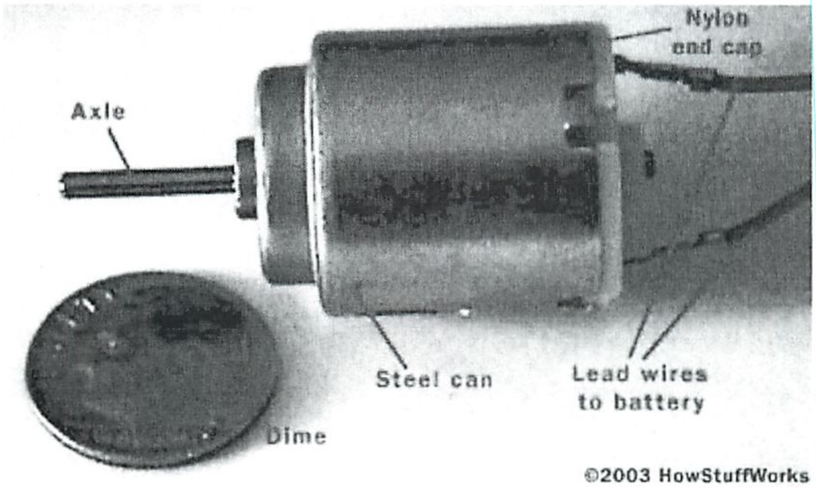
Parts of an electric motor

An electric motor is all about magnets and magnetism: A motor uses **magnets** to create motion. If you have ever played with magnets you know about the fundamental law of all magnets: Opposites attract and likes repel. So if you have two bar magnets with their ends marked "north" and "south," then the north end of one magnet will attract the south end of the other. On the other hand, the north end of one magnet will repel the north end of the other (and similarly, south will repel south). Inside an electric motor, these attracting and repelling forces create **rotational motion**.

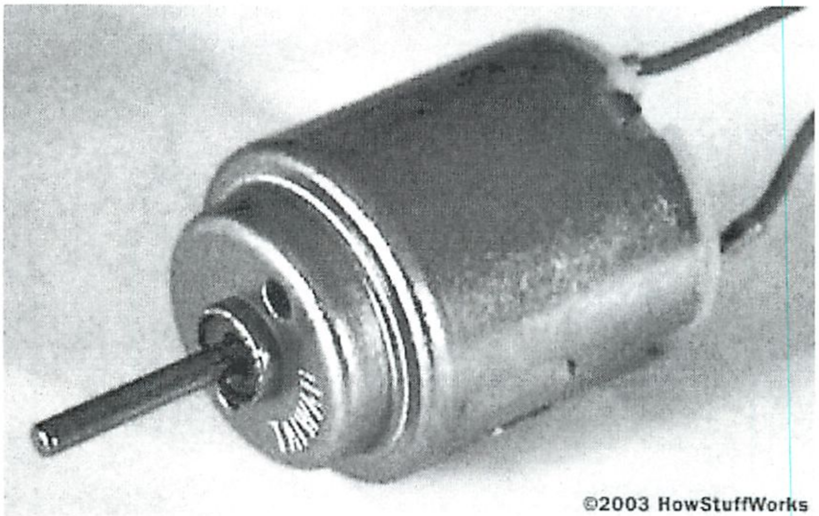
In the above diagram, you can see two magnets in the motor: The armature (or rotor) is an electromagnet, while the field magnet is a permanent magnet (the field magnet could be an electromagnet as well, but in most small motors it isn't in order to save power).

