Materials For the Course

Instruction

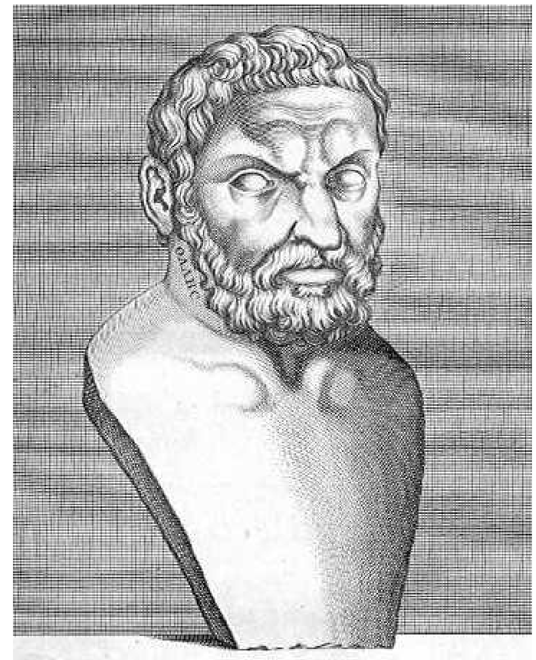
Here are some materials related with the course, we hope that readers can obtain more information to expand widely their field. Some knowledge are extracted briefly. If you want to know more contents or the knowledge in detail, you would search for other material.

Acknowledge

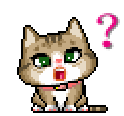
During the PPT 's preparation, we downloaded some material such as texts, videos, photos, and so on, form http://www.wikipedia.org/ and http://www.youtube.com/ . So, here I would like to thank these website's staffs.

Thales —— Father of Science

Thales (from 624-625 to c. 547-546)：Philosopher from Miletus in Asia Minor, who was not only one of the Seven Wise Men of Greece but is also considered the founder of philosophy and the first geometrist and Father of Science.



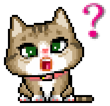
Thales of Miletus discovered that when amber was rubbed against cloth, sparks were produced and then the amber attracted husks and small wooden splinters. This force was given the name "electricity" after the Greek word *electron* which means amber.



Elektron —— the name for amber in Greek

Amber a pale yellow, sometimes reddish or brownish, fossil resin of vegetable origin, translucent, brittle, and capable of gaining a negative electrical charge by friction and of being an excellent insulator: used for making jewelry and other ornamental articles.

The Greek word for amber is “elektron” and the phenomenon became known as electricity.

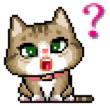


Benjamin Franklin ——one of Fathers of USA

Benjamin Franklin was one of the Founding Fathers of the United States of America. A noted polymath, Franklin was a leading author and printer, satirist, political theorist, politician, scientist, inventor, civic activist, statesman and diplomat. As a scientist he was a major figure in the Enlightenment and the history of physics for his discoveries and theories regarding electricity. He invented the lightning rod, bifocals, the Franklin stove, a carriage odometer, and a musical instrument.

(January 17, 1706 [O.S. January 6, 1705] – April 17, 1790)

http://en.wikipedia.org



Benjamin Franklin ——one of Fathers of USA

He formed both the first public lending library in America and first fire department in Pennsylvania. He was an early proponent of colonial unity and as a political writer and activist he, more than anyone, invented the idea of an American nation and as a diplomat during the American Revolution, he secured the French alliance that helped to make independence possible.

In 1743, Franklin founded the American Philosophical Society to help scientific men discuss their discoveries and theories. He began the electrical research that, along with other scientific inquiries, would occupy him for the rest of his life, in between bouts of politics and moneymaking.

Benjamin Franklin ——one of Fathers of USA

An illustration from Franklin's paper on "Water-spouts and Whirlwinds."In 1748, he retired from printing and went into other businesses. He created a partnership with his foreman, David Hall, which provided Franklin with half of the shop's profits for 18 years. This lucrative business arrangement provided leisure time for study, and in a few years he had made discoveries that gave him a reputation with the educated throughout Europe and especially in France.

His discoveries included his investigations of electricity. Franklin proposed that "vitreous" and "resinous" electricity were not different types of "electrical fluid" (as electricity was called then), but the same electrical fluid under different pressures.

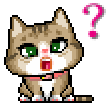
Benjamin Franklin ——one of Fathers of USA

He was the first to label them as positive and negative respectively, and he was the first to discover the principle of conservation of charge.[18] In 1750, he published a proposal for an experiment to prove that lightning is electricity by flying a kite in a storm that appeared capable of becoming a lightning storm. On May 10, 1752, Thomas-François Dalibard of France conducted Franklin's experiment (using a 40-foot (12 m)-tall iron rod instead of a kite) and extracted electrical sparks from a cloud. On June 15, Franklin may have possibly conducted his famous kite experiment in Philadelphia and also successfully extracted sparks from a cloud, although there are theories that suggest he never performed the experiment.

Benjamin Franklin ——one of Fathers of USA

Franklin's experiment was not written up until Joseph Priestley's 1767 History and Present Status of Electricity; the evidence shows that Franklin was insulated (not in a conducting path, since he would have been in danger of electrocution in the event of a lightning strike). (Others, such as Prof. Georg Wilhelm Richmann of Saint Petersburg, Russia, were electrocuted during the months following Franklin's experiment.)

If Franklin did perform this experiment, he did not do it in the way that is often described, flying the kite and waiting to be struck by lightning, as it would have been fatal.[19] Instead, he used the kite to collect some electric charge from a storm cloud, which implied that lightning was electrical.



Benjamin Franklin ——one of Fathers of USA

On October 19 in a letter to England explaining directions for repeating the experiment, Franklin wrote:

"When rain has wet the kite twine so that it can conduct the electric fire freely, you will find it streams out plentifully from the key at the approach of your knuckle, and with this key a phial, or Leiden jar, maybe charged: and from electric fire thus obtained spirits may be kindled, and all other electric experiments [may be] performed which are usually done by the help of a rubber glass globe or tube; and therefore the sameness of the electrical matter with that of lightening completely demonstrated."

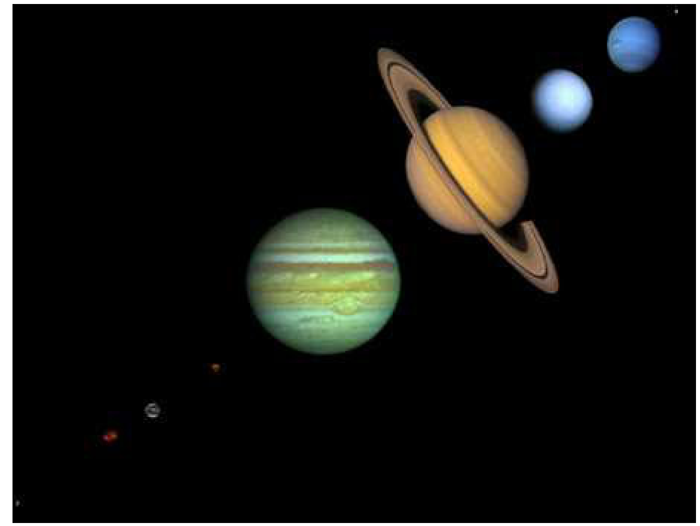
Benjamin Franklin ——one of Fathers of USA

Franklin's electrical experiments led to his invention of the lightning rod. He noted that conductors with a sharp rather than a smooth point were capable of discharging silently, and at a far greater distance. He surmised that this knowledge could be of use in protecting buildings from lightning, by attaching "upright Rods of Iron, made sharp as a Needle and gilt to prevent Rusting, and from the Foot of those Rods a Wire down the outside of the Building into the Ground

Following a series of experiments on Franklin's own house, lightning rods were installed on the Academy of Philadelphia (later the University of Pennsylvania) and the Pennsylvania State House (later Independence Hall) in 1752

Action at a distance

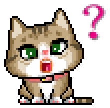
In physics, action at a distance is the interaction of two objects which are separated in space with no known mediator of the interaction. This term was used most often with early theories of gravity and electromagne - tism to describe how an object could "know" the mass (in the case of gravity) or charge (in electromagnetism) of another distant object.



http://en.wikipedia.org/

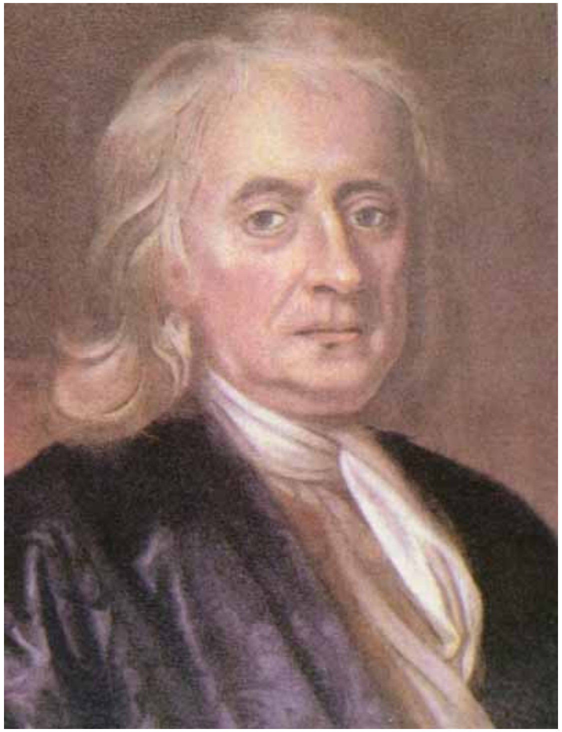
Electricity ——Action at a distance

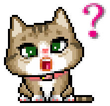
Coulomb's law in electrostatics appears to be a theory with action-at-a-distance - Coulomb's law deals with charges which have always been static. Efforts to develop a theory of interaction between moving charges, electrodynamics, led to the necessity to introduce the concept of a field with physical properties. In the theory of electrodynamics as formulated in Maxwell's equations, interactions between moving charges are mediated by propagating deformations of an electromagnetic field. These deformations propagate with the speed of light and Maxwell's wave theory was later extended to cover Coulomb's law by the Lorenz gauge. The deformations of the field can carry momentum independently, thus facilitating conservation of angular momentum.



Gravity ——Action at a distance

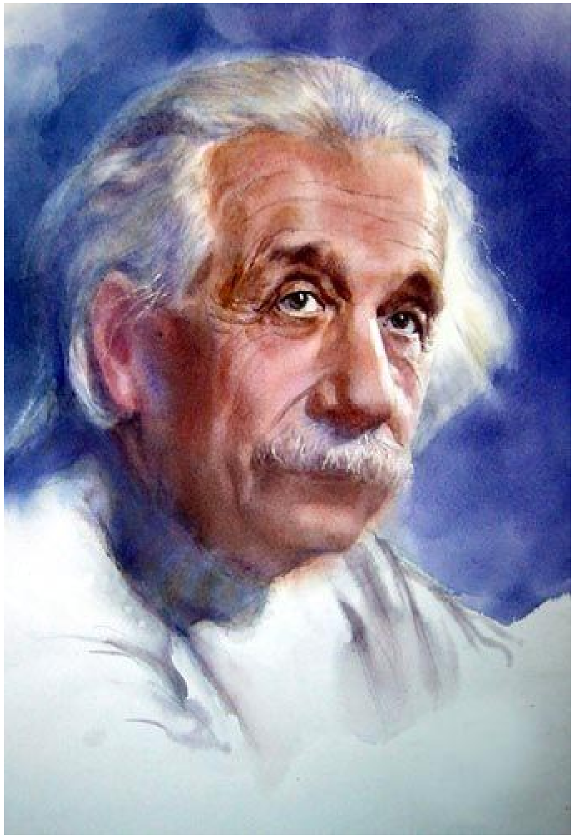
Newton： Newton's theory of gravity offered no prospect of identifying any mediator of gravitational interaction. His theory assumed that gravitation acts instantaneously, regardless of distance. Newton had shown mathematically that if the gravitational interaction is not instantaneous, angular momentum is not conserved, and Kepler's observations gave strong evidence that in planetary motion angular momentum is conserved. (The mathematical proof is only valid in the case of an Euclidean geometry.)

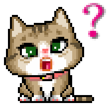




Gravity ——Action at a distance

Einstein： According to Albert Einstein's theory of special relativity, instantaneous action-at-a-distance was seen to violate the relativistic upper limit on speed of propagation of information. If one of the interacting objects were suddenly displaced from its position, the other object would feel its influence instantaneously, meaning information had been transmitted faster than the speed of light.

