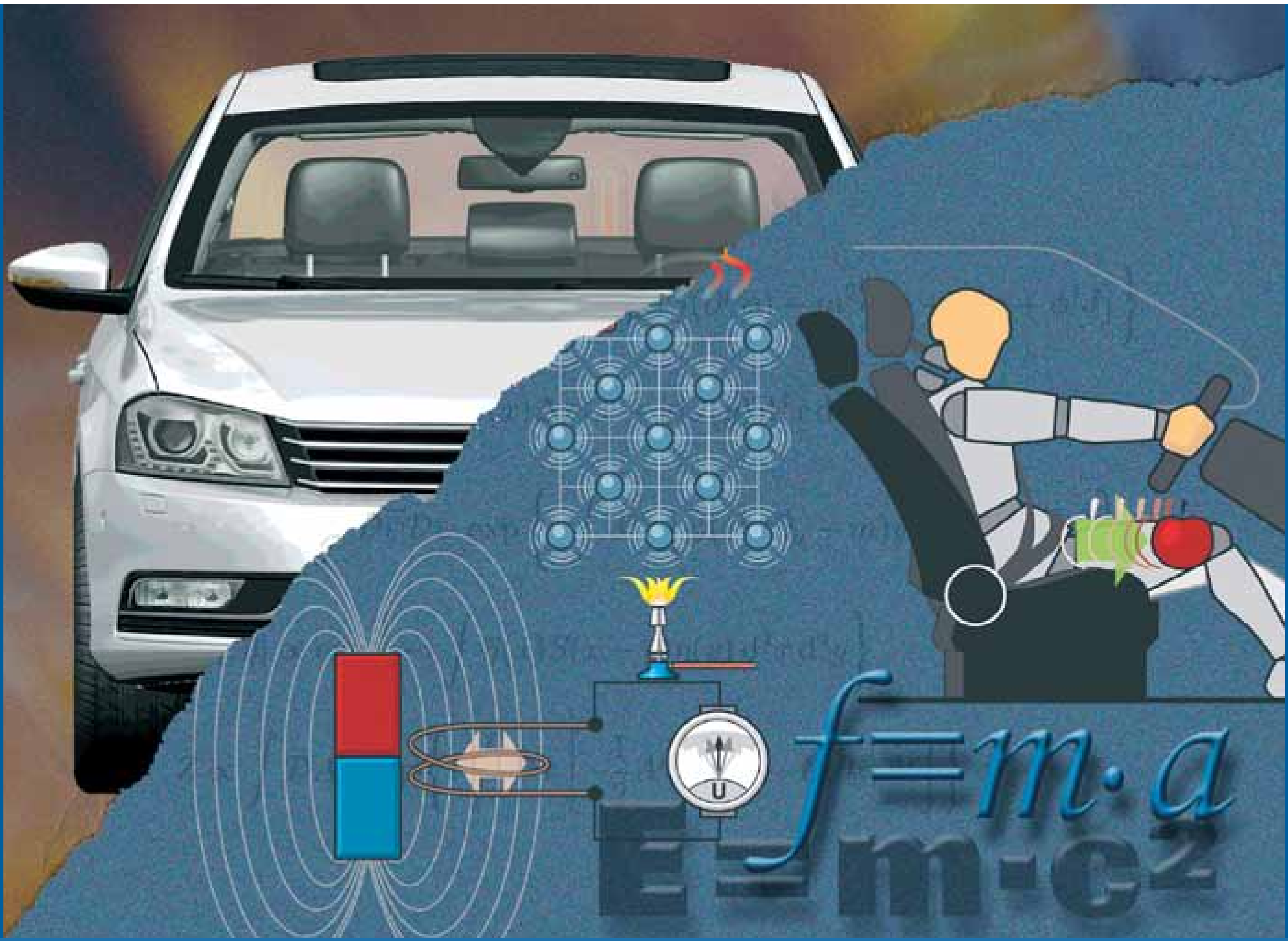
Service Training

Self Study Program 870133

Vehicle Sensor Technology

Physical Principles



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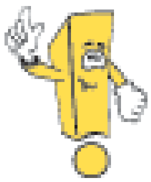
Contents



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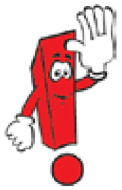


Important!

Introduction

In automotive engineering, high standards of safety, operation, and comfort are leading to increasingly complex vehicle control systems. These systems require a lot of information that must be supplied by sensors located throughout the vehicle.

Although there are many different types of sensors in these systems, sensor function relies on just a few basic physical principles and measurement processes.

This self-study program explains these physical principles and measurement processes in plain language, and associates them with the different types of sensors.

Introduction

Vehicle Sensor Technology SSP Series Structure

There are three SSPs in the vehicle sensor technology series:

- Vehicle Sensor Technology - Physical Principles (this SSP)
- Vehicle Sensor Technology - Measuring Methods
- Vehicle Sensor Technology - Sensor Technology

Together, these three SSPs provide a complete overview of vehicle sensor technology basics. The courses build on each other and should be studied in the order listed.

Vehicle Sensor Technology SSP Series Content Summary

This SSP is the first in the vehicle sensor technology series. It covers the basic physical principles that determine sensor function. Images are used wherever possible to illustrate these concepts.

The second SSP, "Vehicle Sensor Technology - Measuring Methods," covers the different measurement processes used by vehicle control system sensors. The concepts in the second SSP will require knowledge of the physical principles explained in this one.

Finally, "Vehicle Sensor Technology - Sensor Technology" provides an overview of the different types of sensors used in automotive engineering and relates them to the measurement processes presented in the second SSP. The description for each type of sensor will cover:

- How its signal can be used
- How the sensor is constructed
- How it functions in relation to the measurement process

What Does Sensor Technology Mean?

Sensor technology as discussed here is the application of sensors to control and regulate systems. A sensor is a gauge used to register specific physical characteristics and convert them to an electronic signal. A sensor is the interface between the monitored component and the control system.

Vehicle "Senses"

Automotive sensors can be compared to the human senses. Humans have five basic senses (sight, hearing, taste, smell, and touch) and we have specific gauges for each of them (eyes, ears, mouth, nose, and skin). We also have an awareness of balance, pressure, temperature, pain, and motion based on multiple inputs from other parts of our bodies to our brains.

Sight

Our eyes have photosensitive sensors that enable our brains to recognize color, brightness, and patterns. As we mature and gain experience of our surroundings, the evaluation of optical data in our brains enables us to estimate the distance, speed, and movement of objects in our environment.

Hearing

Our ears collect sound waves, register them by sensing their vibration, and send audio signals to our brains.

Additional sensors in our inner ears provide our brains with input that helps give us a sense of balance. Our sense of balance enables us to walk upright and makes us sensitive to movement and acceleration.

Taste and Smell

For the purposes of this course, there is no direct correlation between vehicle control system sensors and our senses of taste and smell, although smell can certainly be an aid to vehicle diagnosis.

Touch

In the truest sense of the word, the pressure-sensitivity of our sense of touch enables us to "grasp" our environment. Sensors inside us and in our skin provide inputs to our brains that register our sense of temperature. They can warn us of excessively high or low temperatures that could harm our bodies.