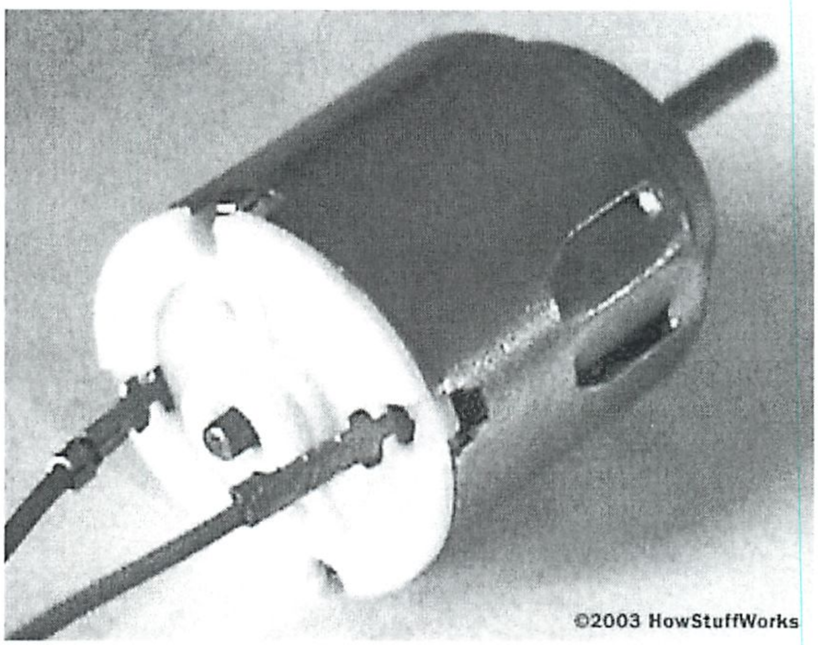
Toy Motor

The motor being dissected here is a simple electric motor that you would typically find in a toy:

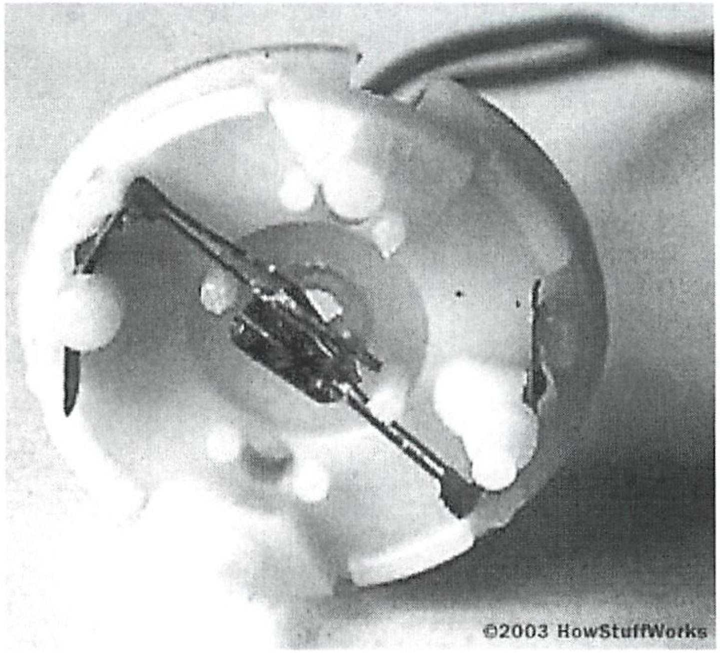


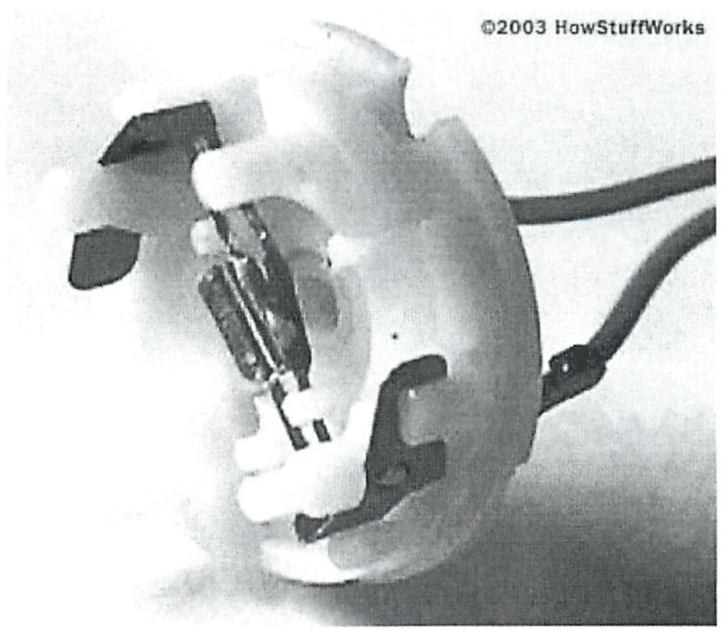
You can see that this is a small motor, about as big around as a dime. From the outside you can see the steel can that forms the body of the motor, an axle, a nylon end cap and two battery leads. If you hook the battery leads of the motor up to a flashlight battery, the axle will spin. If you reverse the leads, it will spin in the opposite direction. Here are two other views of the same motor. (Note the two slots in the side of the steel can in the second shot -- their purpose will become more evident in a moment.)