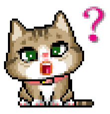




Gravity ——Action at a distance

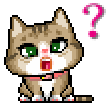
One of the conditions that a relativistic theory of gravitation must meet is to be mediated with a speed that does not exceed lightspeed. It could be seen from the previous success of electrodynamics that the relativistic theory of gravitation would have to use the concept of a field or something similar.

This problem has been resolved by Einstein's theory of general relativity in which gravitational interaction is mediated by deformation of space-time geometry. Matter warps the geometry of space-time and these effects are, as with electric and magnetic fields, propagated at the speed of light.



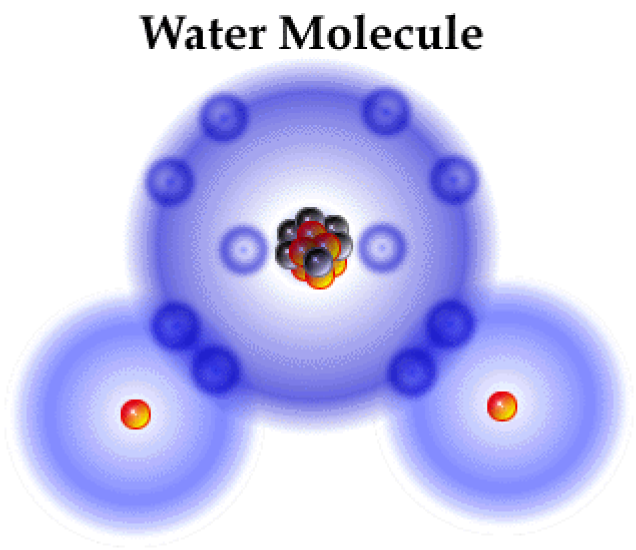
Gravity ——Action at a distance

Thus, in the presence of matter, space-time becomes non-Euclidean, resolving the apparent conflict between Newton's proof of the conservation of angular momentum and Einstein's theory of special relativity. Mach's question regarding the bulging of rotating bodies is resolved because local space-time geometry is informing a rotating body about the rest of the universe. In Newton's theory of motion, space acts on objects, but is not acted upon. In Einstein's theory of motion, matter acts upon space-time geometry, deforming it, and space-time geometry acts upon matter.



Water (H_2O, HOH)

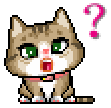
Water (H_2O, HOH) is the most abundant molecule on Earth's surface, composing of about 70% of the Earth's surface as liquid and solid state in addition to being found in the atmosphere as a vapor. It is in dynamic equilibrium between the liquid and vapor states at standard temperature and pressure. At room temperature, it is a nearly colorless (with a hint of blue), tasteless, and odorless liquid.



www. hyperphysics. edu

Molecular Dipole Moments

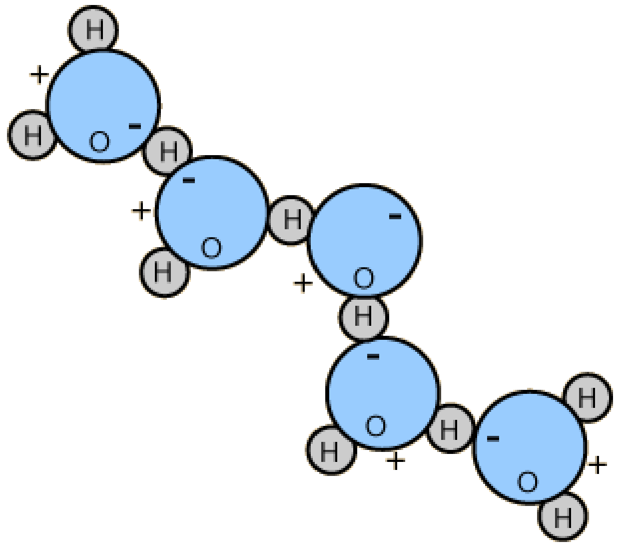
Even though the total charge on a molecule is zero, the nature of chemical bonds is such that the positive and negative charges do not completely overlap in most molecules. Such molecules are said to be polar because they possess a permanent dipole moment. A good example is the dipole moment of the water molecule. Molecules with mirror symmetry like oxygen, nitrogen, carbon dioxide, and carbon tetrachloride have no permanent dipole moments. Even if there is no permanent dipole moment, it is possible to induce a dipole moment by the application of an external electric field. This is called polarization and the magnitude of the dipole moment induced is a measure of the polarizability of the molecular species.

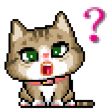


Dipolar Bonding in Water

The polar nature of water molecules allows them to bond to each other in groups and is associated with the high surface tension.

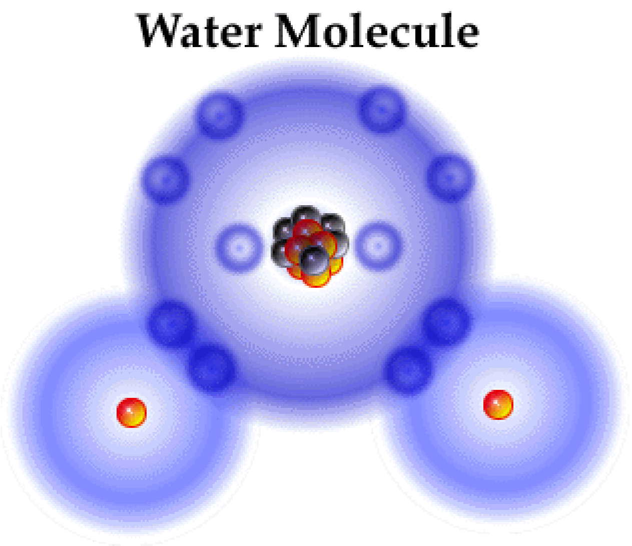
The dipolar interaction between water molecules represents a large amount of internal energy and is a factor in water's large specific heat. The dipole moment of water provides a "handle" for interaction with microwave electric fields in a microwave oven. Microwaves can add energy to the water molecules, whereas molecules with no dipole moment would be unaffected.

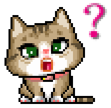




Human Body and Water

Many substances dissolve in water and it is commonly referred to as the universal solvent. Because of this, water in nature and in use is rarely pure, and may have some properties different from those in the laboratory. However, there are many compounds that are essentially, if not completely, insoluble in water. Water is the only common substance found naturally in all three common states of matter—for other substances, see Chemical properties. Water also makes up 55% to 78% of the human body.



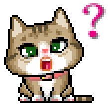


Johann Carl Friedrich Gauss

Johann Carl Friedrich Gauss was a German mathematician and scientist who contributed significantly to many fields, including number theory, statistics, analysis, differential geometry, geodesy, electrostatics, astronomy, and optics. Sometimes known "the Prince of Mathematicians“

Gauss had a remarkable influence in many fields of mathematics and science

Johann Carl Friedrich Gauss (1777-1855),



Johann Carl Friedrich Gauss

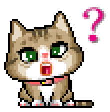
Gauss was a child prodigy. There are many anecdotes pertaining to his precocity while a toddler, and he made his first ground-breaking mathematical discoveries while still a teenager. He completed Disquisitiones Arithmeticae, his magnum opus, in 1798 at the age of 21, though it would not be published until 1801. This work was fundamental in consolidating number theory as a discipline and has shaped the field to the present day.

Statue of Gauss in his birthplace of Braunschweig

Gauss Personality

Gauss was an ardent perfectionist and a hard worker. According to Isaac Asimov, Gauss was once interrupted in the middle of a problem and told that his wife was dying. He is purported to have said, "Tell her to wait a moment till I'm done."[9] This anecdote is briefly discussed in Waldo Dunnington 's Gauss, Titan of Science where it is suggested that it is an apocryphal story.

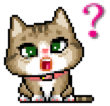
He was never a prolific writer, refusing to publish works which he did not consider complete and above criticism. This was in keeping with his personal motto pauca sed matura ("few, but ripe"). His personal diaries indicate that he had made several important mathematical discoveries years or decades before his contemporaries published them.



Lightning

Lightning is an atmospheric discharge of electricity, which typically occurs during thunder-storms, and sometimes during volcanic eruptions or dust storms. In the atmospheric electrical discharge, a leader of a bolt of lightning can travel at speeds of 60,000 m/s, and can reach temperatures approaching 30,000° C (54,000° F), hot enough to fuse silica sand into petrified lightning.

Lightning



Lightning

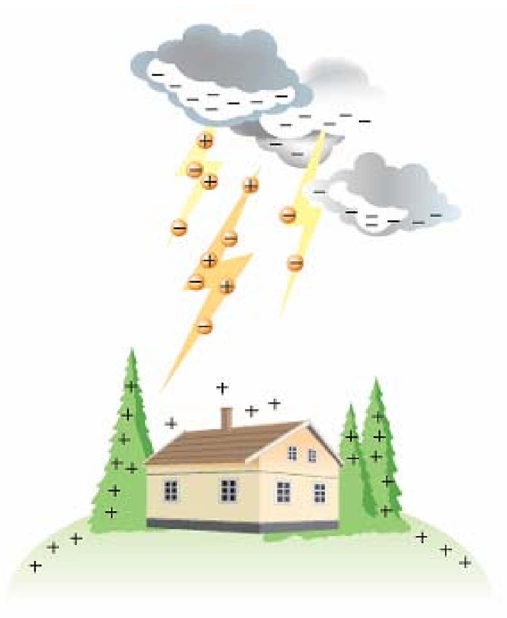
There are some 16 million lightning storms in the world every year. For an American, the chance of being struck by lightning is approximately 576,000 to 1 and the chance of actually being killed by lightning is approximately 2,320,000 to 1.

Lightning can also occur within the ash clouds from volcanic eruptions, or can be caused by violent forest fires which generate sufficient dust to create a static charge.

Lightning over Oradea in Romania

Lightning

How lightning initially forms is still a matter of debate:[7] Scientists have studied root causes ranging from atmospheric perturbations (wind, humidity, friction, and atmospheric pressure) to the impact of solar wind and accumulation of charged solar particles.[4] Ice inside a cloud is thought to be a key element in lightning development, and may cause a forcible separation of positive and negative charges within the cloud, thus assisting in the formation of lightning.



Lightning—— Cloud-to-cloud

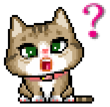
Multiple paths of cloud-to-cloud lightning, Swifts Creek, Australia Lightning discharges may occur between areas of cloud having different potentials without contacting the ground. These are most common between the anvil and lower reaches of a given thunderstorm.

Multiple paths of cloud-to-cloud lightning, Swifts Creek, Australia

This lightning can sometimes be observed at great distances at night as so-called "heat lightning". In such instances, the observer may see only a flash of light without thunder. The "heat" portion of the term is a folk association between locally-experienced warmth and the distant lightning flashes.

Lightning Rod

A lightning rod (USA) is a single component in a lightning protection system. In addition to rods placed at regular intervals on the highest portions of a structure, a lightning protection system typically includes a rooftop network of conductors, multiple conductive paths from the roof to the ground, bonding connections to metallic objects within the structure and a grounding network. The actual rooftop lightning rod is a metal strip or rod, usually of copper or aluminum. Lightning protection systems are installed on structures, trees, monuments, bridges and even water vessels to protect from lightning damage.

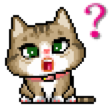


Anisotropic Material

In a homogeneous linear and isotropic dielectric medium, the polarization is aligned with and proportional to the electric field E. In an anisotropic material, the polarization and the field are not necessarily in the same direction. Then, the ith component of the polarization is related to the jth component of the electric field according to:

$$P_i = \sum_{j=1}^{3} \varepsilon_0 \chi_{ij} E_j$$

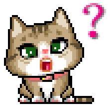
where ε_0 is the permittivity of free space, and χ is the electric susceptibility tensor of the medium. The case of an anisotropic dielectric medium is described by the field of crystal optics.



Relation between P and E in various materials

This reflects the fact that the dipoles in the material cannot respond instantaneously to the applied field, and causality considerations lead to the Kramers–Kronig relations.

As in most electromagnetism, this relation deals with macroscopic averages of the fields and dipole density, so that one has a continuum approximation of the dielectric materials that neglects atomic-scale behaviors. The polarizability of individual particles in the medium can be related to the average susceptibility and polarization density by the Clausius -Mossotti relation.



