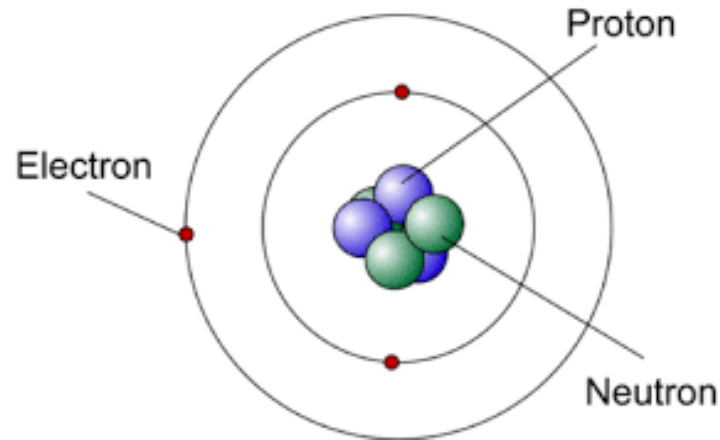


Atoms



**Most of the materials in
this course are from
Wikipedia, the free
encyclopedia**

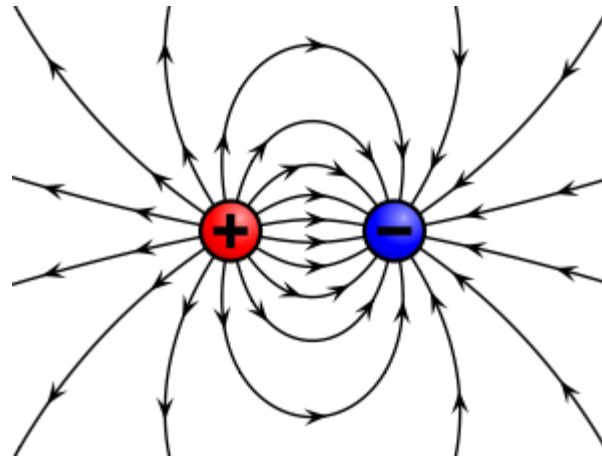
All things are made of atoms.

Clothes, foods, air, buildings, even our bodies.

All atoms are built from 3 elements: protons,
neutrons and electrons.

https://en.wikipedia.org/wiki/Atomic_theory

Electric charge



Electric field of a positive and a negative point charge. An object is negatively charged if it has an excess of electrons, and is otherwise positively charged or uncharged. The SI derived unit of electric charge is the coulomb (C). The symbol Q is often used to denote charge. https://en.wikipedia.org/wiki/Electric_charge

Electric charge

Twentieth-century [experiments](#) demonstrated that electric charge is [quantized](#); that is, it comes in integer multiples of individual small units called the [elementary charge](#), e , approximately equal to 1.602×10^{-19} coulombs.

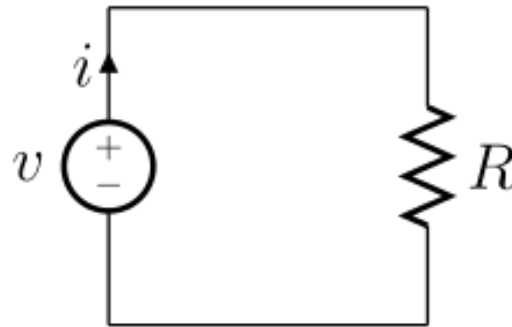
The [SI](#) unit of [quantity of electric charge](#) is the [coulomb](#), which is equivalent to about 6.242×10^{18} [\$e\$](#) (e is the charge of a proton). Hence, the charge of an electron is approximately -1.602×10^{-19} C.

Electric current

Conventional Current

When electricity was discovered, they assumed that current flows from positive terminal, through the circuit and into the negative terminal.

Wrong!



https://en.wikipedia.org/wiki/Electric_current

Electric current

An **electric current** is a flow of [electric charge](#). In electric circuits this charge is often carried by moving [electrons](#) in a [wire](#). It can also be carried by [ions](#) in an [electrolyte](#), or by both ions and electrons such as in a [plasma](#). https://en.wikipedia.org/wiki/Electric_current

Conductors

Conductors are made up of atoms whose electrons (conduction band) are able to escape from the atom's influence.