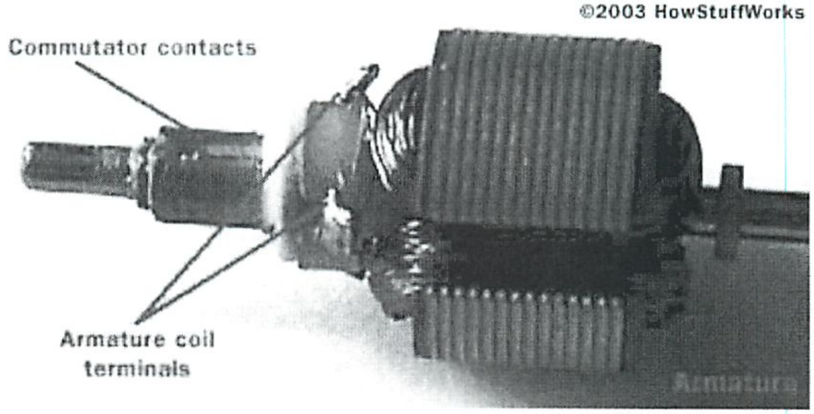
The nylon end cap is held in place by two tabs that are part of the steel can. By bending the tabs back, you can free the end cap and remove it. Inside the end cap are the motor's brushes. These brushes transfer power from the battery to the commutator as the motor spins:





More Parts

The axle holds the armature and the commutator. The armature is a set of electromagnets, in this case three. The armature in this motor is a set of thin metal plates stacked together, with thin copper wire coiled around each of the three poles of the armature. The two ends of each wire (one wire for each pole) are soldered onto a terminal, and then each of the three terminals is wired to one plate of the commutator. The figures below make it easy to see the armature, terminals and commutator:



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The final piece of any DC electric motor is the field magnet. The field magnet in this motor is formed by the can itself plus two curved permanent magnets:

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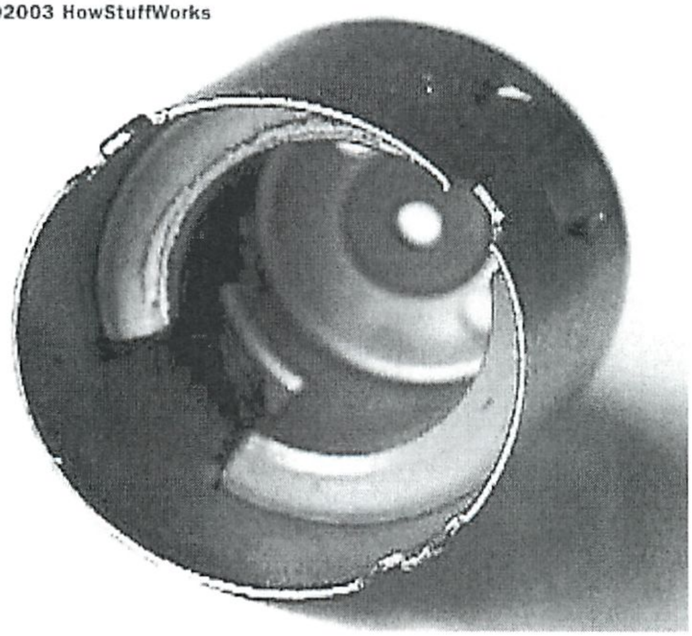