Limitations to Our Senses

Humans have no sense of electromagnetic waves outside of infrared or visible light, nor do we have the sensors required to register electricity, radioactivity, or air pressure, to name just a few physical variables. We gain many of the sensory impressions of our environment indirectly as interpretations on the part of our brain, without being able to specifically quantify them. We may be able to classify our sensitivity as stronger or weaker, but we have no concrete measurable data. Without measurable data, the indirect inputs from a biological system's sensors are extremely individual and difficult to compare with others. This is not true of technical sensors.

Technical Sensors

With its multitude of control systems and driver assistance systems, a modern vehicle has significantly more senses than we do. Temperature, rotational speed, proximity, linear speed, torque, pressure, distance, quantity, and much more are registered by technical sensors and converted into concrete measurable data. The results are evaluated by vehicle system controllers to determine control processes.

What is Motion?

Absolute and Relative Motion

We no longer talk about absolute physical motion. In the past, absolute motion was considered to be the movement of an object within the surrounding absolute space (the universe).

According to the current view, this so-called absolute motion is also relative — that is, the "absolute" motion of an object moving in the universe is "relative" to the reference system of the universe itself.

To add to the confusion, motion can be described in reference not only to the surrounding space, but also in reference to the observer or to another object. Depending on which reference system is used, motion is observed in different ways.

To a passenger on a train (the first observer), a cup of coffee sitting on a table in the moving train appears to be at rest.

At the same time, a second observer standing on the station platform sees the cup (and passenger) in motion.

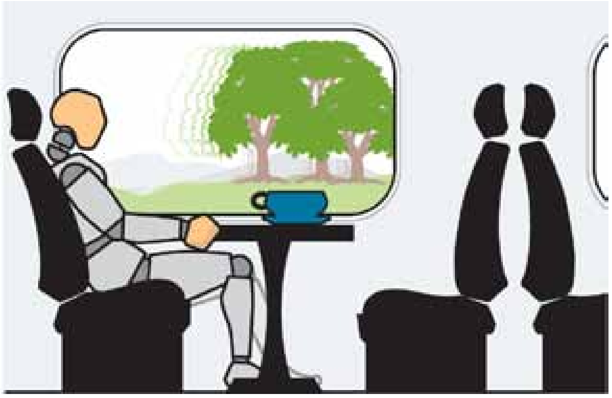
Also at the same time, a third observer at the center of the Milky Way sees the cup (and the passenger and the second observer on the station platform) moving smartly along at approximately 597,262 mph (961,200 km/h) relative to the rest of our galaxy.

When asked what the speed of the cup is:

- The first observer would reply: 0 mph (0 km/h).
- The second observer would reply (for example): 155 mph (250 km/h).
- The third observer would reply: approximately 597,262 mph (961,200 km/h).

These are three different answers, all of which can be checked, and all of which are "true" relative to their frames of reference.

Therefore, it is important to specify the reference system when describing motion.



For the first observer (the passenger) in the "train" reference system, the cup remains at rest in relation to the observer and the train.

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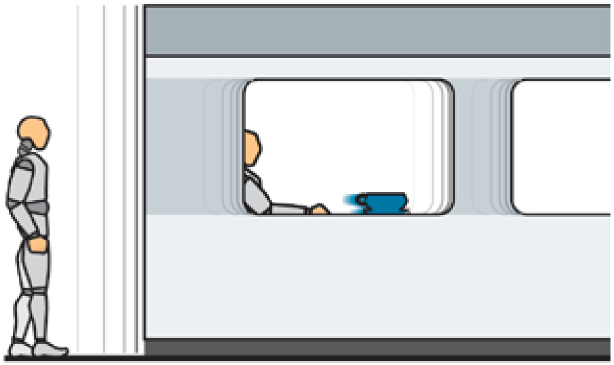

For the second observer on the station platform, the cup (together with the train and passenger) is in motion in relation to himself and the "station" reference system.

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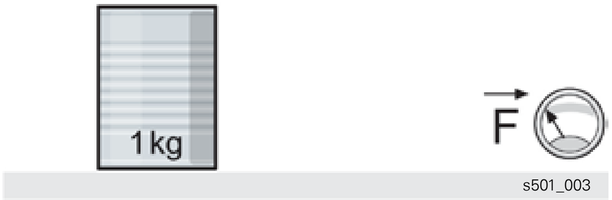
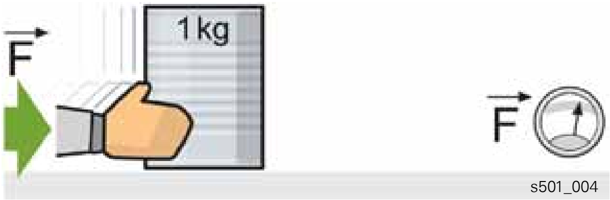
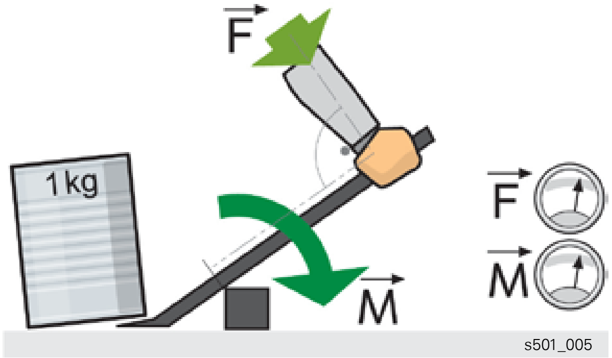
Force and Torque



The body is at rest and no force (F) is acting.



A linear force (F) acting on the body can accelerate or deform the body.



If a force (F) acts on a lever arm, a rotational force, torque (M), results.

To define motion we must address its causes — the reasons motion occurs. These include the concepts of force, acceleration, and torque.

Force causes motion. A force is a targeted physical variable that can deform or accelerate a body.

Mathematically, force is described as the product of the mass of the body upon which it acts and the acceleration that it undergoes as a result of the application of the force (Newton's second law).

Net Force equals mass times acceleration: Fnet = m * a

If the force acts on a lever arm around a pivot point, or fulcrum, torque is obtained as a physical variable.

Torque is a rotational force. If the direction of the force and the lever arm form a right angle, the torque can be described in simplified form as the product of the force and the length of the lever arm.

Acceleration due to a force (including torque) changes the state of motion — its speed or its direction changes.

There are several types of forces that play roles in describing how sensors function:

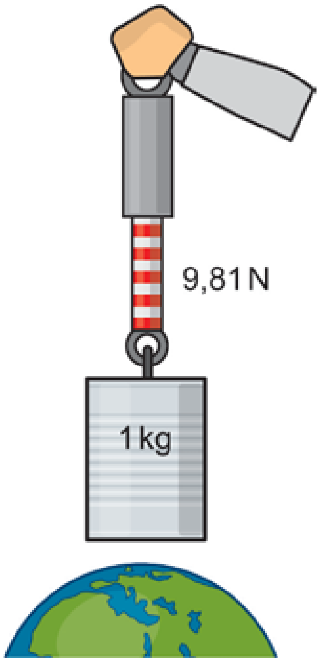
- Gravitational force
- Inertial force
- Centrifugal force
- Centripetal force
- Coriolis force

Gravitational Force

For us on earth, gravitational force is caused primarily by the mass of our planet. Gravitation acts towards the center of the earth. Every object in the earth's sphere of influence experiences gravity. Gravitational force decreases by the square of the distance of the object from the earth.