<https://www.google.com.hk/search?q=atom+model&tbm=isch&tbo=u&source=univ&sa=X&ved=0ahUKEwibxJXJp4PKAhUD6KYKHaasAtUQsAQIGw&biw=1280&bih=806&dpr=1.25>

In a metal, some electrons are not stuck (fixed) to any particular atom and are free to wander in the metal.

For instance, the copper, the most used conductor in the world, there is usually a free electron from every copper atom. As the electrons move, they collide with the atoms and thus meet resistance to their motion. The greater the number of collisions the greater the resistance.

Superconductivity

<https://en.wikipedia.org/wiki/Superconductivity>

- **Superconductivity** is a phenomenon of exactly zero electrical resistance and expulsion of magnetic fields occurring in certain materials when cooled below a characteristic critical temperature.
- In a superconductor, the resistance drops abruptly to zero when the material is cooled below its critical temperature. An electric current flowing through a loop of superconducting wire can persist indefinitely with no power source.

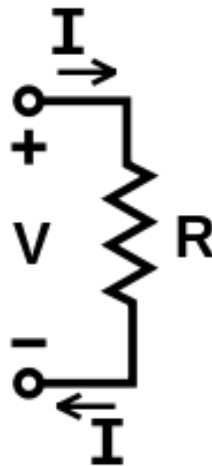
[Lexus Hoverboard](#)

Ohm's law

Ohm's law states that the current through a conductor between two points is directly proportional to the potential difference across the two points. The law was named after the German physicist Georg Ohm, who, in a treatise published in 1827.

https://en.wikipedia.org/wiki/Ohm%27s_law

$$I = V/R$$

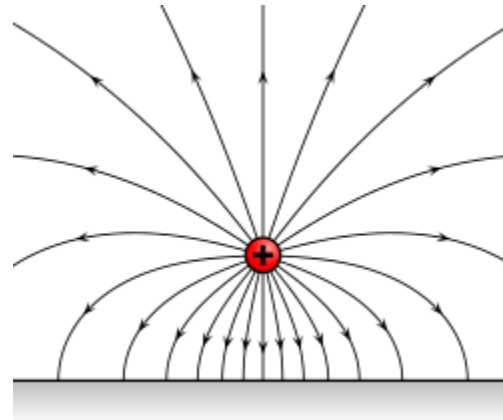


V, I, and R, the parameters of Ohm's law.

Electric field

The **electric field** is a component of the electromagnetic field. It is a vector field, and it is generated by electric charges or time-varying magnetic fields as described by Maxwell's equations.^[1] The concept of an electric field was introduced by Michael Faraday.^[2]

https://en.wikipedia.org/wiki/Electric_field

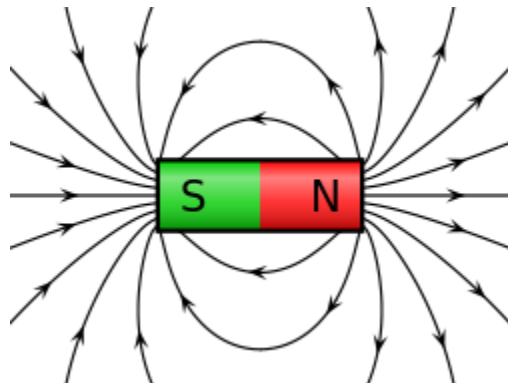


Electric field lines emanating from a point positive electric charge suspended over an infinite sheet of conducting material.

Magnetic field

A **magnetic field** is the magnetic effect of electric currents and magnetic materials.

The magnetic field at any given point is specified by both a *direction* and a *magnitude* (or strength); as such it is a vector field. https://en.wikipedia.org/wiki/Magnetic_field



Magnetic field of an ideal cylindrical magnet with its axis of symmetry inside the image plane. The magnetic field is represented by magnetic field lines, which show the direction of the field at different points.