Nonlinear Susceptibilities

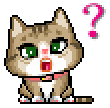
In general, the susceptibility is a function of the frequency ω of the applied field. When the field is an arbitrary function of time t, the polarization is a convolution of the Fourier transform of $\chi(\omega)$ with the E(t).

If the polarization P is not linearly proportional to the electric field E, the medium is termed nonlinear and is described by the field of nonlinear optics. To a good approximation (for sufficiently weak fields, assuming no permanent dipole moments are present), P is usually given by a Taylor series in E whose coefficients are the nonlinear susceptibilities:

$$P_i / \varepsilon_0 = \sum_j \chi_{ij}^{(1)} E_j + \sum_{jk} \chi_{ijk}^{(2)} E_j E_k + \sum_{jk} \chi_{ijkl}^{(3)} E_j E_k E_l \cdots$$

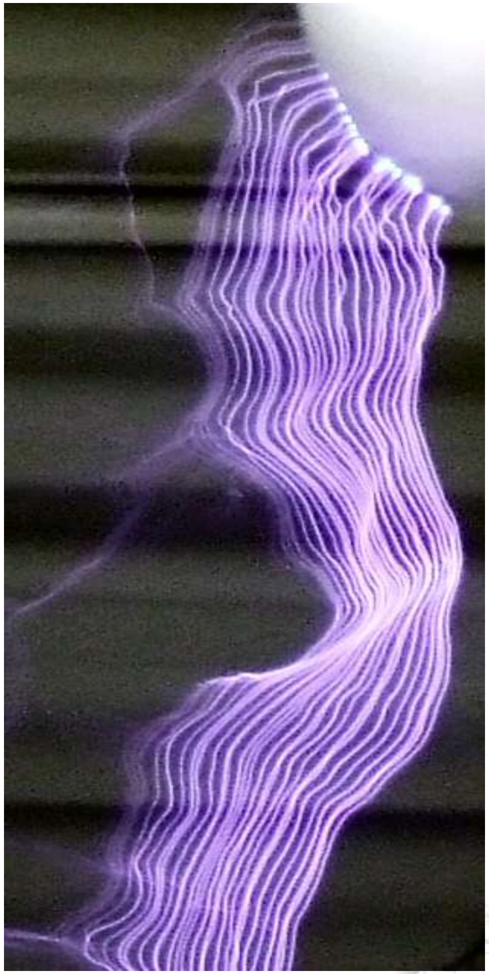
Relation between P and E in various materials

where $\chi^{(1)}$ is the linear susceptibility, $\chi^{(2)}$ gives the Pockels effect, and $\chi^{(3)}$ gives the Kerr effect.
In ferroelectric materials, there is no one-to-one correspondence between P and E at all because of hysteresis.



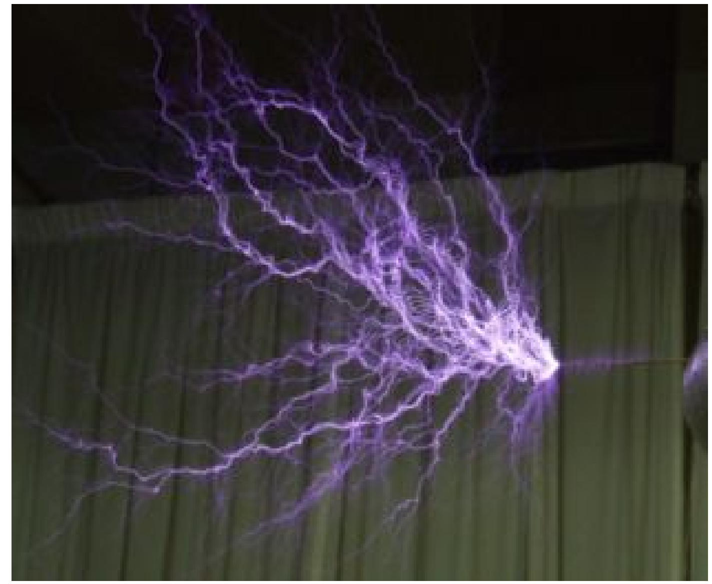
Electrical breakdown

Electrical breakdown in an electric discharge showing the ribbon-like plasma filaments from a Tesla coil. The term electrical breakdown has several similar but distinctly different meanings. The term can apply to the failure of an electric circuit. Alternately, it may refer to a rapid reduction in the resistance of an electrical insulator that can lead to a spark jumping around or through the insulator. This may be a momentary event, or may lead to a continuous arc discharge if protective devices fail to interrupt the current in a high power circuit.



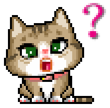
Electrical System Failure

The most common meaning is related to automobiles and is the failure of an electric circuit or associated device resulting in a loss of vehicle function (a break-down). Common problems include battery discharge, alternator failure, broken wires, blown fuses, and a failed fuel pump.



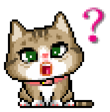
Failure of Electrical Insulation

The second meaning of the term is more specifically a reference to the breakdown of the insulation of an electrical wire or other electrical component. Such breakdown usually results in a short circuit or a blown fuse. This occurs at the breakdown voltage. Actual insulation breakdown is more generally found in high-voltage applications, where it sometimes causes the opening of a protective circuit breaker. Electrical breakdown is often associated with the failure of solid or liquid insulating materials used inside high voltage transformers or capacitors in the electricity distribution grid.



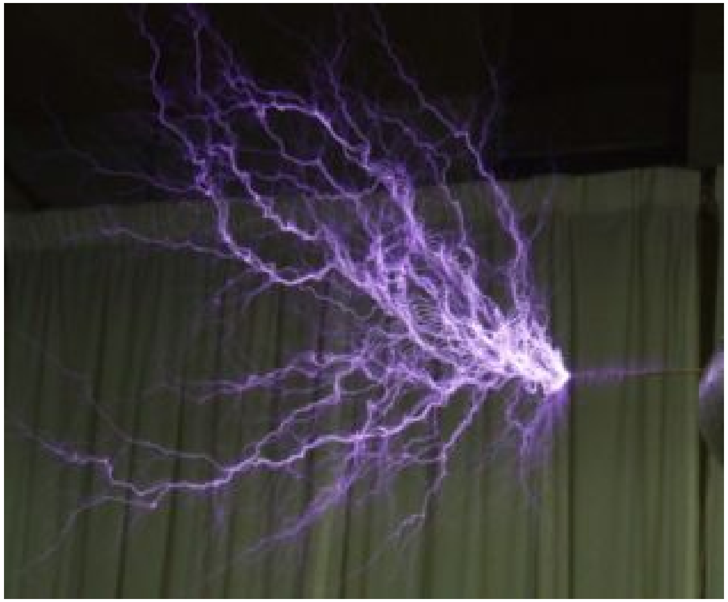
Failure of Electrical Insulation

Electrical breakdown can also occur across the strings of insulators that suspend overhead power lines, within underground power cables, or lines arcing to nearby branches of trees. Under sufficient electrical stress, electrical breakdown can occur within solids, liquids, or gases. However, the specific breakdown mechanisms are significantly different for each phase of dielectric. All this leads to catastrophic failure of the instruments.



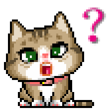
Mechanism

Electrical breakdown occurs within a gas (or mixture of gases, such as air) when the dielectric strength of the gas(es) is exceeded. Regions of high electrical stress can cause nearby gas to partially ionize and begin conducting. This is done deliberately in low pressure discharges such as in fluorescent lights (see also Electrostatic Discharge) or in an electrostatic precipitator



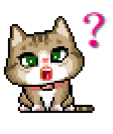
Mechanism

Partial electrical breakdown of the air causes the "fresh air" smell of ozone during thunderstorms or around high-voltage equipment. Although air is normally an excellent insulator, when stressed by a sufficiently high voltage (an electric field strength of about 3 x 106V/m), air can begin to break down, becoming partially conductive. If the voltage is sufficiently high, complete electrical breakdown of the air will culminate in an electrical spark or arc that bridges the entire gap. While the small sparks generated by static electricity may barely be audible, larger sparks are often accompanied by a loud snap or bang. Lightning is an example of an immense spark that can be many miles long. The color of the spark depends upon the gases that make up the gaseous media.



Mechanism

If a fuse or circuit breaker fails to interrupt the current through a spark in a power circuit, current may continue, forming a very hot electric arc. The color of an arc depends primarily upon the conductor materials (as they are vaporized and mix within the hot plasma in the arc). Although sparks and arcs are usually undesirable, they can be useful in everyday applications such as spark plugs for gasoline engines, electrical welding of metals, or for metal melting in an electric arc furnace.

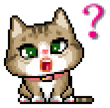


Supercapacitors

Electric double-layer capacitors, also known as supercapacitors, electrochemical double layer capacitors (EDLCs) or ultracapacitors are electrochemical capacitors that have an unusually high energy density when compared to common capacitors, typically on the order of thousands of times greater than a high-capacity electrolytic capacitor. For instance, a typical D-cell sized electrolytic capacitor will have a capacitance measured in microfarads, while the same size electric double-layer capacitor would have a capacitance of several farads, an improvement of about four orders of magnitude in capacitance, but usually at a lower working voltage. Larger, commercial electric double-layer capacitors have capacities as high as 5,000 farads.

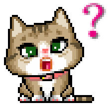
Supercapacitors

Electric double-layer capacitors have a variety of commercial applications, notably in “energy smoothing” and momentary-load devices. Some of the earliest uses were motor startup capacitors for large engines in tanks and submarines, and as the cost has fallen they have started to appear on diesel trucks and railroad locomotives.[2] More recently they have become a topic of some interest in the green energy world, where their ability to soak up energy quickly makes them particularly suitable for regenerative braking applications, whereas batteries have difficulty in this application due to slow charging times. If the LEES or EEStor devices can be commercialized, they will make an excellent replacement for batteries in all-electric cars and plug-in hybrids, as they combine quick charging, temperature stability and excellent safety properties.



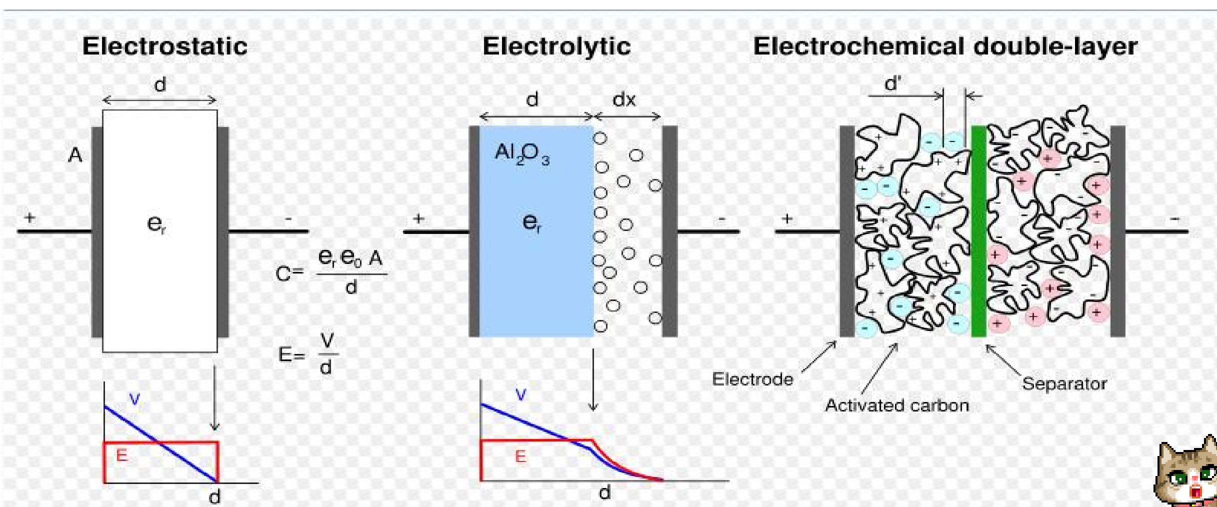
Concept

Comparison of construction diagrams of three capacitors. Left: "normal" capacitor, middle: electrolytic, right: electric double-layer capacitorIn a conventional capacitor, energy is stored by the removal of charge carriers, typically electrons, from one metal plate and depositing them on another. This charge separation creates a potential between the two plates, which can be harnessed in an external circuit. The total energy stored in this fashion is a combination of the number of charges stored and the potential between the plates. The former is essentially a function of size and the material properties of the plates, while the latter is limited by the dielectric breakdown between the plates. Various materials can be inserted between the plates to allow higher voltages to be stored, leading to higher energy densities for any given size.