According to Newton's second law, the acceleration which a falling body experiences can be mathematically derived from gravitational force. This acceleration is 32 ft/s^2 (9.81 m/s^2). Disregarding the influences of such things as friction and lift in a theoretical free-fall to the earth, for each second we continued to fall we would accelerate an additional 32 ft/s (9.81 m/s).

According to Newton, we feel gravitational force when standing on the earth because an equally large, opposing force is pressing against our feet from below. He formulated this as "action = reaction" (Newton's third law). Newtonian mechanics can be used to describe gravitation as we experience it and how it can be calculated mathematically.



A body with a mass of 1 kg on the earth is subject to a gravitational force of 9.81 N.

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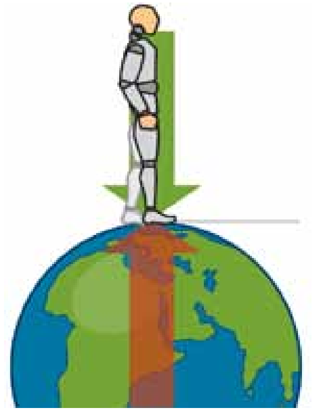

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According to Newton's third law, forces always occur in opposing pairs. As we do not normally sink into the ground or begin to float without cause, an equally large force (red arrow) must act counter to the gravitational force (green arrow).

What is Motion?

Based on Albert Einstein's general theory of relativity, gravity is not regarded as a force that acts on a body in free fall but as a geometrical characteristic of the four-dimensional space (space-time). This model of the fundamental structure of the universe is formed by the three spatial dimensions and time.

What was new about this view was that objects don’t interact with each other on an unchangeable, static stage (the space surrounding us). This view holds that the objects influence the stage and each other, just as the stage influences the objects.

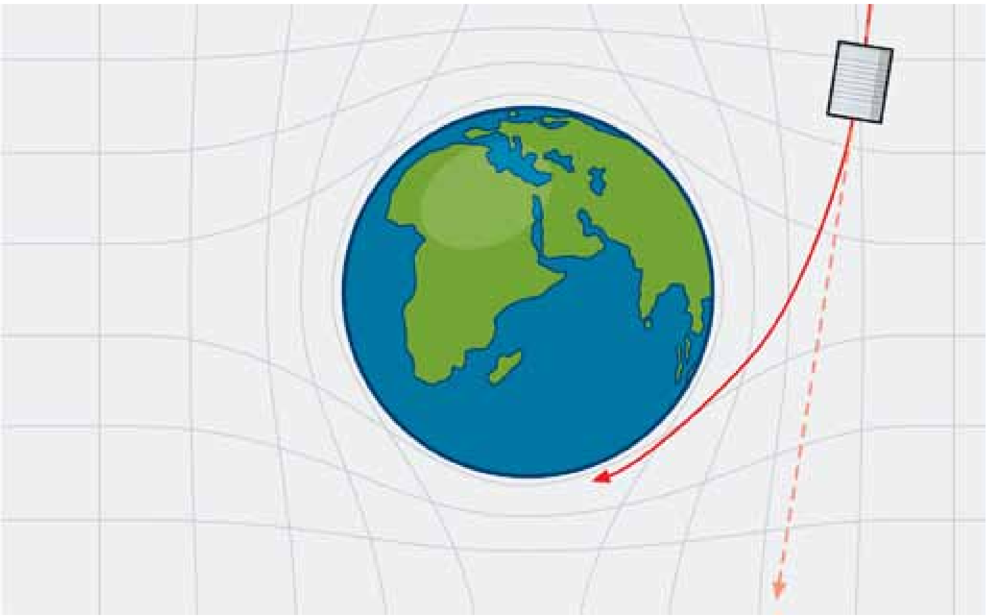
All objects that have mass generate a disturbance or curvature in the structure of this space-time at their location. The greater the mass, the more the space-time structure is "bent".

If the difference in mass between two objects is great, the influence of the lighter one on the heavier one is so small that it is not noticeable. For example, in comparison with the influence the earth exercises on an airplane, the influence of that airplane on the earth is too small to have much effect.

If an object with lesser mass encounters such a curved area on its way through the universe, it is diverted towards the object of greater mass due to the curvature in the space-time structure.

If the strength and direction of the object's own motion are sufficient to pass through this curvature, the object is able to leave the curved area on an altered course. If the strength and direction of the object's own motion are not sufficient, the object with lesser mass crashes into the object with greater mass.

In contrast to Newton's definition, Einstein’s general theory of relativity states that no forces act on the body during this free fall. It is weightless.



The "curvature" of the space-time structure due to a mass-rich object causes a object of lesser mass moving on a linear course to deviate from its path.

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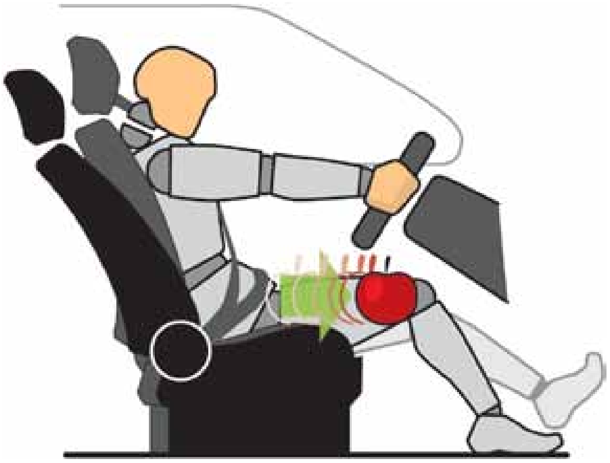
Inertial Force

Inertial forces are also called apparent forces. Centrifugal, centripetal, and Coriolis forces are among the inertial or apparent forces. When describing a force's action, the need to identify an apparent force depends on whether the observer and the observed object are located in the same reference system.

As an example, let us use an apple which is sitting next to you on the passenger seat in a car. You are driving at a constant speed and the apple, like you, is at rest with reference to the car. You can see that the apple is not moving on the seat. If you now brake abruptly, the apple flies off in the direction of travel while you are restrained by the seat belt. From your point of view, the apple's state of motion changes while yours remains the same.

The apparent change in motion of the apple leads us to conclude that there must be a force acting on the apple that causes it to move relative to the reference system of the car. This is inertial force. It is also referred to as inertia or a body's effort to retain its state of motion.

The perception is different from the perspective of an observer that you pass on the road as you brake. While you undergo negative acceleration due to the braking force because you are firmly connected to the braking car by the seat belt, the apple continues forward at constant speed because no braking force is acting on it. From the outside observer's point of view, your state of motion changes while that of the apple remains the same. The observer does not need to identify an inertial force to explain the behavior of the apple.



From the point of view of the driver, the apple is accelerated on braking due to its inertial force.

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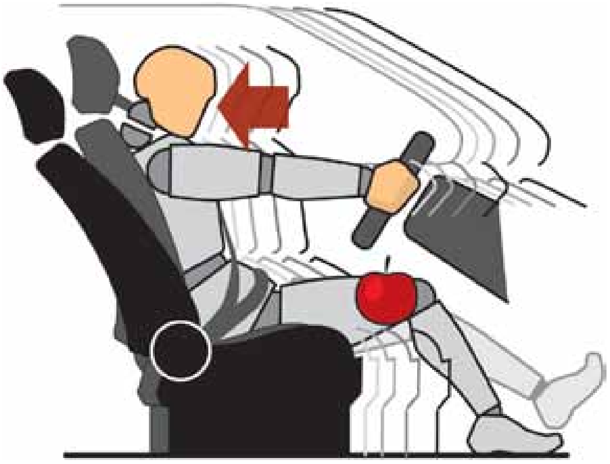

To an outside observer, the driver and car are decelerated (negatively accelerated) due to the braking force, while the apple retains its state of motion virtually force-free.