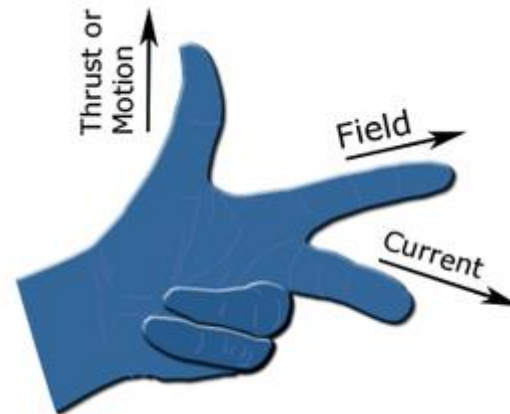
Fleming's left-hand rule for motors

The **Thumb** represents the direction of the **Thrust** on the conductor / *Motion* of the Conductor

The **Fore** finger represents the direction of the magnetic **Field**

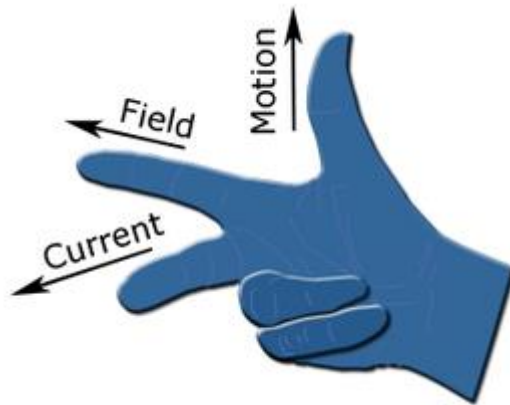
The **Centre** finger represents the direction of the **Current**.

[Motor operation animation:](#)



Fleming's right-hand rule for generators

The two rules were originated by John Ambrose Fleming, in the late 19th century, as a simple way of working out the direction of motion in an electric motor, or the direction of electric current in an electric generator.^[1] https://en.wikipedia.org/wiki/Fleming%27s_left-hand_rule_for_motors



Alternating current

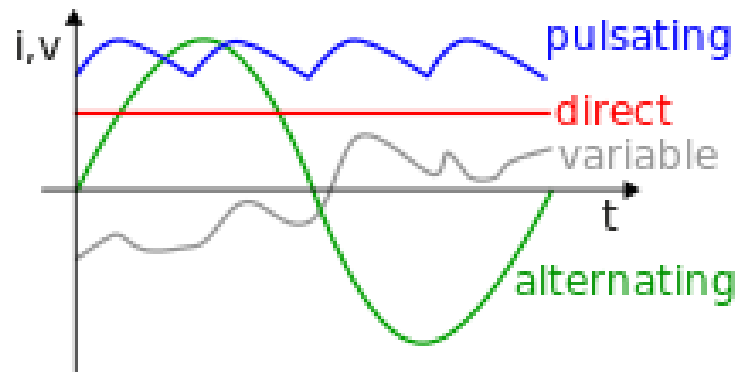
In **alternating current (AC)**, the flow of electric charge periodically reverses direction, whereas in direct current (DC, also **dc**), the flow of electric charge is only in one direction.

AC is the form in which electric power is delivered to businesses and residences.

The usual waveform of an AC power circuit is a sine wave.

https://en.wikipedia.org/wiki/Alternating_current

$$P_L = I^2 R. \quad P_T = IV.$$



High voltage transmission lines



$$P_T = IV .$$

In a [power plant](#), power is generated at a convenient voltage for the design of a [generator](#), and then stepped up to a high voltage for transmission. Near the loads, the transmission voltage is stepped down to the voltages used by equipment.

High voltages also have disadvantages, the main one being the increased insulation required, and generally increased difficulty in their safe handling

AC power supply frequencies

The [frequency of the electrical system](#) varies by country and sometimes within a country; most electric power is generated at either 50 or 60 [hertz](#). Some countries have a mixture of 50 Hz and 60 Hz supplies, notably [electricity power transmission in Japan](#).

Further information: [Mains power around the world](#)

Electricity sector in Japan

Electricity transmission in Japan is divided for historical reasons into two regions each running at a different [mains frequency](#).

Eastern Japan (including [Tokyo](#), [Kawasaki](#), [Sapporo](#), [Yokohama](#), and [Sendai](#)) runs at 50 Hz; Western Japan (including [Okinawa](#), [Osaka](#), [Kyoto](#), [Kobe](#), [Nagoya](#), [Hiroshima](#)) runs at 60 Hz.