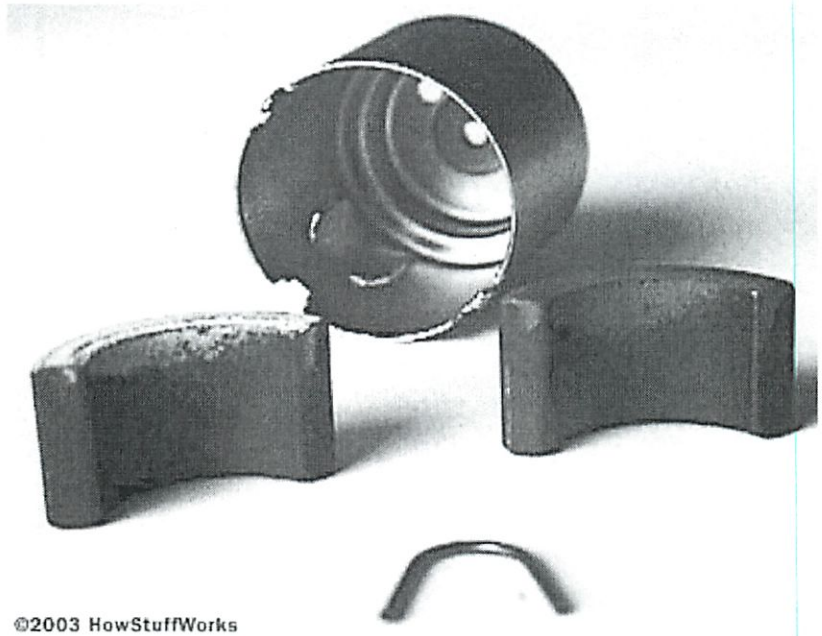

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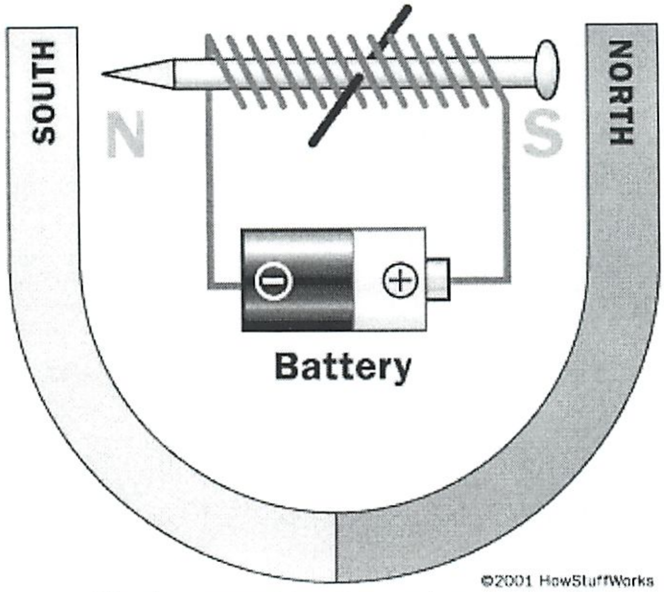
One end of each magnet rests against a slot cut into the can, and then the retaining clip presses against the other ends of both magnets.

Electromagnets and Motors

To understand how an electric motor works, the key is to understand how the electromagnet works. (See How Electromagnets Work for complete details.)

An electromagnet is the basis of an electric motor. You can understand how things work in the motor by imagining the following scenario. Say that you created a simple electromagnet by wrapping 100 loops of wire around a nail and connecting it to a battery. The nail would become a magnet and have a north and south pole while the battery is connected.

Now say that you take your nail electromagnet, run an axle through the middle of it and suspend it in the middle of a horseshoe magnet as shown in the figure below. If you were to attach a battery to the electromagnet so that the north end of the nail appeared as shown, the basic law of magnetism tells you what would happen: The north end of the electromagnet would be repelled from the north end of the horseshoe magnet and attracted to the south end of the horseshoe magnet. The south end of the electromagnet would be repelled in a similar way. The nail would move about half a turn and then stop in the position shown.

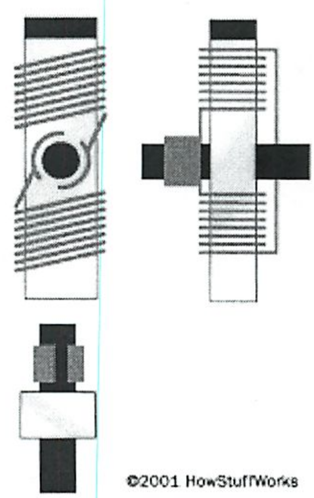


Electromagnet in a horseshoe magnet

You can see that this half-turn of motion is simply due to the way magnets naturally attract and repel one another. The key to an electric motor is to then go one step further so that, at the moment that this half-turn of motion completes, the field of the electromagnet **flips**. The flip causes the electromagnet to complete another half-turn of motion. You flip the magnetic field just by changing the direction of the electrons flowing in the wire (you do that by flipping the battery over). If the field of the electromagnet were flipped at precisely the right moment at the end of each half-turn of motion, the electric motor would spin freely.