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From the point of view of the driver, who is located in the same reference system as the apple, a force that accelerates the apple outwards must exist during cornering.

s501_011

Centrifugal Force

When observing a rotating reference system, a force that pulls an object away from an observer appears to exist.

We will continue with the example of the apple on the passenger seat in the car. As you drive into a curve, the apple on the seat moves away from the center of rotation of the curve, while you counteract this pull using the seat belt and your physical posture. From your point of view, the apple is accelerated outwards by the centrifugal force.

In order for an apple to remain at rest during cornering from the point of view of an observer, an opposing centripetal force (red) of the same magnitude as the centrifugal force (green) pulling the apple outwards must exist.

s501_012

Centripetal Force

One of the basic principles of Newtonian mechanics is that a body is at rest when the sum of all forces acting on it is equal to zero. In order for a body to remain at rest, a counterforce must exist for each acting force. If a body is located in a rotating reference system, a centrifugal force which accelerates it outwards acts on it, with the result that it moves relative to the reference system. This force acts as long as the reference system executes the rotation. If, however, the body remains at rest in relation to the observer, a counterforce which is equally as large as the centrifugal force must exist. This is the centripetal force.

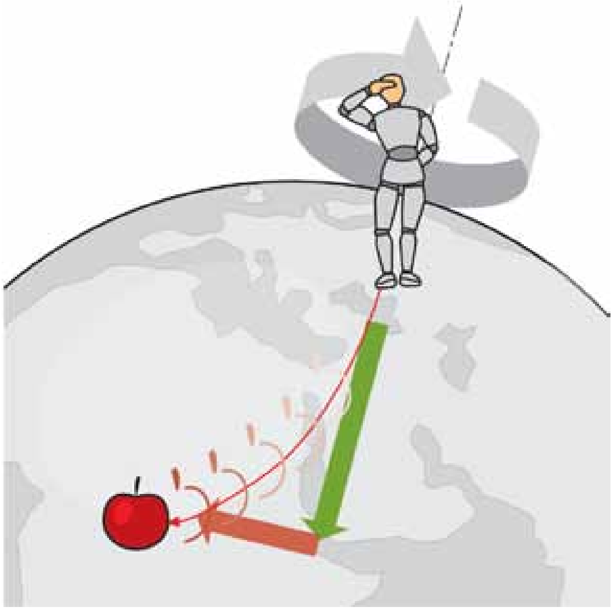
Coriolis Force

The Coriolis force is an inertial or apparent force. The apparent change in motion occurs when a body moves in relation to a rotating reference system.

A Coriolis force acts during both vertical and horizontal motion of a body within this rotating reference system. Its observed effects are determined by the rotational direction of the reference system.

If the earth is the reference system, the Coriolis force is caused by the earth's rotation. It acts on all moving objects on the earth.

The Coriolis force plays an important role in the dynamics of weather and ocean currents.



For an observer on the earth, it appears that a force that diverts an apple thrown in a straight line must exist: the Coriolis force.

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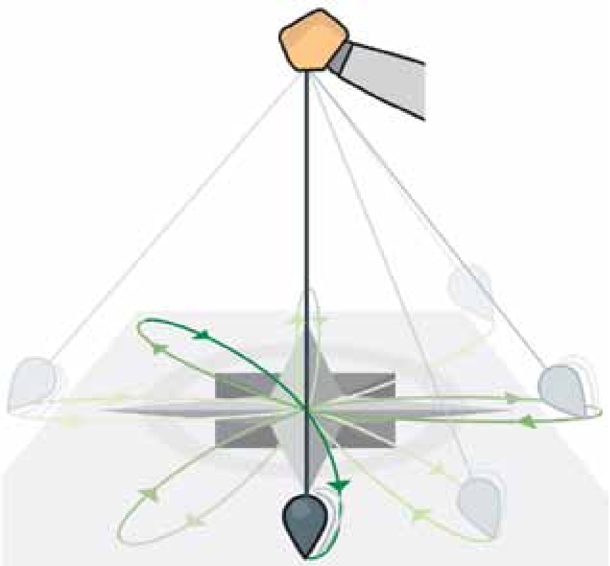
The effect of the Coriolis force can be seen using a swinging pendulum on a long wire (a Foucault pendulum). In the northern hemisphere, the Coriolis force causes the pendulum to shift to the right as it swings back and forth. As it swings, the pendulum's plane of oscillation is rotated clockwise.

In sensor technology, the Coriolis force plays a role in the measurement of yaw rates and mass flows.



The effect of the Coriolis force can be shown using a Foucault pendulum. The plane of pedulum oscillation rotates 360° once in 24 hours. As a result of this, the pendulum describes a pattern of overlapping ellipses.

s501_014

Uniform and Non-Uniform Motion

We use the term uniform motion when a body moves at a constant speed. If additional acceleration takes place to change the body's speed, we call this non-uniform motion. If this acceleration is constant, we describe the result as uniformly accelerated non-uniform motion.

As long as the rocket motor is running, the rocket continues to be accelerated. Its speed increases. This is a non-uniform motion.

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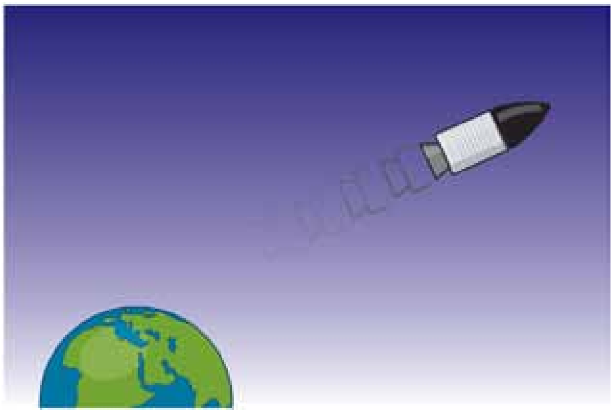


After the rocket motor has been shut off, the rocket glides through space without additional acceleration. It now flies at a constant speed (as long as other effects such as gravitational influences are disregarded). This is uniform motion.

s501_016

The laws of Newtonian mechanics are usually precise enough to describe the motion of objects that we perceive in our daily lives. Only in cases of very large and very small masses (black holes, elementary particles), and very high speeds (close to the speed of light), are Newton's laws no longer sufficient to get results that correspond to the observations.

Einstein's general or special theory of relativity must be used to describe large masses and high speeds.

Quantum mechanics are used to describe very small masses and high speeds.

What is Energy?

Mass and Energy

Einstein postulated that mass and energy are equivalent, defining the concept in his world famous equation $E=mc^2$ (energy equals mass times the speed of light squared). The vast amount of energy that is bound up in matter became clear when the first atomic weapon tests were conducted.

In classical mechanics, energy is understood as a physical variable that is capable of performing work.

Forms of Energy

Depending on which branch of the natural sciences is concerned, different definitions are used for energy or forms of energy. Different terms are used depending on what is being investigated.

The kinetic energy that a body contains as a result of acceleration requires a definition or physical derivation. This differs from the description for the energy that has to be applied to create or break a chemical bond.