This originates from the first purchases of generators from [AEG](#) for Tokyo in 1895 and from [General Electric](#) for Osaka in 1896. [\[4\]](#)[\[5\]](#)

https://en.wikipedia.org/wiki/Electricity_sector_in_Japan#Transmission

Effect of power supply frequencies

A low frequency eases the design of electric motors, crushing and rolling applications, and commutator-type [traction motors](#) for applications such as [railways](#). However, low frequency also causes noticeable flicker in [arc lamps](#) and [incandescent light bulbs](#). **The use of lower frequencies also provided the advantage of lower impedance losses, which are proportional to frequency.**

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

Effects at high frequencies (1)

A direct current flows uniformly throughout the cross-section of a uniform wire.

An alternating current of any frequency is forced away from the wire's center, toward its outer surface. 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 wires of a few [skin depths](#). The skin depth is the thickness at which the current density is reduced by 63%.

For example, the skin depth of a copper conductor is approximately 8.57 mm at 60 Hz, so high current conductors are usually hollow to reduce their mass and cost.

Effects at high frequencies (2)

At 60 Hz, the skin depth of a copper wire is about $\frac{1}{3}$ inch (8.5 mm).

At 60,000 Hz (60 kHz), the skin depth of copper wire is about 0.01 inches (0.25 mm).

At 6,000,000 Hz (6 MHz) [5] the skin depth of copper wire is about 0.001 inches (25 μm). https://en.wikipedia.org/wiki/Litz_wire

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.

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

- Conductors can be divided into stranded wires, each insulated from one other, and the relative positions of individual strands specially arranged 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 throughout the total cross section of the stranded conductors.

The term litz wire originates from *Litzendraht* (coll. *Litze*) [German](#) for braided/stranded wire^[3] or woven wire.^[4]



Direct current

Direct current (DC) is the unidirectional flow of [electric charge](#). Direct current is produced by sources such as [batteries](#), [thermocouples](#), [solar cells](#), and commutator-type electric machines of the [dynamo](#) type.

Direct current may be obtained from an alternating current supply by use of a current-switching arrangement called a [rectifier](#).

Direct current may be made into alternating current with an [inverter](#) or a motor-generator set. https://en.wikipedia.org/wiki/Direct_current

Electric power transmission DC or AC?

The first commercial [electric power transmission](#) (developed by [Thomas Edison](#) in the late nineteenth century) used direct current.

Because of the significant advantages of alternating current over direct current in transforming and transmission, electric power distribution is nearly all (but not all) alternating current today.

e.g. between countries, such as [NorNed](#), the NorNed cable is a [bipolar HVDC](#) link with a voltage of ± 450 kV and a capacity of 700 MW. <https://en.wikipedia.org/wiki/NorNed>

Question Time

In Hong Kong, which organization uses most electricity and what kind of power supply do they use?

On your electricity bill, what is one unit of electricity?

DC Applications

Most [electronic](#) circuits require a DC [power supply](#).

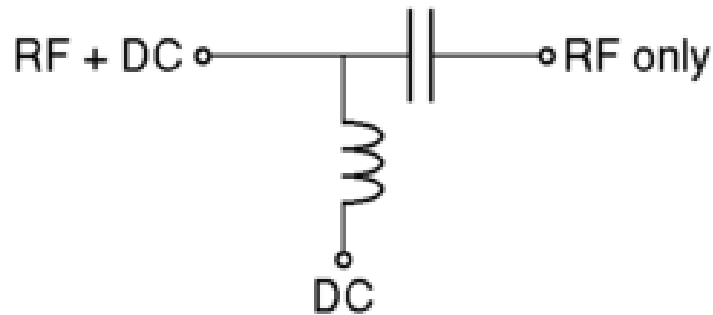
DC is commonly found in many [extra-low voltage](#) applications and some [low-voltage](#) applications, especially where these are powered by [batteries](#), which can produce only DC, or [solar power](#) systems, since [solar cells](#) can produce only DC.