Concept

In contrast with traditional capacitors, electric double-layer capacitors do not have a conventional dielectric, as such. They are based on a structure that contains an electrical double layer. In a double layer, the effective thickness of the "dielectric" is exceedingly thin—on the order of nanometers—and that, combined with the very large surface area, is responsible for their extraordinarily high capacitances in practical sizes.



Concept

In an electrical double layer, each layer by itself is quite conductive, but the physics at the interface where the layers are effectively in contact means that no significant current can flow between the layers. However, the double layer can withstand only a low voltage, which means that electric double-layer capacitors rated for higher voltages must be made of matched series-connected individual electric double-layer capacitors, much like series-connected cells in higher-voltage batteries.

In general, electric double-layer capacitors improve storage density through the use of a nanoporous material, typically activated charcoal, in place of the conventional insulating barrier. Activated charcoal is a powder made up of extremely small and very "rough" particles, which in bulk form a low-density volume of particles with holes between them that resembles a sponge.

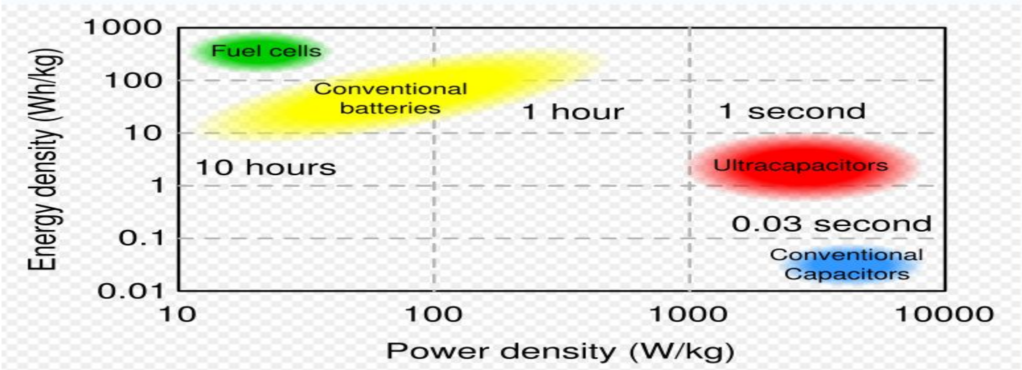
Concept

The overall surface area of even a thin layer of such a material is many times greater than a traditional material like aluminum, allowing many more electrons to be stored in any given volume. The downside is that the charcoal is taking the place of the improved insulators used in conventional devices, so in general electric double-layer capacitors use low potentials on the order of 2 to 3 V.

A completely different approach is being pioneered by EEStor, who claim to have developed a dramatically improved insulator based on barium titanate that improves the permittivity of the insulator by several orders of magnitude, improving energy density not through electron capacity but via much higher potentials. EEStor claims that their capacitors can operate at extremely high voltages, on the order of several thousand volts.

Concept

Additionally, electric double-layer capacitors offer much higher power density than batteries. Power density combines the energy density with the speed that the energy can be drawn out of the device. Batteries, which are based on the movement of charge carriers in a liquid electrolyte, have relatively slow charge and discharge times. Capacitors, on the other hand, can be charged or discharged at a rate that is typically limited by current heating of the electrodes. So while existing electric double-layer capacitors have energy densities that are perhaps 1/10th that of a conventional battery, their power density is generally ten to one-hundred times as great (see diagram, down).



Transportation applications

China is experimenting with a new form of electric bus (capabus) that runs without powerlines using power stored in large onboard electric double-layer capacitors, which are quickly recharged whenever the electric bus stops at any bus stop (under so-called electric umbrellas), and fully charged in the terminus. A few prototypes were being tested in Shanghai in early 2005. In 2006, two commercial bus routes began to use electric double-layer capacitor buses; one of them is route 11 in Shanghai.

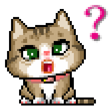
In 2001 and 2002, VAG, the public transport operator in Nuremberg, Germany tested a hybrid bus which uses a diesel-electric drive system with electric double-layer capacitors.

Since 2003 Mannheim Stadtbahn in Mannheim, Germany has operated an LRV (light-rail vehicle) which uses electric double-layer capacitors to store braking energy.

Transportation applications

Other companies from the public transport manufacturing sector are developing electric double-layer capacitor technology: The Transportation Systems division of Siemens AG is developing a mobile energy storage based on double-layer capacitors called Sibac Energy Storage [14] and also Sitras SES, a stationary version integrated into the trackside power supply [15]. The company Cegelec is also developing a electric double-layer capacitor-based energy storage system [citation needed].

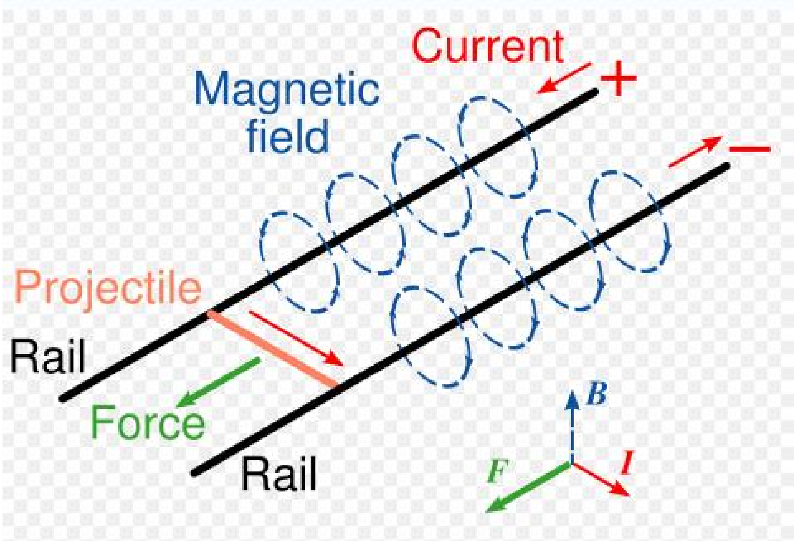
Proton Power Systems has created the world's first triple hybrid Forklift Truck, which uses fuel cells and battery as primary energy storage and electric double-layer capacitors to supplement this overall energy efficient storage solution.



Railgun

A railgun is a purely electrical gun that accelerates a conductive projectile along a pair of metal rails using the same principles as the homopolar motor.

Railguns use two sliding or rolling contacts that permit a large electric current to pass through the projectile. This current interacts with the strong magnetic fields generated by the rails and this accelerates the projectile.

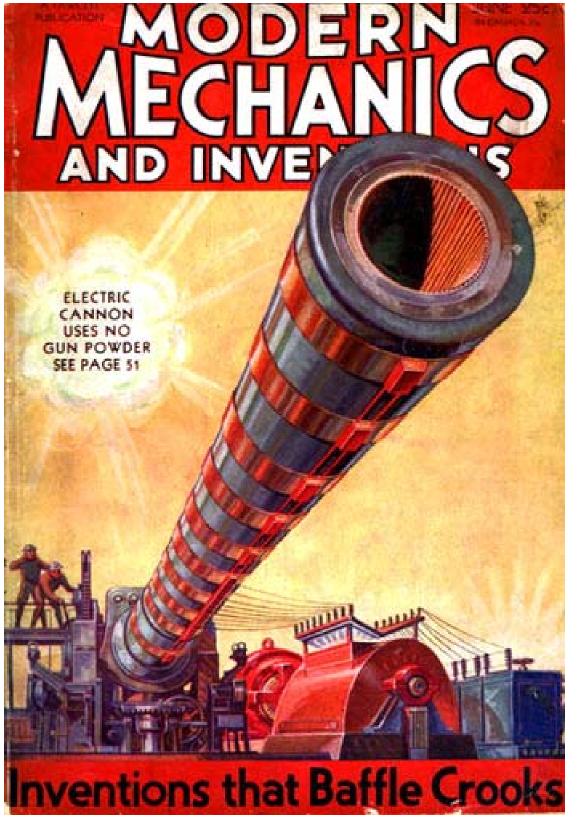


Schematic diagram of a railgun

Railgun

The U.S. Navy has tested a railgun that accelerates a 7 pound projectile to seven times the speed of sound. A wire carrying an electric current, when in a magnetic field, experiences a force perpendicular to the direction of the current and the direction of the magnetic field.

In an electric motor, fixed magnets create a magnetic field, and a coil of wire is carried upon a shaft that is free to rotate. An electric current flows through the coil causing it to experience a force due to the magnetic field. The wires of the coil are arranged such that all the forces on the wires make the shaft rotate, and so the motor runs.

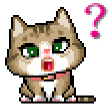


Electric gun in *Modern Mechanics*, June 1932

Railgun

A railgun consists of two parallel metal rails (hence the name) connected to an electrical power supply. When a conductive projectile is inserted between the rails (from the end connected to the power supply), it completes the circuit. Electrical current runs from the negative terminal of the power supply up the negative rail, across the projectile, and down the positive rail, back to the power supply.

This current makes the railgun act like an electromagnet, creating a powerful magnetic field in the region of the rails up to the position of the projectile. In accordance with the right-hand rule, the created magnetic field circulates around each conductor. Since the current is in opposite direction along each rail, the net magnetic field between the rails (B) is directed vertically.



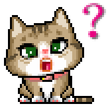
Railgun

In combination with the current (I) across the projectile, this produces a Lorentz force which accelerates the projectile along the rails. There are also forces acting on the rails attempting to push them apart, but since the rails are firmly mounted, they cannot move. The projectile slides up the rails away from the end with the power supply.

If a very large power supply providing a million amperes or so of current is used, then the force on the projectile will be tremendous, and by the time it leaves the ends of the rails it can be travelling at many kilometres per second. 20 kilometers per second has been achieved with small projectiles explosively injected into the railgun. Although these speeds are theoretically possible, the heat generated from the propulsion of the object is enough to rapidly erode the rails. Such a railgun would require frequent replacement of the rails, or use a heat resistant material that would be conductive enough to produce the same effect.

Considerations in railgun design

The rails and projectiles must be built from strong conductive materials; the rails need to survive the violence of an accelerating projectile, and heating due to the large currents and friction involved. The recoil force exerted on the rails is equal and opposite to the force propelling the projectile. The seat of the recoil force is still debated. The traditional equations predict that the recoil force acts on the breech of the railgun. Another school of thought invokes Ampère's force law and asserts that it acts along the length of the rails (which is their strongest axis)[3]. The rails also repel themselves via a sideways force caused by the rails being pushed by the magnetic field, just as the projectile is. The rails need to survive this without bending, and must be very securely mounted.

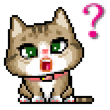


Considerations in railgun design

Design considerations

The power supply must be able to deliver large currents, sustained and controlled over a useful amount of time. The most important gauge of power supply effectiveness is the energy it can deliver, measured in joules. As of February 2008, the largest known energy ever used in a railgun was 32 million joules.[4]. The most common forms of power supplies used in railguns are capacitors and compulsators.

The rails need to withstand enormous repulsive forces during firing, and these forces will tend to push them apart and away from the projectile. As rail/projectile clearances increase, arcing develops, which causes rapid vaporization and extensive damage to the rail surfaces and the insulator surfaces. This limited some early research railguns to one shot per service interval.

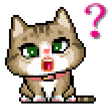


Considerations in railgun design

The inductance and resistance of the rails and power supply limit the efficiency of a railgun design. Currently different rail shapes and railgun configurations are being tested, most notably by the United States Navy and BAE Systems.

Heat dissipation

Massive amounts of heat are created by the electricity flowing through the rails, as well as the friction of the projectile leaving the device. The heat created by this friction itself can cause thermal expansion of the rails and projectile, further increasing the frictional heat. This leads to three main problems: melting of equipment, safety of personnel, and detection by enemy forces. As briefly discussed above, the stresses involved in firing this sort of device require an extremely heat-resistant material. Otherwise the rails, barrel, and all equipment attached would melt or be irreparably damaged.



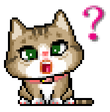
Considerations in railgun design

In practice the rails are, with most designs of railgun, subject to erosion due to each launch; and projectiles can be subject to some degree of ablation also, and this can limit railgun life, in some cases severely.