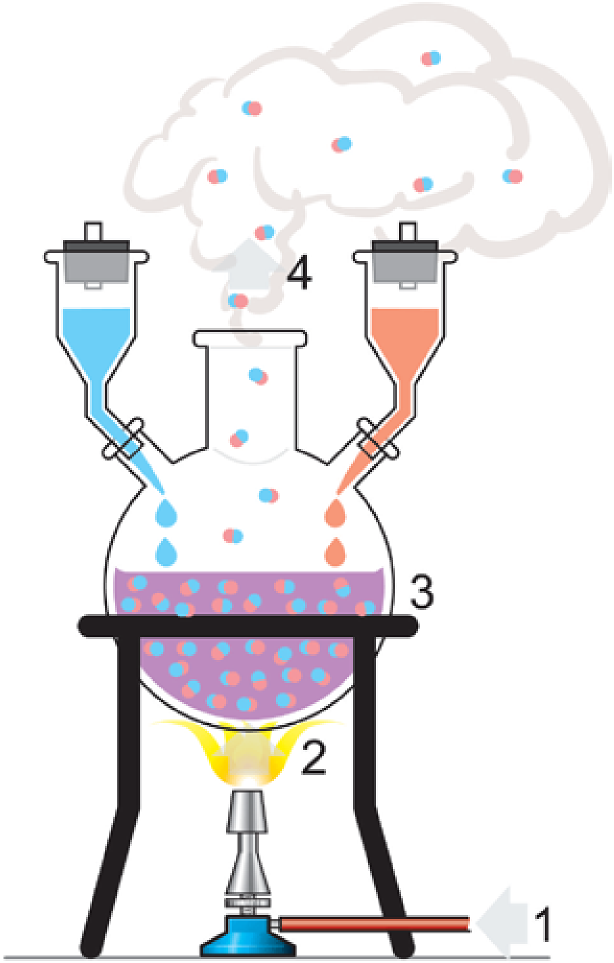
Regardless the individual definition of any form of energy, in the final analysis all forms of energy can be converted into each other (at least mathematically). They are equivalent like the mass and energy in Einstein's formula.

In terms of practical application this equivalence is limited. Side-effects or interactions usually lead to either "energy devaluation" (apparent energy losses) or conversion to another form of energy that may be technically impossible or too complex.

Just a few of the energy terms used to describe measurement techniques or basic physical concepts in this series will be briefly explained here.

They are:

- Potential energy
- Kinetic energy
- Thermal energy
- Chemical energy



Examples of different forms of energy:
1 - Chemical energy bound in the burner gas
2 - Thermal energy in the burner flame
3 - Kinetic and bonding energy during the two reactants' chemical reaction
4 - Kinetic energy of the vapor molecules

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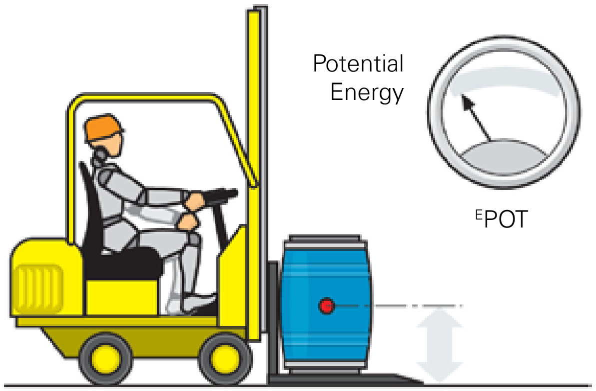
Potential Energy



The body's potential energy (^{E}POT) is low.

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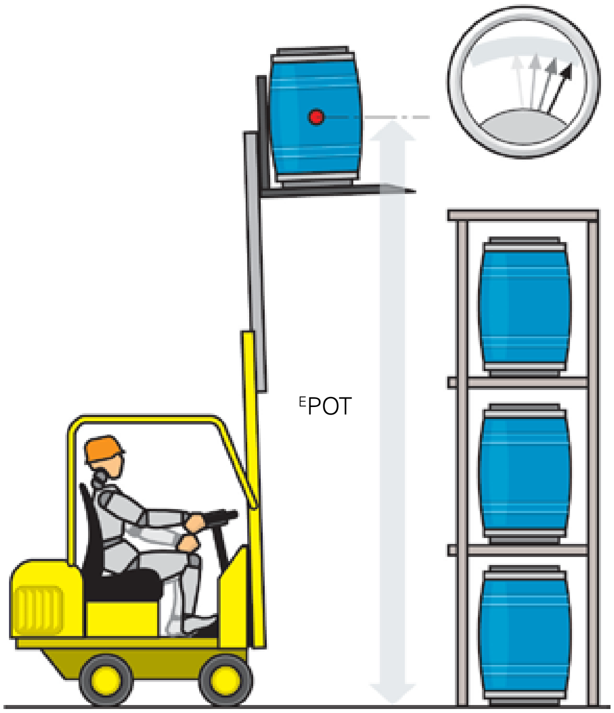
If a body at rest on the floor is raised up, such as when a barrel is lifted by a fork-lift truck and placed on a shelf, its amount of potential energy has increased by the amount of energy that the fork-lift truck used to lift it.



The barrel's potential energy increases by an amount equivalent to the amount of work the fork-lift truck performs when lifting the body.

s501_019

This potential energy is defined as the amount of energy added to a body due to its change in location with reference to a surrounding force field (usually a gravitational field — in this case the earth's gravitation).

If the location of the body changes in the direction in which the gravitation acts, such as falling down, its potential energy decreases.

If it gains height against the gravitational force, its potential energy increases.

If the location of the body changes perpendicular to gravitation, staying at the same height from the earth's surface, its potential energy remains constant.

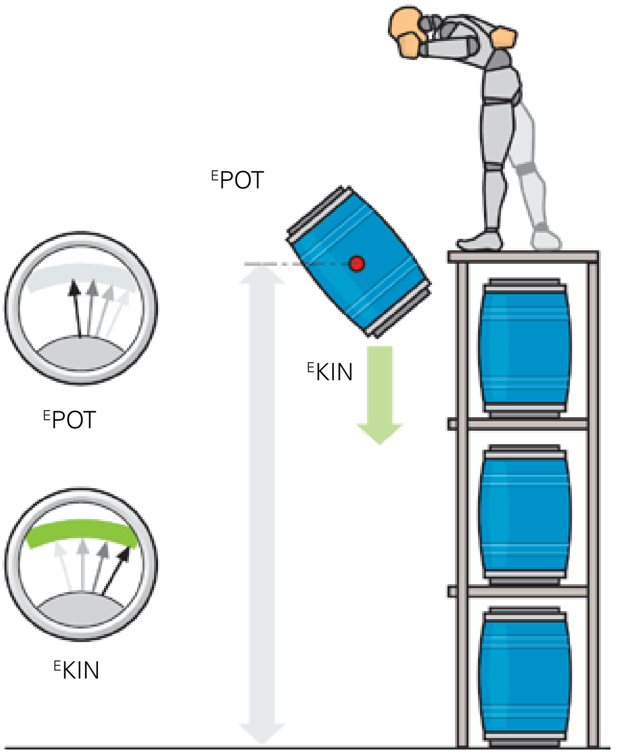
If the body drops down from the shelf, its potential energy is gradually transformed into kinetic energy during free fall.

What is Energy?