Most automotive applications use DC, although the [alternator](#) is an AC device which uses a [rectifier](#) to produce DC.

Applications using [fuel cells](#) (mixing hydrogen and oxygen together with a catalyst to produce electricity and water as byproducts) also produce only DC.

DC Applications

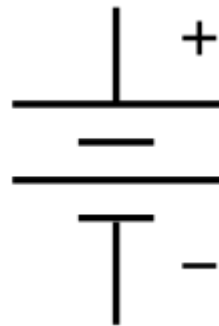
Many telephones connect to a twisted pair of wires, and use a bias tee to internally separate the AC component of the voltage between the two wires (the audio signal) from the DC component of the voltage between the two wires (used to power the phone).



Equivalent circuit of a bias tee.

Battery (electricity)

An electric **battery** is a device consisting of two or more [electrochemical cells](#) that convert stored chemical energy into electrical energy. Each cell contains a positive terminal, or [anode](#), and a negative terminal, or [cathode](#). [Electrolytes](#) allow ions to move between the electrodes and terminals, which allows current to flow out of the battery to perform work.^{[\[1\]](#)}



https://en.wikipedia.org/wiki/Battery_%28electricity%29

Battery (electricity)

Primary (single-use or "disposable") batteries are used once and discarded; the electrode materials are irreversibly changed during discharge. Disposable primary cells cannot be reliably recharged. Common examples are the alkaline battery, zinc-carbon batteries.

Secondary (rechargeable batteries) can be discharged and recharged multiple times; the original composition of the electrodes can be restored by reverse current. Examples include the lead-acid batteries (The oldest form of rechargeable battery) used in vehicles and lithium ion batteries used for portable electronics.

Battery cell performance

A battery's characteristics may vary over load cycle, over [charge cycle](#), and over lifetime due to many factors including internal chemistry, [current](#) drain, and temperature, Self-discharge, charging speed, memory effect, battery life time, ...

Capacity - the amount of [electric charge](#) it can deliver at the rated voltage.

Capacity is measured in units such as [amp-hour](#) (A·h).

C-rate - a measure of the rate at which a battery is being discharged. It is defined as the discharge current divided by the theoretical current draw under which the battery would deliver its nominal rated capacity in one hour.^[30] A 1C discharge rate would deliver the battery's rated capacity in 1 hour. A 2C discharge rate means it will discharge twice as fast (30 minutes). A 1C discharge rate on a 1.6 Ah battery means a discharge current of 1.6 A. A 2C rate would mean a discharge current of 3.2 A. Standards for rechargeable batteries generally rate the capacity over a 4 hour, 8 hour or longer discharge time.

Because of internal resistance loss and the chemical processes inside the cells, a battery rarely delivers rated capacity in only one hour. Types intended for special purposes, such as in a computer uninterruptible power supply, may be rated by manufacturers for discharge periods much less than one hour.

Fast-charging batteries

As of 2012 [lithium iron phosphate \(LiFePO₄\) battery technology](#) was the fastest-charging/discharging, fully discharging in 10–20 seconds.[\[31\]](#)

Largest Batteries

As of 2013, the world's largest battery was in [Hebei Province](#), China. 36 megawatt-hours of electricity, cost of \$500 million.^[32] This plant is larger than a football field and is enough to power something like 12,000 homes for an hour during a total power failure.

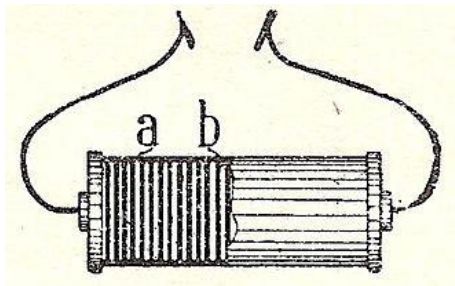
It is hooked into 140 megawatts of wind and solar power generation projects as well as a smart grid transmission system.