Mathematical formula

In relation to railgun physics, the magnitude of the force vector can be determined from a form of the Biot- Savart Law and a result of the Lorentz force. It can be expressed mathematically in terms of the permeability constant (μ_0), the radius of the rails (which are assumed to be circular in cross section) (r), the distance between the centerpoints of the rails (d) and the current in amps through the system (I) as follows

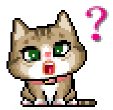
$$F = \frac{\mu_0 I^2}{2\pi} \ln \frac{d-r}{r}$$



Considerations in railgun design

The formula is based on the assumption that the distance(l) between the point where the force (F) is measured and the beginning of the rails is greater than the separation of the rails (d) by a factor of about 3 or 4 (l > 3d). Some other simplifying assumptions have also been made; to describe the force more accurately, the geometry of the rails and the projectile must be taken into consideration.

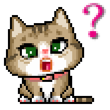
Railguns are being pursued as weapons with projectiles that do not contain explosives, but are given extremely high velocities: 3500 m/s (11,500 ft/s, approximately Mach 10 at sea level) or more (for comparison, the M16 rifle has a muzzle speed of 930 m/s, or 3,000 ft/s), which would make their kinetic energy equal or superior to the energy yield of an explosive-filled shell of greater mass. This would allow more ammunition to be carried and eliminate the hazards of carrying explosives in a tank or naval weapons platform.



Considerations in railgun design

Also, by firing at higher velocities railguns have greater range, less bullet drop and less wind drift, bypassing the inherent cost and physical limitations of conventional firearms - "the limits of gas expansion prohibit launching an unassisted projectile to velocities greater than about 1.5 km/s and ranges of more than 50 miles [80 km] from a practical conventional gun system."

If it were possible to apply the technology as a rapid-fire automatic weapon, a railgun would have further advantages in increased rate of fire. The feed mechanisms of a conventional firearm must move to accommodate the propellant charge as well as the ammunition round, while a railgun would only need to accommodate the projectile. Furthermore, a railgun would not have to extract a spent cartridge case from the breech, meaning that a fresh round could be cycled almost immediately after the previous round has been shot.



Tests

Naval Surface Warfare Center test firing in January 2008Full-scale models have been built and fired, including a very successful 90 mm bore, 9 megajoules (6.6 million foot-pounds) kinetic energy gun developed by DARPA. Rail and insulator wear issues still need to be addressed before railguns can start to replace conventional weapons. Probably the oldest consistently successful system was built by the UK's Defence Research Agency at Dundrennan Range in Kirkcudbright, Scotland. This system has now been operational for over 10 years at an associated flight range for internal, intermediate, external and terminal ballistics, and achieved several mass and velocity records.

Tests

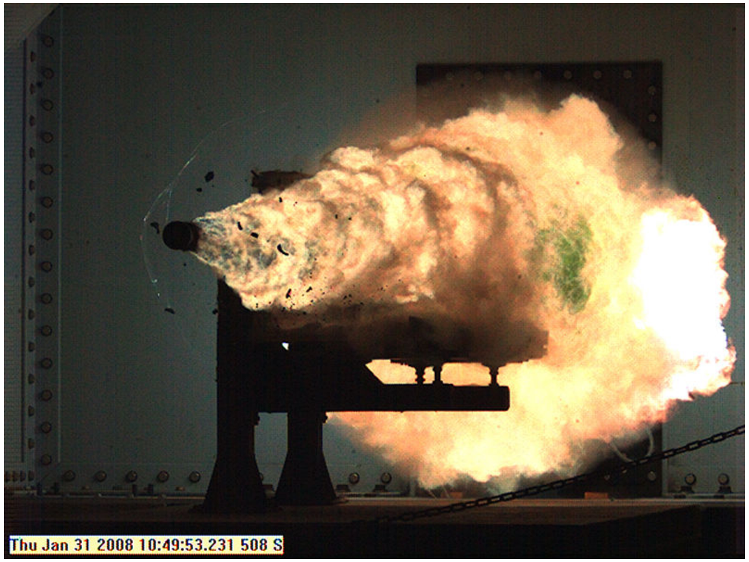
The United States military is funding railgun experiments. At the University of Texas at Austin Institute for Advanced Technology, military railguns capable of delivering tungsten armor piercing bullets with kinetic energies of nine megajoules have been developed.[7] Nine MJ is enough energy to deliver 2 kg of projectile at 3 km/s - at that velocity a rod of tungsten or of another dense metal could easily penetrate a tank, and potentially pass through it.

The United States Naval Surface Warfare Center Dahlgren Division demonstrated an 8 MJ rail gun firing 3.2 kilogram projectiles in October 2006 as a prototype of a 64 MJ weapon to be deployed aboard Navy warships. The main problem the navy has had with implementing a railgun cannon system is that the guns wear out due to the immense heat produced by firing. Such weapons are expected to be powerful enough to do a little more damage than a BGM-109 Tomahawk missile at a fraction of the projectile cost

Tests

Due to the very high muzzle velocity that can be attained with railguns, there is interest in using them to shoot down high-speed missiles.

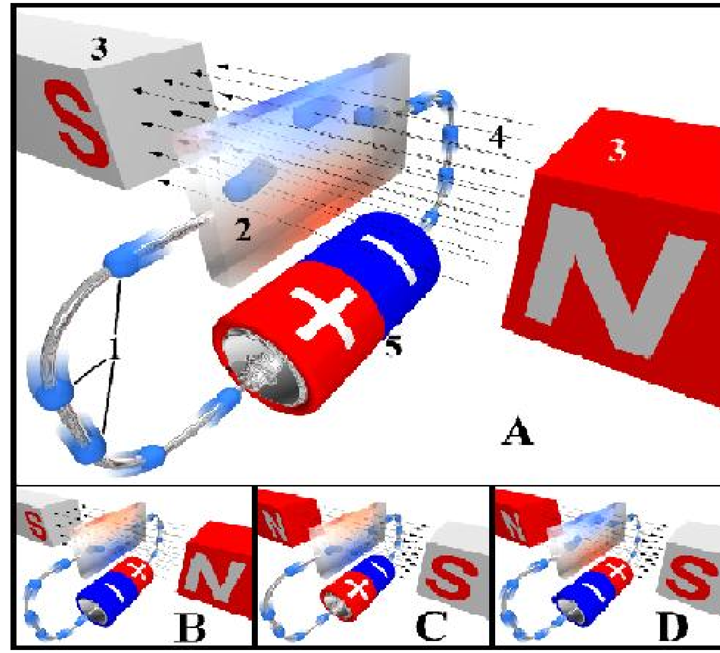
On January 31, 2008 the US Navy tested a magnetic railgun; it fired a shell at 2520 m/s using 10.64 megajoules of energy. [10] Its expected performance is over 5800 m/s muzzle velocity, accurate enough to hit a 5 meter target from 200 nautical miles (370 km) away while shooting at 10 shots per minute. It is expected to be ready in 2020 to 2025. Image and comments



Naval Surface Warfare Center test firing in January 2008

Hall effect

The Hall effect refers to the potential difference (Hall voltage) on the opposite sides of an electrical conductor through which there is an electric current, created by a magnetic field applied perpendicularly to the current. Edwin Hall discovered this effect in 1879.



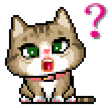
Hall effect diagram, showing electron flow (rather than conventional current)

Hall effect

The ratio of the voltage created to the product of the current and the magnetic field (I*B) divided by the element thickness, is known as the Hall coefficient. It is a characteristic of the material from which the conductor is made, as its value depends on the type, number and properties of the charge carriers that constitute the current.

Hall effect in semiconductors

When a current-carrying semiconductor is kept in a magnetic field, the charge carriers of the semiconductor experience a force in a direction perpendicular to the magnetic field and current. At equilibrium, a voltage appears at the semiconductor edges.



Hall effect

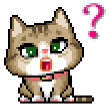
The simple formula for the Hall coefficient given above becomes more complex in semiconductors where the carriers are generally both electrons and holes which may be present in different concentrations and have different mobilities. For moderate magnetic fields the Hall coefficient is

$$R_H = \frac{-n\mu_e^2 + p\mu_h^2}{e(n\mu_e + p\mu_h)^2}$$

where n is the electron concentration, p the hole concentration, μ_e the electron mobility , μ_h the hole mobility and the absolute value of the electronic charge.

For large applied fields the simpler expression analogous to that for a single carrier type holds

$$R_H = \frac{1}{(p-n)\ e}$$



Hall effect

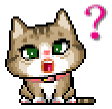
Technological applications

So-called "Hall effect sensors" are readily available from a number of different manufacturers, and may be used in various sensors such as rotating speed sensors, fluid flow sensors, current sensors, and pressure sensors. Other applications may be found in some electric airsoft guns and on the triggers of electropneumatic paintball guns.

Quantum Hall effect

Main article: Quantum Hall effect

For a two dimensional electron system which can be produced in a MOSFET. In the presence of large magnetic field strength and low temperature, one can observe the quantum Hall effect, which is the quantization of the Hall voltage.



Hall effect

Spin Hall effect

Main article: Spin Hall effect

The Spin Hall effect consists in the spin accumulation on the lateral boundaries of a current-carrying sample. No magnetic field is needed. It was predicted by M.I. Dyakonov and V.I. Perel in 1971 and observed experimentally more than 30 years later, both in semiconductors and in metals, at cryogenic as well as at room temperatures.

Quantum Spin Hall effect

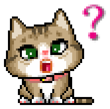
Main article: Quantum Spin Hall Effect

For HgTe two dimensional quantum wells with strong spin-orbit coupling, in zero magnetic field, at low temperature, the Quantum Spin Hall effect has been recently observed.

Hall effect

Hall effect in magnetic systems

In ferromagnetic materials (and paramagnetic materials in a magnetic field), the Hall resistivity includes an additional contribution, known as the Anomalous Hall Effect (or the Extraordinary Hall effect), which depends directly on the magnetization of the material, and is often much larger than the ordinary Hall effect. (Note that this effect is not due to the contribution of the magnetization to the total magnetic field.) Although a well-recognized phenomenon, there is still debate about its origins in the various materials. The anomalous Hall effect can be either an extrinsic (disorder-related) effect due to spin-dependent scattering of the charge carriers, or an intrinsic effect which can be described in terms of the Berry phase effect in the crystal momentum space (k-space).



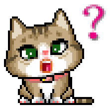
Hall effect

Hall effect in ionized gases

The Hall effect in an ionized gas (plasma) is significantly different from the Hall effect in solids (where the Hall parameter is always very inferior to unity). In a plasma, the Hall parameter can take any value.

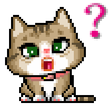
Physically, the trajectories of electrons are curved by the Lorentz force. Nevertheless when the Hall parameter is low, their motion between two encounters with heavy particles (neutral or ion) is almost linear. But if the Hall parameter is high, the electron movements are highly curved. The current density vector J is no more colinear with the electric field vector E. The two vectors J and E make the Hall angle θ which also gives the Hall parameter:

$$\beta = \tan\theta$$



Applications

Hall effect devices produce a very low signal level and thus require amplification. While suitable for laboratory instruments, the vacuum tube amplifiers available in the first half of the 20th century were too expensive, power consuming, and unreliable for everyday applications. It was only with the development of the low cost integrated circuit that the Hall effect sensor became suitable for mass application. Many devices now sold as "Hall effect sensors" are in fact a device containing both the sensor described above and a high gain integrated circuit (IC) amplifier in a single package. Recent advances have resulted in the addition of ADC (Analog to Digital) converters and I^2C (Inter-integrated circuit communication protocol) IC for direct connection to a microcontroller's I/O port being integrated into a single package, see Advanced Hall Effect Current Transducer. Reed switch electrical motors using the hall effect IC is another application.



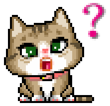
Applications

Hall probes are often used to measure magnetic fields, or inspect materials (such as tubing or pipelines) using the principles of Magnetic flux leakage.

Hall effect current sensor with internal integrated circuit amplifier. 8 mm opening. Zero current output voltage is midway between the supply voltages that maintain a 4 to 8 volt differential.

Advantages over other methods

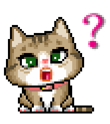
Hall effect devices when appropriately packaged are immune to dust, dirt, mud, and water. These characteristics make Hall effect devices better for position sensing than alternative means such as optical and electromechanical sensing.