Kinetic Energy

Kinetic energy is the energy "contained" in a state of motion. The more a body is accelerated and the higher its speed then becomes, the greater is its kinetic energy. If no outside forces act on the body and no energy losses occur, such as those due to friction, its kinetic energy remains constant and its speed does not change.

If a body loses speed due to friction, part of its kinetic energy is transformed into thermal energy.



The body's potential energy (^{E}POT) decreases to the extent that the kinetic energy (^{E}KIN) increases during free fall as a result of gravitational acceleration.

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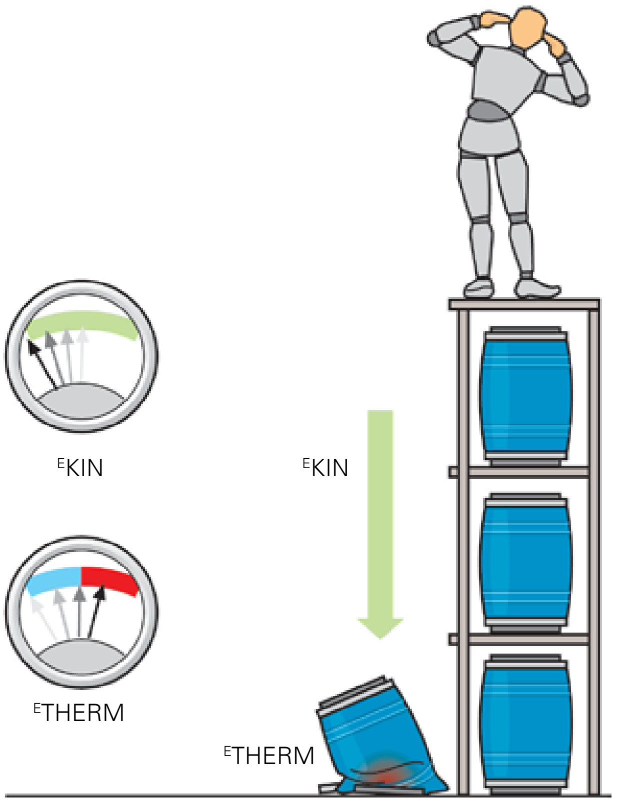


Due to the deformation forces that occur on impact, part of the kinetic energy (^{E}KIN) is transformed into thermal energy (^{E}THERM).

s501_021

Thermal Energy

In simplified terms, thermal energy (also called heat energy) is based on the motion of a body's atoms.

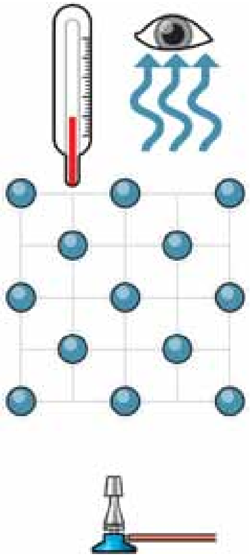
The more thermal energy that is transferred to the body, the more the atoms (and therefore its molecules) begin to oscillate in their position in the body's structural lattice.

Each heated body attempts to get rid of the thermal energy that has been supplied to it in order to return to a lower-energy and more stable thermodynamic state.

One way this happens is by the atoms dissipating surplus energy into the environment in the form of electromagnetic radiation. Depending on the characteristics of the material, we can feel this as heat and possibly see it as a glow.

If the energy supplied exceeds a specific value for the material in the body, the atoms are released from the body's structure. The material melts or evaporates.

If enough thermal energy is applied to a mixture of atoms under the right conditions, the atoms may bond differently to form new molecules. When this happens, thermal energy is transformed into chemical binding energy.



Without an energy supply, the body is at ambient temperature. Its structural lattice elements (atoms combined into molecules) oscillate slightly at their lattice sites. Only at a temperature of absolute zero (0 K; -459.67°F; -273.15°C) would the lattice elements stop moving altogether.

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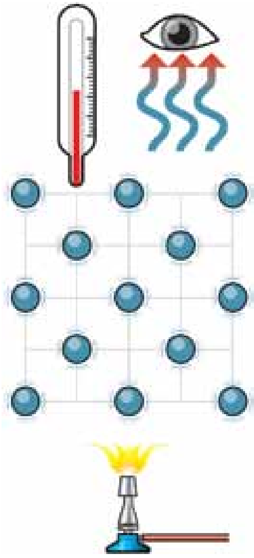

As the body is heated, its temperature increases. The motion of the lattice elements increases. The body begins emitting electromagnetic radiation as infrared radiation (heat) and possibly light (glowing).

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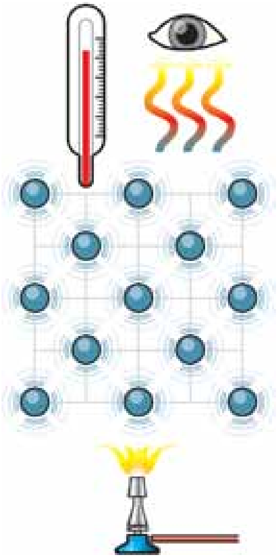

As the energy supply and motion of the lattice elements increase, electromagnetic radiation increases.

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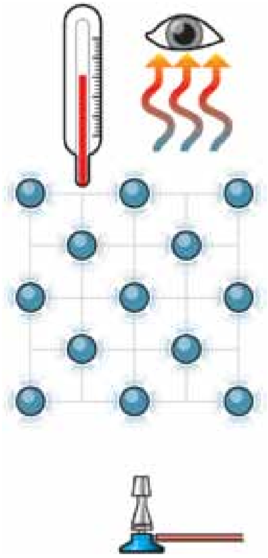


When the supplied heat energy is stopped, the body continues to emit electromagnetic radiation until it reaches ambient temperature again.

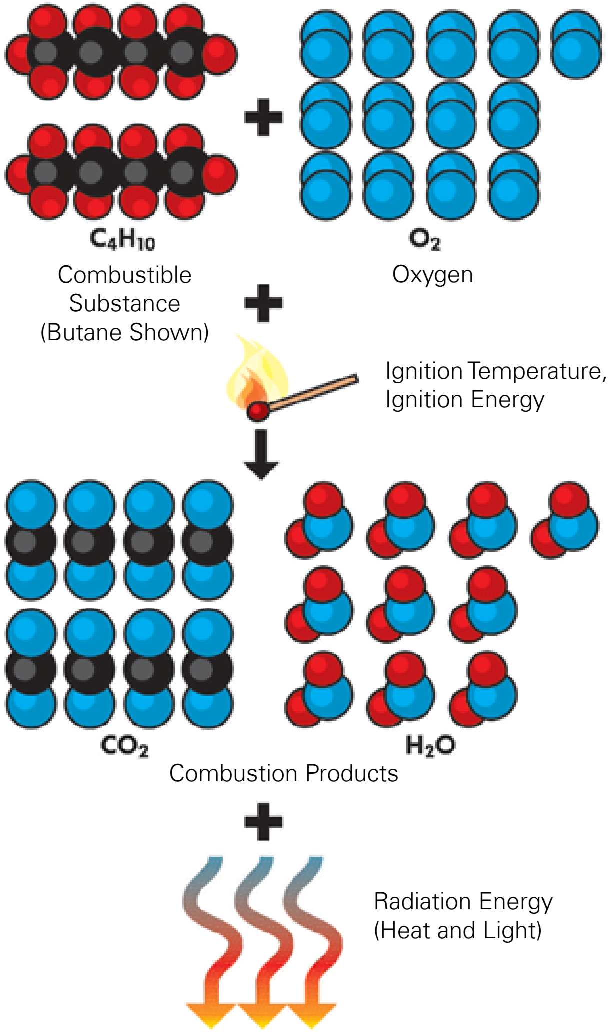
s501_026

What is Energy?