<http://www.popsci.com/science/article/2012-01/china-builds-worlds-largest-battery-36-megawatt-hour-behemoth>



The Longest Lifetime Battery

In contrast to most of today's batteries, the [Zamboni pile](#), invented in 1812, offers a very long service life without refurbishment or recharge, although it supplies current only in the nanoamp range. The [Oxford Electric Bell](#) has been ringing almost continuously since 1840 on its original pair of batteries, thought to be Zamboni piles. Located in the [Clarendon Laboratory](#) at the [University of Oxford](#).



https://en.wikipedia.org/wiki/Zamboni_pile



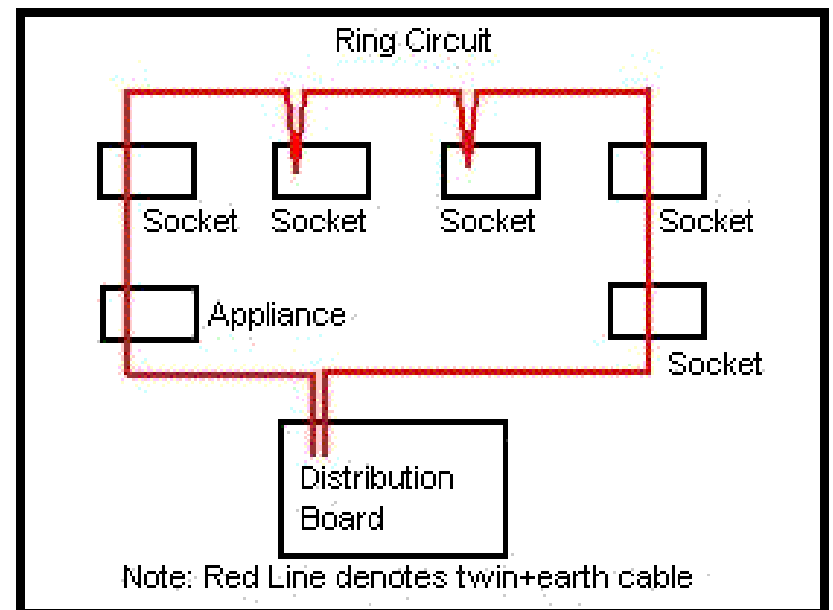
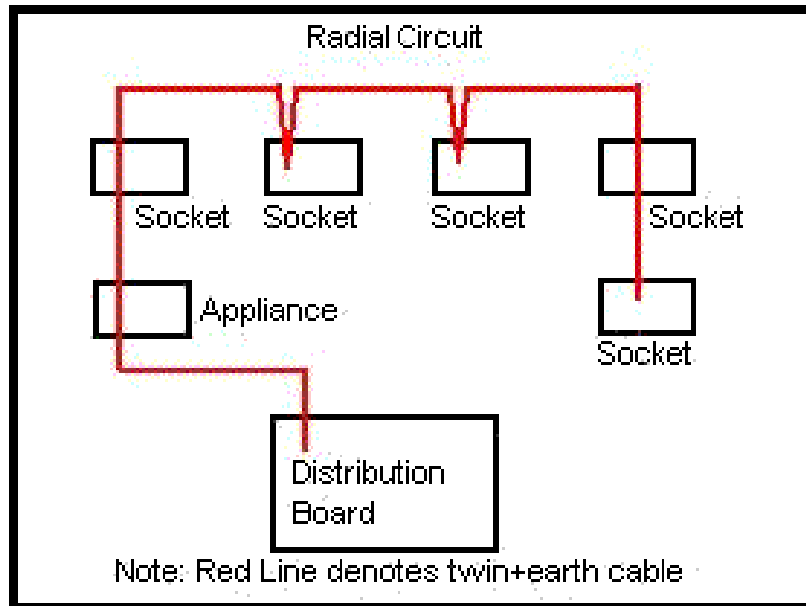
https://en.wikipedia.org/wiki/Oxford_Electric_Bell

Electrical wiring

Electrical wiring is commonly distinguished by a number of criteria, such as [voltage](#) (low, very low, high, etc.), [phase](#) (single or 3 phase), nature of electrical signal (power, data), type and design of [cable](#) (conductors and insulators used, cable design, solid/fixed or stranded/flexible, intended use, protective materials), circuit design ([ring](#), [radial](#)), and so on.

https://en.wikipedia.org/wiki/Electrical_wiring_in_the_United_Kingdom#Circuit_design