Armature, Commutator and Brushes

Consider the image on the previous page. The **armature** takes the place of the nail in an electric motor. The armature is an electromagnet made by coiling thin wire around two or more poles of a metal core.



Armature

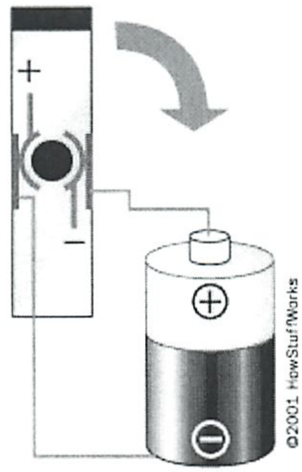
The armature has an **axle**, and the commutator is attached to the axle. In the diagram to the right, you can see three different views of the same armature: front, side and end-on. In the end-on view, the winding is eliminated to make the commutator more obvious. You can see that the commutator is simply a pair of plates attached to the axle. These plates provide the two connections for the coil of the electromagnet.

The "flipping the electric field" part of an electric motor is accomplished by two parts: the **commutator** and the **brushes**.

The diagram at the right shows how the commutator and brushes work together to let current flow to the electromagnet, and also to flip the direction that the electrons are flowing at just the right moment. The contacts of the commutator are attached to the axle of the electromagnet, so they spin with the magnet. The brushes are just two pieces of springy metal or carbon that make contact with the contacts of the commutator.

Putting It All Together

When you put all of these parts together, what you have is a complete electric motor:



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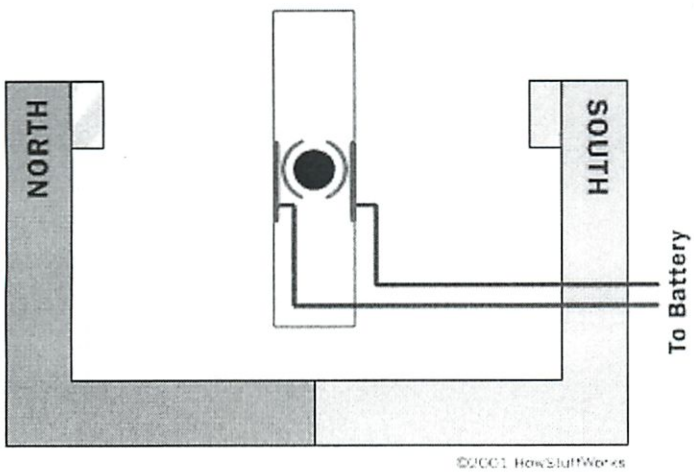

Armature

In this figure, the armature winding has been left out so that it is easier to see the commutator in action. The key thing to notice is that as the armature passes through the horizontal position, the poles of the electromagnet flip. Because of the flip, the north pole of the electromagnet is always above the axle so it can repel the field magnet's north pole and attract the field magnet's south pole.

If you ever have the chance to take apart a small electric motor, you will find that it contains the same pieces described above: two small permanent magnets, a commutator, two brushes, and an electromagnet made by winding wire around a piece of metal. Almost always, however, the rotor will have **three poles** rather than the two poles as shown in this article. There are two good reasons for a motor to have three poles:

- It causes the motor to have better dynamics. In a two-pole motor, if the electromagnet is at the balance point, perfectly horizontal between the two poles of the field magnet when the motor starts, you can imagine the armature getting "stuck" there. That never happens in a three-pole motor.
- Each time the commutator hits the point where it flips the field in a two-pole motor, the commutator shorts out the battery (directly connects the positive and negative terminals) for a moment. This shorting wastes energy and drains the battery needlessly. A three-pole motor solves this problem as well.

It is possible to have any number of poles, depending on the size of the motor and the specific