Chemical Energy

Chemical energy or binding energy corresponds to the amount of energy that is needed to bond the involved substances (atoms or molecules).

If these bonds are broken apart, such as during fuel combustion, part of this binding energy is released as thermal energy and can be used to carry out work (as in the combustion engine for example).



Due to the combustion (oxidation) of a combustible substance, part of the chemical binding energy stored in the substance is released as heat.

s501_027

Conversion of forms of energy and conservation of energy

Energy can be converted into completely different forms. It is important to remember the concept that no energy can be lost during this conversion.

Take for example the function of a combustion engine. It converts chemical energy from fuel into kinetic energy. There does not seem to be complete combustion and energy appears to have been lost. This apparent loss is due to the fact that some of the chemical energy that is released by combustion is converted into thermal energy and other forms of energy.

The sum of all of these forms of energy are the same as the original amount of chemical energy.

Example of Angular Momentum

A body's behavior or movement may appear to change without any external influence.

Consider an ice skater performing a pirouette. In this example, angular momentum is a form of kinetic energy.

If the skater begins the pirouette with his arms outstretched, then pulls his arms inward towards his body, his rotational speed increases without other forces acting externally to increase acceleration. How does this change occur?

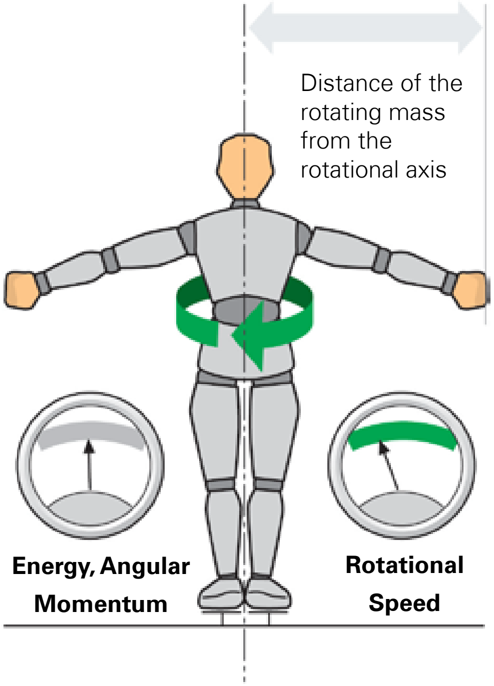
The ice skater gives himself a certain angular momentum when he starts his pirouette. His angular momentum is dependent on three things:

1. His mass.
2. His rotational speed.
3. The distance between his total rotating mass and his rotational axis.

By pulling his arms in, the skater reduces the distance of his total rotating mass from his rotational axis.

To satisfy the law of conservation of energy (in this case to conserve angular momentum), at least one of the two other variables must change.

Since the skater's weight (mass) remains the same, his rotational speed has to increase to compensate for the decrease in the distance of his total rotating mass from his rotational axis.



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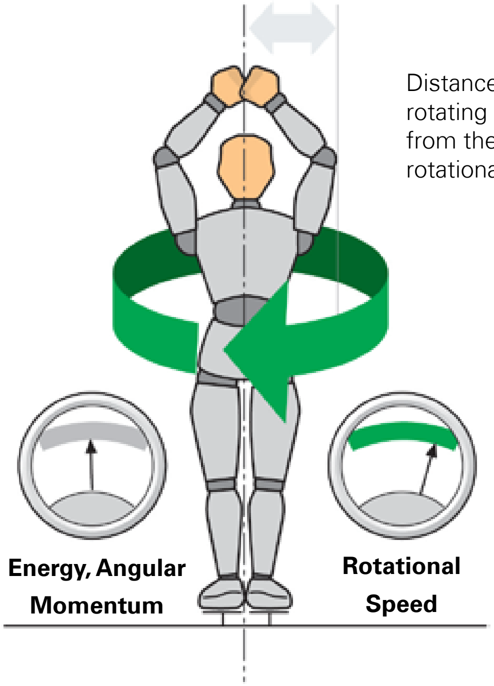

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To fulfill the principle of energy conservation, the rotational speed of the pirouettes must increase if the distance between the total rotating mass and the rotational axis is reduced.

What is Matter?

Foundations of Atomic Theory

According to Einstein's $E=mc^2$ equation, matter can be perceived as solidified tangible energy. But, this does not explain what matter actually is.

Even the ancient philosophers assumed that all things around us are made up of certain types of the same basic substances. What these basic substances were was subject to doubt and disagreement.

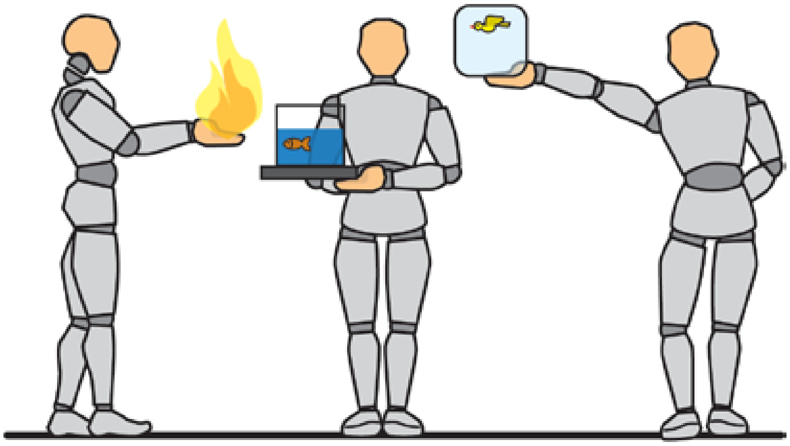
Heraclitus was of the opinion that everything had originated from fire. Thales decided that water was the basic or primordial substance. Anaximenes attributed everything to gas (air).

Empedocles pronounced that all things consisted of fire, water, earth, and air. Empedocles' opinion was upheld well into the Middle Ages. This led to attempts by alchemists to obtain gold or the philosopher's stone from these basic substances.

According to our current knowledge, Democritus, another ancient philosopher, was closest to the mark. Together with his teacher Leucippus, he presented the opinion that everything was formed from the same types of atom — units of matter that cannot be broken down any further. This roughly corresponds to our present concept of matter.

However, it was later demonstrated that Democritus' atoms could in fact be broken down further. This resulted in our current theories about the structure of matter that look deep into the atom and define new, even smaller elementary particles.

There is not just one "type of atom" (element) that makes up matter with the aid of elementary particles. Instead, there are now 118 elements that we have identified. Of these, only the first 83 are stable. The other 35 elements are radioactive, and break down into other types of atoms while emitting radiation and/or subatomic elementary particles. Many of these radioactive elements can only be generated artificially for very short periods of time in a laboratory using a particle accelerator.



The ancient natural philosophers attributed the elements of matter to different basic substances such as fire, water, or air.