Radial Circuit and Ring Circuit



http://claydons.org/public-html/elec/domestic_electrical_wiring.htm

The ring [circuit](#) and the associated [BS 1363](#) plug and socket system were developed in Britain during 1942–1947.^{[\[1\]](#)}

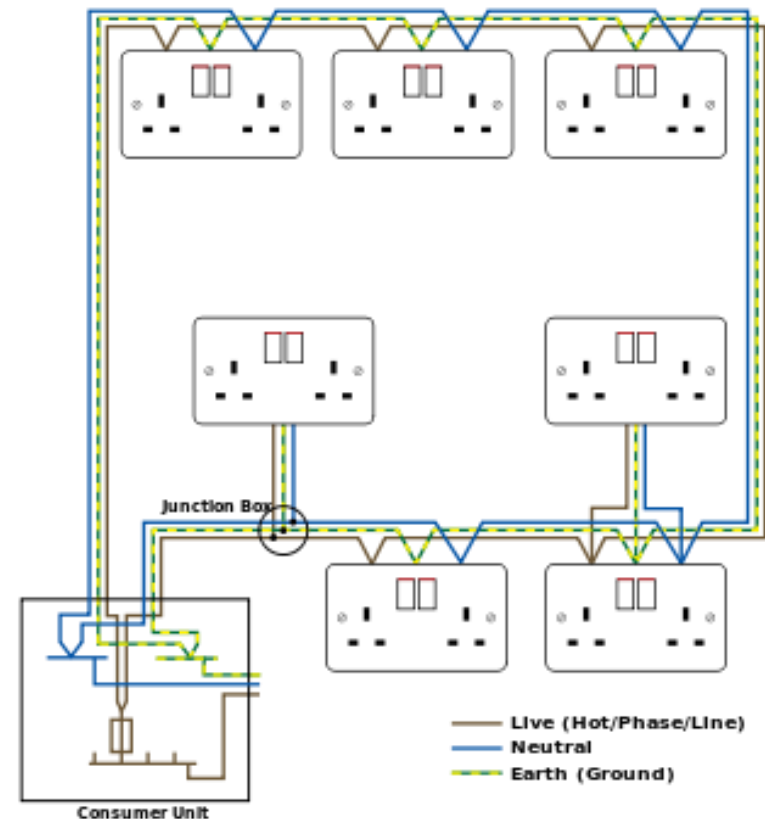
In [electricity supply](#), a **ring circuit** (often incorrectly called a **ring main**) is an [electrical wiring](#) technique developed and primarily used in the [United Kingdom](#). This design enables the use of smaller-diameter wire than would be used in a [radial circuit](#) of equivalent total current.

Ideally, the ring circuit acts like two radial circuits proceeding in opposite directions around the ring, the dividing point between them dependent on the distribution of load in the ring. If the load is evenly split across the two directions, the current in each direction is half of the total, allowing the use of wire with half the current-carrying capacity. In practice, the load does not always split evenly, so thicker wire is used.

Safety Devices

The ring starts at the consumer unit (also known as fuse box, distribution board, breaker box, or Residual-current device RCD), visits each socket in turn, and then returns to the consumer unit. https://en.wikipedia.org/wiki/Ring_circuit

A **circuit breaker** is an electrical switch designed to protect an electrical circuit from damage caused by overload or short circuit.



A Device That May Save Your Life

A residual-current device (RCD), or residual-current circuit breaker (RCCB) is an [electrical wiring](#) device that disconnects a circuit whenever it detects that the [electric current](#) is not balanced between the energized (line) conductor(s) and the return ([neutral](#)) conductor. https://en.wikipedia.org/wiki/Residual-current_device



A two-pole, or double pole, residual-current device. The test button and connect/disconnect switch are colored blue. A fault will trigger the switch to its down (off) position, in this device it would disconnect both conductors.

How a RCD Save Life

To prevent electrocution, RCDs should operate within 25-40 milliseconds with any leakage currents (through a person) of greater than 30 milliamperes, before electric shock can drive the heart into ventricular fibrillation, the most common cause of death through electric shock.

https://en.wikipedia.org/wiki/Residual-current_device

Beware: A residual-current circuit breaker cannot remove all risk of electric shock or fire.