Applications

Hall effect current sensor with internal integrated circuit amplifier. 8 mm opening. Zero current output voltage is midway between the supply voltages that maintain a 4 to 8 volt differential. Non-zero current response is proportional to the voltage supplied and is linear to 60 amperes for this particular (25 A) device. When electrons flow through a conductor, a magnetic field is produced. Thus, it is possible to create a non-contacting current sensor.

The device has three terminals. A sensor voltage is applied across two terminals and the third provides a voltage proportional to the current being sensed. This has several advantages; no additional resistance (a shunt, required for the most common current sensing method) need be inserted in the primary circuit. Also, the voltage present on the line to be sensed is not transmitted to the sensor, which enhances the safety of measuring equipment.



Ferrite toroid Hall effect current transducer

Hall sensors can detect stray magnetic fields easily, including that of Earth, so they work well as electronic compasses: but this also means that such stray fields can hinder accurate measurements of small magnetic fields. To solve this problem, Hall sensors are often integrated with magnetic shielding of some kind. For example, a Hall sensor integrated into a ferrite ring (as shown) can reduce stray fields by a factor of 100 or better. This configuration also provides an improvement in signal-to-noise ratio and drift effects of over 20 times that of a 'bare' Hall device. The range of a given feedthrough sensor may be extended upward and downward by appropriate wiring.

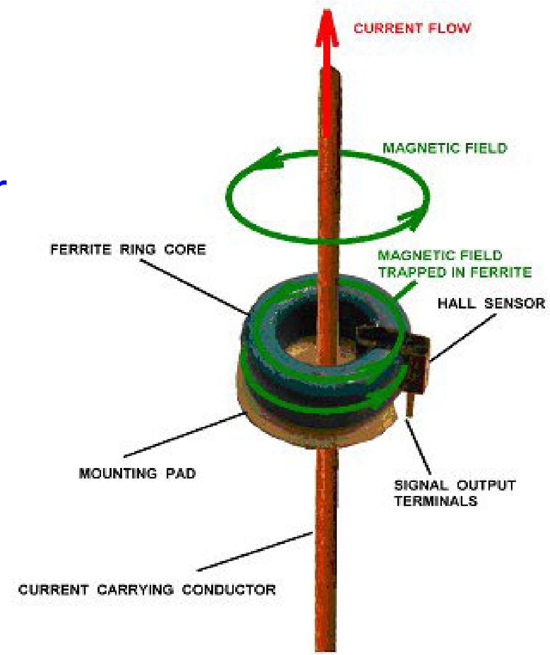
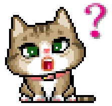
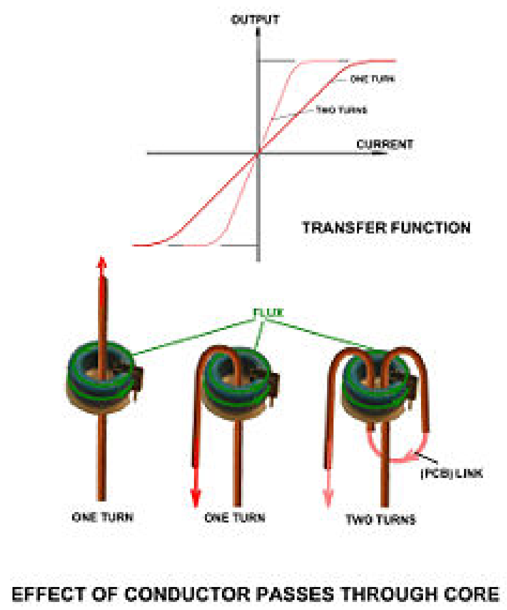


Diagram of Hall effect current transducer integrated into ferrite ring.



Applications

To extend the range to lower currents, multiple turns of the current-carrying wire may be made through the opening. To extend the range to higher currents, a current divider may be used. The divider splits the current across two wires of differing widths and the thinner wire, carrying a smaller proportion of the total current, passes through the sensor.



Multiple 'turns' and corre-sponding transfer function.

The principle of increasing the number of 'turns' a conductor takes around the ferrite core is well understood, each turn having the effect of 'amplifying' the current under measurement. Often these additional turns are carried out by a staple on the PCB.

Applications

Split ring clamp-on sensor

A variation on the ring sensor uses a split sensor which is clamped onto the line enabling the device to be used in temporary test equipment. If used in a permanent installation, a split sensor allows the electrical current to be tested without dismantling the existing circuit.

Analog multiplication

The output is proportional to both the applied magnetic field and the applied sensor voltage. If the magnetic field is applied by a solenoid, the sensor output is proportional to product of the current through the solenoid and the sensor voltage. As most applications requiring computation are now performed by small (even tiny) digital computers, the remaining useful application is in power sensing, which combines current sensing with voltage sensing in a single Hall effect device.

Applications

Current sensing

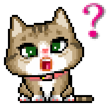
By sensing the current provided to a load and using the device's applied voltage as a sensor voltage it is possible to determine the power dissipated by a device. This power is (for direct current devices) the product of the current and the voltage. With appropriate refinement the devices may be applied to alternating current applications where they are capable of reading the true power produced or consumed by a device.

Position and motion sensing

Hall effect devices used in motion sensing and motion limit switches can offer enhanced reliability in extreme environments. As there are no moving parts involved within the sensor or magnet, typical life expectancy is improved compared to traditional electromechanical switches. Additionally, the sensor and magnet may be encapsulated in an appropriate protective material.

Applications

Automotive ignition and fuel injection
Commonly used in distributors for ignition timing (and in some types of crank and camshaft position sensors for injection pulse timing, speed sensing, etc.) the Hall effect sensor is used as a direct replacement for the mechanical breaker points used in earlier automotive applications. Its use as an ignition timing device in various distributor types is as follows. A stationary permanent magnet and semiconductor Hall effect chip are mounted next to each other separated by an air gap, forming the Hall effect sensor. A metal rotor consisting of windows and tabs is mounted to a shaft and arranged so that during shaft rotation, the windows and tabs pass though the air gap between the permanent magnet and semiconductor Hall chip. This effectively shields and exposes the Hall chip to the permanent magnet's field respective to whether a tab or window is passing though the Hall sensor.

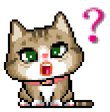


Applications

For ignition timing purposes, the metal rotor will have a number of equal-sized tabs and windows matching the number of engine cylinders. This produces a uniform square wave output since the on/off (shielding and exposure) time is equal. This signal is used by the engine computer or ECU to control ignition timing. It is worth noting that many automotive Hall effect sensors have a built-in internal NPN transistor with an open collector and grounded emitter, meaning that rather than a voltage being produced at the Hall sensor signal output wire, the transistor is turned on providing a circuit to ground though the signal output wire.

Wheel rotation sensing

The sensing of wheel rotation is especially useful in anti-lock brake systems. The principles of such systems have been extended and refined to offer more than anti-skid functions, now providing extended vehicle handling enhancements.



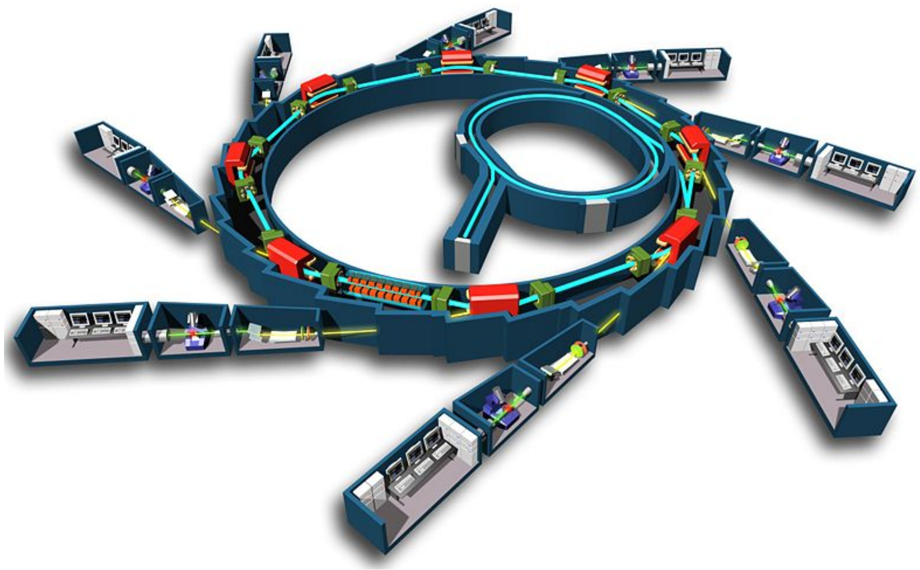
Applications

Electric motor control
Some types of brushless DC electric motors use Hall effect sensors to detect the position of the rotor and feed that information to the motor controller.

Industrial applications
Applications for Hall Effect sensing have also expanded to the industrial/off-highway market, which now use Hall Effect Joysticks to control hydraulic valves, replacing the traditional mechanical levers. Such applications include; Mining Trucks, Backhoe Loaders, Cranes, Diggers, Scissor Lifts, etc. The leading manufacturer of Industrial Hall Effect Joysticks is P-Q Controls, Inc., which was one of the first companies to expand the use of Hall Effect sensing to such applications in the 1980s, and in fact holds exclusive patents for contactless sensing.

synchrotron

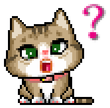
A synchrotron is a particular type of cyclic particle accelerator in which the magnetic field (to turn the particles so they circulate) and the electric field (to accelerate the particles) are carefully synchronized with the travelling particle beam. They were originally developed by Luis Walter Alvarez to study high-energy particle physics.



Synchrotrons are now mostly used for producing monochromatic high intensity X-ray beams; here, the synchrotron is the circular track, off which the beamlines branch.

Characteristics

While a cyclotron uses a constant magnetic field and a constant-frequency applied electric field (one of these is varied in the synchrocyclotron), both of these fields are varied in the synchrotron. By increasing these parameters appropriately as the particles gain energy, their path can be held constant as they are accelerated. This allows the vacuum container for the particles to be a large thin torus. In reality it is easier to use some straight sections between the bending magnets and some bent sections within the magnets giving the torus the shape of a round-cornered polygon. A path of large effective radius may thus be constructed using simple straight and curved pipe segments, unlike the disc-shaped chamber of the cyclotron type devices. The shape also allows and requires the use of multiple magnets to bend the particle beam.



Characteristics

The interior of the Australian Synchrotron facility. Dominating the image is the storage ring, with an experimental end station at front right. In the middle of the storage ring is the booster synchrotron and linac

Characteristics

The maximum energy that a cyclic accelerator can impart is typically limited by the strength of the magnetic field(s) and the minimum radius (maximum curvature) of the particle path

In a cyclotron the maximum radius is quite limited as the particles start at the center and spiral outward, thus this entire path must be a self-supporting disc-shaped evacuated chamber. Since the radius is limited, the power of the machine becomes limited by the strength of the magnetic field. In the case of an ordinary electromagnet the field strength is limited by the saturation of the core (when all magnetic domains are aligned the field may not be further increased to any practical extent). The arrangement of the single pair of magnets the full width of the device also limits the economic size of the device.

Characteristics

Synchrotrons overcome these limitations, using a narrow beam pipe which can be surrounded by much smaller and more tightly focusing magnets. The ability of this device to accelerate particles is limited by the fact that the particles must be charged to be accelerated at all, but charged particles under acceleration emit photons (light), thereby losing energy. The limiting beam energy is reached when the energy lost to the lateral acceleration required to maintain the beam path in a circle equals the energy added each cycle. More powerful accelerators are built by using large radius paths and by using more numerous and more powerful microwave cavities to accelerate the particle beam between corners. Lighter particles (such as electrons) lose a larger fraction of their energy when turning. Practically speaking, the energy of electron/positron accelerators is limited by this radiation loss, while it does not play a significant role in the dynamics of proton or ion accelerators. The energy of those is limited strictly by the strength of magnets and by the cost.

Characteristics

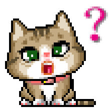
Modern industrial-scale synchrotrons can be very large (here, Soleil near Paris)

Characteristics

Large synchrotrons

One of the early large synchrotrons, now retired, is the Bevatron, constructed in 1950 at the Lawrence Berkeley Laboratory. The name of this proton accelerator comes from its power, in the range of 6.3 GeV (then called BeV for billion electron volts10^{10}eV; the name predates the adoption of the SI prefix giga-10^{9}). A number of heavy elements, unseen in the natural world, were first created with this machine. This site is also the location of one of the first large bubble chambers used to examine the results of the atomic collisions produced here.

Another early large synchrotron is the Cosmotron built at Brookhaven National Laboratory which reached 3.3 GeV in 1953.

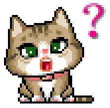


Characteristics

Until August 2008, the highest energy synchrotron in the world was the Tevatron, at the Fermi National Accelerator Laboratory, in the United States. It accelerates protons and antiprotons to slightly less than 1 TeV of kinetic energy and collides them together. The Large Hadron Collider (LHC), which has been built at the European Laboratory for High Energy Physics (CERN), has roughly seven times this energy. It is housed in the 27 km tunnel which formerly housed the Large Electron Positron (LEP) collider, so it will maintain the claim as the largest scientific device ever built. The LHC will also accelerate heavy ions (such as Lead) up to an energy of 1.15 PeV.

Characteristics

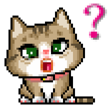
The largest device of this type seriously proposed was the Superconducting Super Collider (SSC), which was to be built in the United States. This design, like others, used superconducting magnets which allow more intense magnetic fields to be created without the limitations of core saturation. While construction was begun, the project was cancelled in 1994, citing excessive budget overruns — this was due to naïve cost estimation and economic management issues rather than any basic engineering flaws. It can also be argued that the end of the Cold War resulted in a change of scientific funding priorities that contributed to its ultimate cancellation.



Characteristics

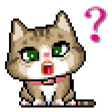
While there is still potential for yet more powerful proton and heavy particle cyclic accelerators, it appears that the next step up in electron beam energy must avoid losses due to synchrotron radiation. This will require a return to the linear accelerator, but with devices significantly longer than those currently in use. There is at present a major effort to design and build the International Linear Collider (ILC), which will consist of two opposing linear accelerators, one for electrons and one for positrons. These will collide at a total center of mass energy of 0.5 TeV.

However, synchrotron radiation also has a wide range of applications (see synchrotron light) and many synchrotrons have been built especially to harness it. The largest of those 3rd generation synchrotron light sources are the European Synchrotron Radiation Facility (ESRF) in Grenoble, France, the Advanced Photon Source (APS) near Chicago, USA, and SPring-8 in Japan, accelerating electrons up to 6, 7 and 8 GeV, respectively.



Characteristics

Synchrotrons which are useful for cutting edge research are large machines, costing tens or hundreds of millions of dollars to construct, and each beamline (there may be 20 to 50 at a large synchrotron) costs another two or three million dollars on average. These installations are mostly built by the science funding agencies of governments of developed countries, or by collaborations between several countries in a region, and operated as infrastructure facilities available to scientists from universities and research organisations throughout the country, region, or world. More compact models, however, have been developed, such as the Compact Light Source.



Applications

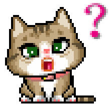
- Life sciences: protein and large molecule crystallography
- Drug discovery and research
- "Burning" computer chip designs into metal wafers
- Studying molecule shapes and protein crystals
- Analyzing chemicals to determine their composition
- Observing the reaction of living cells to drugs
- Inorganic material crystallography and microanalysis
- Fluorescence studies
- Semiconductor material analysis and structural studies
- Geological material analysis
- Medical imaging
- Proton therapy to treat some forms of cancer

The Large Hadron Collider（I）

The Large Hadron Collider（II）

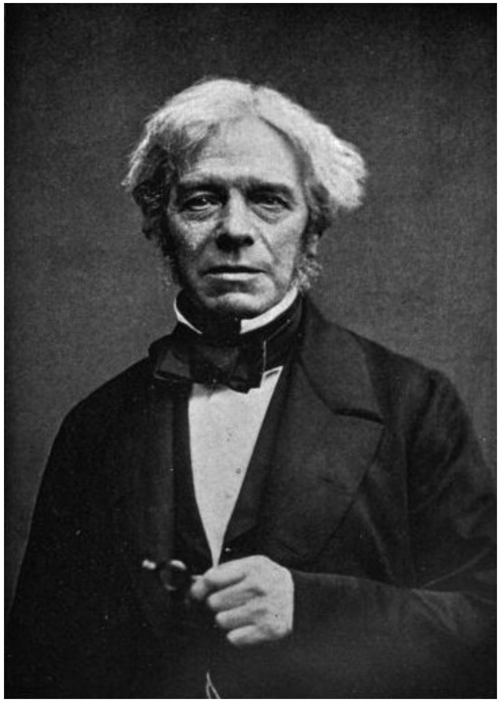
The Large Hadron Collider（III）

LHC-the end of universe

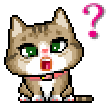


Michael Faraday

Michael Faraday, FRS (September 22, 1791–August 25, 1867) was an English chemist and physicist (or natural philosopher, in the terminology of the time) who contributed to the fields of electromagnetism and electrochemistry. Faraday studied the magnetic field around a conductor carrying a DC electric current, and established the basis for the magnetic field concept in physics. He discovered electromagnetic induction, diamagnetism, and laws of electrolysis. He established that magnetism could affect rays of light and that there was an underlying relationship between the two phenomena.



Michael Faraday holding a glass bar of the type he used in 1845 to show that magnetism can affect light.



Michael Faraday

His inventions of electromagnetic rotary devices formed the foundation of electric motor technology, and it was largely due to his efforts that electricity became viable for use in technology.

As a chemist, Faraday discovered benzene, investigated the clathrate hydrate of chlorine, invented an early form of the bunsen burner and the system of oxidation numbers, and popularized terminology such as anode, cathode, electrode, and ion.

Although Faraday received little formal education and knew little of higher mathematics, such as calculus, he was one of the most influential scientists in history. Some historians[3] of science refer to him as the best experimentalist in the history of science. The SI unit of capacitance, the farad, is named after him, as is the Faraday constant, the charge on a mole of electrons. Faraday's law of induction states that a magnetic field changing in time creates a proportional electromotive force.

Early life

Michael Faraday in his late thirties Michael Faraday was born in Newington Butts, part of South London, England. His family was not well off. His father, James, was a member of the Sandemanian sect of Christianity. James Faraday had come to London around 1790 from Outhgill in Westmorland, where he had been the village blacksmith. The young Michael Faraday, one of four children, having only the most basic of school educations, had to largely educate himself.[6] At fourteen he became apprenticed to a local bookbinder and bookseller George Riebau and, during his seven-year apprenticeship, he read many books, including Isaac Watts' The Improvement of the Mind, and he enthusiastically implemented the principles and suggestions contained therein. He developed an interest in science and specifically in electricity. In particular, he was inspired by the book Conversations in Chemistry by Jane Marcet.

Early life

At the age of twenty, in 1812, at the end of his apprenticeship, Faraday attended lectures by the eminent English chemist Humphry Davy of the Royal Institution and Royal Society, and John Tatum, founder of the City Philosophical Society. Many tickets for these lectures were given to Faraday by William Dance (one of the founders of the Royal Philharmonic Society). Afterwards, Faraday sent Davy a three hundred page book based on notes taken during the lectures. Davy's reply was immediate, kind, and favorable. When Davy damaged his eyesight in an accident with nitrogen trichloride, he decided to employ Faraday as a secretary. When John Payne, one of the Royal Institution's assistants, was fired, Sir Humphry Davy was asked to find a replacement.

Michael Faraday
in his late thirties

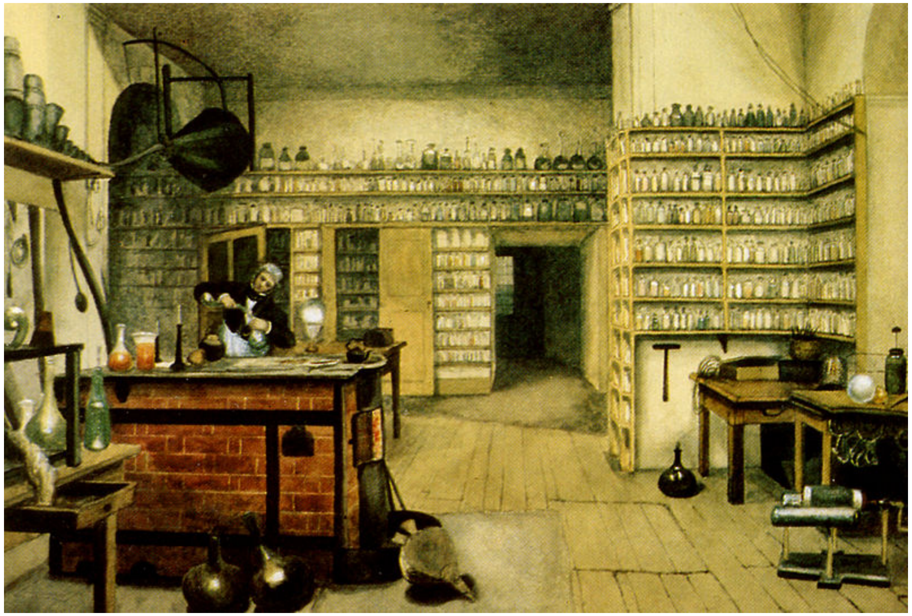
Early life

Faraday was a devout Christian and a member of the small Sandemanian denomination, an offshoot of the Church of Scotland. He later served two terms as an elder in the group's church at Glovers Hall, Barbican, which later moved to Barnsbury, Islington.
Faraday married Sarah Barnard (1800-1879) on 2 June 1821, although they would never have children. They met through attending the Sandemanian church. He was elected a member of the Royal Society in 1824, appointed director of the laboratory in 1825; and in 1833 he was appointed Fullerian professor of chemistry in the institution for life, without the obligation to deliver lectures

Sir Humphry Davy, 1830 engraving based on the painting by Sir Thomas Lawrence (1769-1830)

Scientific achievements

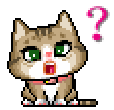
Faraday's greatest work was probably with electricity and magnetism. The first experiment which he recorded was the construction of a voltaic pile with seven halfpence pieces, stacked together with seven disks of sheet zinc, and six pieces of paper moistened with salt water. With this pile he decomposed sulphate of magnesia (first letter to Abbott, 12 July 1812).



Michael Faraday in his laboratory. c1850s by artist Harriet Jane Moore who documented Faraday's life in water colours

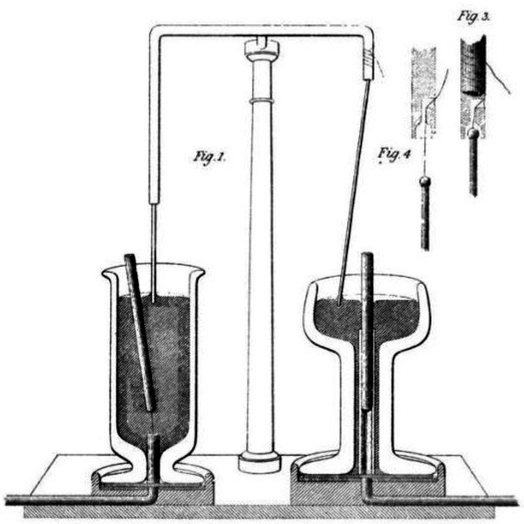
Scientific achievements

Electromagnetic rotation experiment of Faraday, ca. 1821[16]In 1821, soon after the Danish physicist and chemist, Hans Christian Orsted discovered the phenomenon of electromagnetism, Davy and British scientist William Hyde Wollaston tried but failed to design an electric motor.Faraday, having discussed the problem with the two men, went on to build two devices to produce what he called electromagnetic rotation: a continuous circular motion from the circular magnetic force around a wire and a wire extending into a pool of mercury with a magnet placed inside would rotate around the magnet if supplied with current from a chemical battery. The latter device is known as a homopolar motor. These experiments and inventions form the foundation of modern electromagnetic technology. Faraday published his results without acknowledging his debt to Wollaston and Davy, and the resulting controversy caused Faraday to withdraw from electromagnetic research for several years.

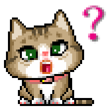


Scientific achievements

At this stage, there is also evidence to suggest that Davy may have been trying to slow Faraday’s rise as a scientist (or natural philosopher as it was known then). In 1825, for instance, Davy set him onto optical glass experiments, which progressed for six years with no great results. It was not until Davy's death, in 1829, that Faraday stopped these fruitless tasks and moved on to endeavors that were more worthwhile. Two years later, in 1831, he began his great series of experiments in which he discovered electromagnetic induction. Joseph Henry likely discovered self-induction a few months earlier and both may have been anticipated by the work of Francesco Zantedeschi in Italy in 1829 and 1830.



Electromagnetic rotation experiment of Faraday, *ca.* 1821



Scientific achievements

Faraday's breakthrough came when he wrapped two insulated coils of wire around an iron ring, and found that upon passing a current through one coil, a momentary current was induced in the other coil.[2] This phenomenon is known as mutual induction. The iron ring-coil apparatus is still on display at the Royal Institution. In subsequent experiments he found that if he moved a magnet through a loop of wire, an electric current flowed in the wire. The current also flowed if the loop was moved over a stationary magnet. His demonstrations established that a changing magnetic field produces an electric field. This relation was mathematically modelled by Faraday's law, which subsequently became one of the four Maxwell equations. These in turn have evolved into the generalisation known today as field theory.

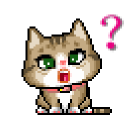
Scientific achievements

Faraday's breakthrough came when he wrapped two insulated coils of wire around an iron ring, and found that upon passing a current through one coil, a momentary current was induced in the other coil.[2] This phenomenon is known as mutual induction. The iron ring-coil apparatus is still on display at the Royal Institution. In subsequent experiments he found that if he moved a magnet through a loop of wire, an electric current flowed in the wire. The current also flowed if the loop was moved over a stationary magnet. His demonstrations established that a changing magnetic field produces an electric field. This relation was mathematically modelled by Faraday's law, which subsequently became one of the four Maxwell equations. These in turn have evolved into the generalisation known today as field theory.

Scientific achievements

In 1839 he completed a series of experiments aimed at investigating the fundamental nature of electricity. Faraday used "static", batteries, and "animal electricity" to produce the phenomena of electrostatic attraction, electrolysis, magnetism, etc. He concluded that, contrary to scientific opinion of the time, the divisions between the various "kinds" of electricity were illusory. Faraday instead proposed that only a single "electricity" exists, and the changing values of quantity and intensity (voltage and charge) would produce different groups of phenomena.

Near the end of his career Faraday proposed that electromagnetic forces extended into the empty space around the conductor. This idea was rejected by his fellow scientists, and Faraday did not live to see this idea eventually accepted. Faraday's concept of lines of flux emanating from charged bodies and magnets provided a way to visualize electric and magnetic fields.

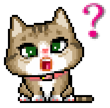


Later life

In June 1832, the University of Oxford granted Faraday a Doctor of Civil Law degree (honorary). During his lifetime, Faraday rejected a knighthood and twice refused to become President of the Royal Society.

In 1848, as a result of representations by the Prince Consort, Michael Faraday was awarded a grace and favour house in Hampton Court, Surrey free of all expenses or upkeep. This was the Master Mason's House, later called Faraday House, and now No.37 Hampton Court Road. In 1858 Faraday retired to live there.

Faraday died at his house at Hampton Court on 25 August 1867. He had previously turned down burial in Westminster Abbey, but he has a memorial plaque there, near Isaac Newton's tomb. Faraday was interred in the Sandemanian plot in High gate Cemetery.



Quotations

Michael Faraday, portrait by Thomas Phillips c1841-1842

- Nothing is too wonderful to be true if it be consistent with the laws of nature, and in such things as these, experiment is the best test of such consistency.
- Work. Finish. Publish.
- The important thing is to know how to take all things quietly.
- Speculations? I have none. I am resting on certainties.
- but still try, for who knows what is possible...
- One day sir, you may tax it.
- If you would cause your view ... to be acknowledged by scientific men; you would do a great service to science. If you would even get them to say yes or no to your conclusions it would help to clear the future progress. I believe some hesitate because they do not like their thoughts disturbed.

James Clerk Maxwell

James Clerk Maxwell (13 June 1831 – 5 November 1879) was a Scottish mathematician and theoretical physicist. His most significant achievement was the development of the classical electromagnetic theory, synthesizing all previous unrelated observations, experiments and equations of electricity, magnetism and even optics into a consistent theory.

James Clerk Maxwell

His set of equations—Maxwell's equations—demonstrated that electricity, magnetism and even light are all manifestations of the same phenomenon: the electromagnetic field. From that moment on, all other classical laws or equations of these disciplines became simplified cases of Maxwell's equations. Maxwell's work in electromagnetism has been called the "second great unification in physics", after the first one carried out by Newton. Maxwell demonstrated that electric and magnetic fields travel through space in the form of waves, and at the constant speed of light. Finally, in 1864 Maxwell wrote A Dynamical Theory of the Electromagnetic Field where he first proposed that light was in fact undulations in the same medium that is the cause of electric and magnetic phenomena. His work in producing a unified model of electromagnetism is considered to be one of the greatest advances in physics.

Education, 1839–1847

Maxwell also developed the Maxwell distribution, a statistical means to describe aspects of the kinetic theory of gases. These two discoveries helped usher in the era of modern physics, laying the foundation for future work in such fields as special relativity and quantum mechanics. He is also known for creating the first true colour photograph in 1861.

Maxwell is considered by many physicists to be the nineteenth century scientist with the greatest influence on twentieth century physics. His contributions to the science are considered by many to be of the same magnitude as those of Isaac Newton and Albert Einstein. In 1931, on the centennial of Maxwell's birthday, Einstein himself described Maxwell's work as the "most profound and the most fruitful that physics has experienced since the time of Newton." Einstein kept a photograph of Maxwell on his study wall, alongside pictures of Michael Faraday and Isaac Newton

Education, 1839–1847

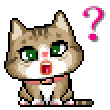
Recognizing the potential of the young boy, his mother Frances took responsibility for James' early education, which in Victorian era was largely the job of the woman of the house. She was however taken ill with abdominal cancer, and after an unsuccessful operation, died in December 1839 when Maxwell was only eight. James' education was then overseen by John Maxwell and his sister-in-law Jane, both of whom played pivotal roles in the life of Maxwell. His formal schooling began unsuccessfully under the guidance of a sixteen-year old hired tutor. Little is known about the young man John Maxwell hired to instruct his son, except that he treated the younger boy harshly, chiding him for being slow and wayward. John Maxwell dismissed the tutor in November 1841, and after considerable thought, sent James to the prestigious Edinburgh Academy.He lodged during term times at the house of his aunt Isabella; while there his passion for drawing was encouraged by his older cousin Jemima, herself a talented artist.

Education, 1839–1847

The ten-year old Maxwell, raised in isolation on his father's countryside estate, did not fit in well at school. The first year had been full, obliging him to join the second year with classmates a year his senior.

Edinburgh Academy, where Maxwell was schooled

His mannerisms and Galloway accent struck the other boys as rustic, and arriving on his first day at school wearing home-made shoes and tunic earned him the unkind nickname of "Daftie". Maxwell, however, never seemed to have resented the epithet, bearing it without complaint for many years. Any social isolation at the Academy however ended when he met Lewis Campbell and Peter Guthrie Tait, two boys of a similar age, and themselves to become notable scholars. They would remain lifetime friends



Education, 1839–1847

Maxwell was fascinated by geometry at an early age, rediscovering the regular polyhedra before any formal instruction. Much of his talent went unnoticed however, and, despite winning the school's scripture biography prize in his second year, his academic work remained unremarkable, until, at the age of 13, he won the school's mathematical medal, and first prizes for English and poetry.

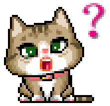
For his first scientific work, at the age of only 14, Maxwell wrote a paper describing a mechanical means of drawing mathematical curves with a piece of twine, and the properties of ellipses and curves with more than two foci. His work, Oval Curves, was presented to the Royal Society of Edinburgh by James Forbes, professor of natural philosophy at Edinburgh University, Maxwell deemed too young for the task. The work was not entirely original, Descartes having examined the properties of such multifocal curves in the seventeenth century, though Maxwell had simplified their construction

Edinburgh University, 1847–1850

Maxwell left the Academy in 1847 at the age of 16 and began attending classes at the University of Edinburgh. Having the opportunity to attend Cambridge after his first term, Maxwell decided instead to complete the full course of his undergraduate studies at Edinburgh. The academic staff of Edinburgh University included some highly regarded names, and Maxwell's first year tutors included Sir William Hamilton.

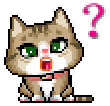
Edinburgh University, 1847–1850

Maxwell did not however find his classes at Edinburgh very demanding, and was able to immerse himself in private study during free time at the university, and particularly when back home at Glenlair. There he would experiment with improvised chemical and electromagnetic apparatus, but his chief preoccupation was the properties of polarized light. He constructed shaped blocks of gelatine, subjecting them to various stresses, and with a pair of polarizing prisms gifted him by the famous scientist William Nichol, would view the coloured fringes developed within the jelly.[28] Maxwell had discovered photoelasticity, a means of determining the stress distribution within physical structures



Cambridge University, 1850–1856

A young Maxwell at Trinity College, Cambridge. He is holding one of his colour wheels. In October 1850, already an accomplished mathematician, Maxwell left Scotland for Cambridge University. He initially attended Peter house, but before the end of his first term transferred to Trinity College, where he believed it would be easier to obtain a fellowship. At Trinity, he was elected to the elite secret society known as the Cambridge Apostles. In November 1851, Maxwell studied under William Hopkins, whose success in nurturing mathematical genius had earned him the nickname of "senior wrangler-maker". A considerable part of Maxwell's translation of his electromagnetism equations was accomplished during his time in Trinity.



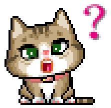
Aberdeen University, 1856–1860

The twenty-five year old Maxwell was a decade and a half younger than any other professor at Marischal, but engaged himself with his new responsibilities as head of department, devising the syllabus and preparing the lectures. He committed himself to lecturing 15 hours a week, including a weekly *pro bono* lecture to the local working men's college. He lived in Aberdeen during the six months of the academic year, and would spend the summers at Glenlair, which he had inherited from his father.

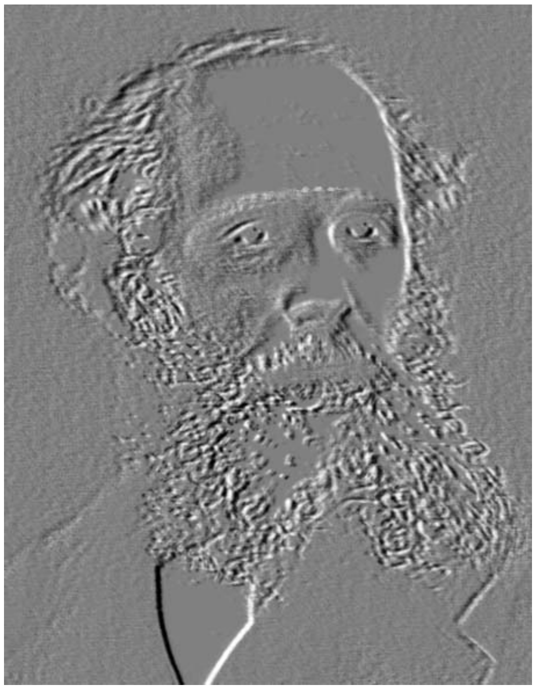
James and Katherine Maxwell, 1869.

Later years

In 1865, Maxwell resigned the chair at King's College London and returned to Glenlair with Katherine.
He wrote a textbook of the Theory of Heat (1871), and an elementary treatise on Matter and Motion (1876). Maxwell was also the first to make explicit use of dimensional analysis in 1871.
In 1871, he became the first Cavendish Professor of Physics at Cambridge. Maxwell was put in charge of the development of the Cavendish Laboratory. He supervised every step of the progress of the building and of the purchase of the very valuable collection of apparatus paid for by its generous founder, the 7th Duke of Devonshire (chancellor of the university, and one of its most distinguished alumni). One of Maxwell's last great contributions to science was the editing (with copious original notes) of the electrical researches of Henry Cavendish, from which it appeared that Cavendish researched such questions as the mean density of the earth and the composition of water, among other things



Later years



He died in Cambridge of abdominal cancer on 5 November 1879 at the age of 48.Maxwell is buried at Parton Kirk, near Castle Douglas in Galloway, Scotland. The extended biography The Life of James Clerk Maxwell, by his former schoolfellow and lifelong friend Professor Lewis Campbell, was published in 1882 and his collected works, including the series of articles on the properties of matter, such as Atom, Attraction, Capillary Action, Diffusion, Ether, etc., were issued in two volumes by the Cambridge University Press in 1890.