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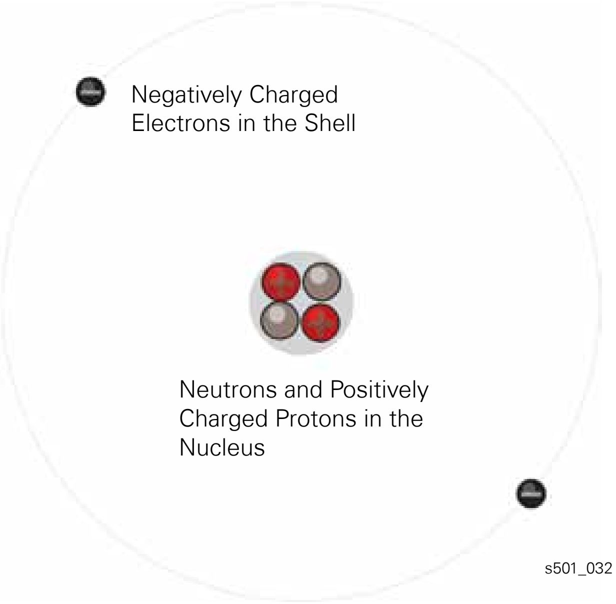
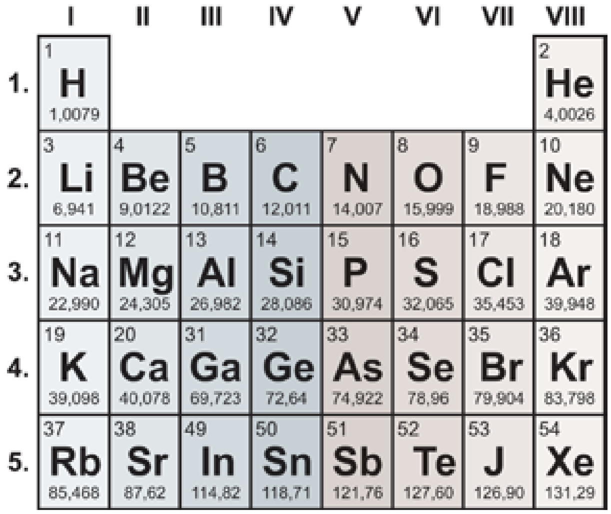
Basic Structure of Elements



Structure of an atom using helium as an example

Each atom consists of electrons, protons and neutrons. These consist of even smaller elementary particles (quarks, bosons, muons, etc). Protons and neutrons form the nucleus and the center of an atom's mass. The size of the nucleus is very small in comparison with the diameter of the atom. The much smaller and lighter electrons form the shell of the atom. This makes up the majority of the atom's volume. An atom includes an extremely small and heavy nucleus with a great deal of "nothing" surrounding it.

Protons carry a positive charge, electrons a negative charge. Neutrons have no electrical charge. In order for an atom to be electrically neutral, it must have the same number of protons and electrons.



	I	II	III	IV	V	VI	VII	VIII
1.	1 H 1,0079							2 He 4,0026
2.	3 Li 6,941	4 Be 9,0122	5 B 10,811	6 C 12,011	7 N 14,007	8 O 15,999	9 F 18,988	10 Ne 20,180
3.	11 Na 22,990	12 Mg 24,305	13 Al 26,982	14 Si 28,086	15 P 30,974	16 S 32,065	17 Cl 35,453	18 Ar 39,948
4.	19 K 39,098	20 Ca 40,078	31 Ga 69,723	32 Ge 72,64	33 As 74,922	34 Se 78,96	35 Br 79,904	36 Kr 83,798
5.	37 Rb 85,468	38 Sr 87,62	49 In 114,82	50 Sn 118,71	51 Sb 121,76	52 Te 127,60	53 J 126,90	54 Xe 131,29

Excerpt from the periodic table of elements.
The elements of the 8 main groups are shown up to the 5th period.
Depending on the design of the periodic table, each box specifies the:

- International abbreviation (as in "Be" for beryllium).
- Atomic number (at the top left of the box in this case).
- Atomic mass (bottom center here).

The periodic table of elements is structured with all the known elements laid out according to:

- The number of protons in their atom’s nucleus (their atomic number)
- Their chemical bonding behavior determined by the atom’s outer electrons (valence electrons)

Elements cannot be broken down any further by chemical processes. This corresponds to Democritus’ concept of atoms as the smallest components of matter.

Atoms of an element with the same number of protons but a different number of neutrons are called isotopes, as they are located in the same position in the periodic table of elements (iso = same, topos = location).

What is Matter?

Models of Atomic Theory

There are different models and theories regarding the precise subatomic structure of elements. A shell or planet model based on the work of Ernest Rutherford and Niels Bohr is very clear. Protons and neutrons can be imagined in a sun-like nucleus which is circled by the electrons, in the same manner as planets on fixed trajectories.

However, this concept is unable to explain the failure of one special effect to materialize:

According to classical electrodynamics, a charge carrier running on a circular track emits electromagnetic radiation — it loses energy. Due to the law governing the conservation of momentum, this should lead to the electron's collapsing into the nucleus. Obviously this does not occur. If it did we would not exist.

Niels Bohr developed the concept that the electrons must have special shells or energy levels at which they do not emit radiation. This non-linear aspect concerning the structure of matter was confirmed in experiments and further developed by Max Planck, the founder of quantum theory.

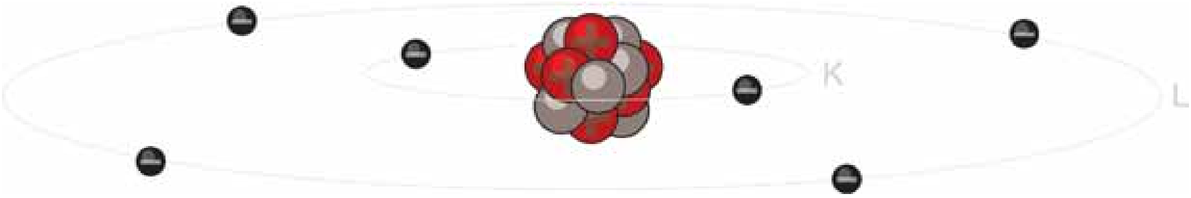
Quantum theory does not portray elementary particles like electrons as concrete particles, specifying a location and a velocity. Instead, they are viewed in the form of highly-complex probability functions.

This is because location and velocity cannot be determined simultaneously within this order of magnitude (an application of the Heisenberg uncertainty principle — the act of observation affects the results).

The statement is no longer "Here is an electron and it has this velocity" but rather "An electron may perhaps be here, and if this is its location, I cannot determine its velocity here".

Relationships that are clear to us, such as cause and effect, also lose their clarity at quantum level. That is why this theory is beyond the comprehension of most people.

Niels Bohr, the co-founder of quantum theory, stated: "Whoever is not appalled by quantum theory hasn't understood it". And even Albert Einstein, whose research into the photoelectric effect contributed extensively to the emergence of quantum theory, said in regard to certain aspects of quantum mechanics: "God does not play dice".



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According to the shell or planet model, an atom's electrons orbit the nucleus like planets orbit a sun. The model of a carbon atom is pictured above, with 6 protons and 6 neutrons in the nucleus, plus 6 electrons in the shell.

A specific number of electrons assume a defined "stable" electron orbit (electron shell), where the electrons are able to circle the nucleus without emitting radiation.

The innermost shell is the K-shell, which has a maximum of 2 electrons, followed by the L-shell with a maximum of 8 electrons (filled with 4 out of 8 possible electrons in the case of carbon).

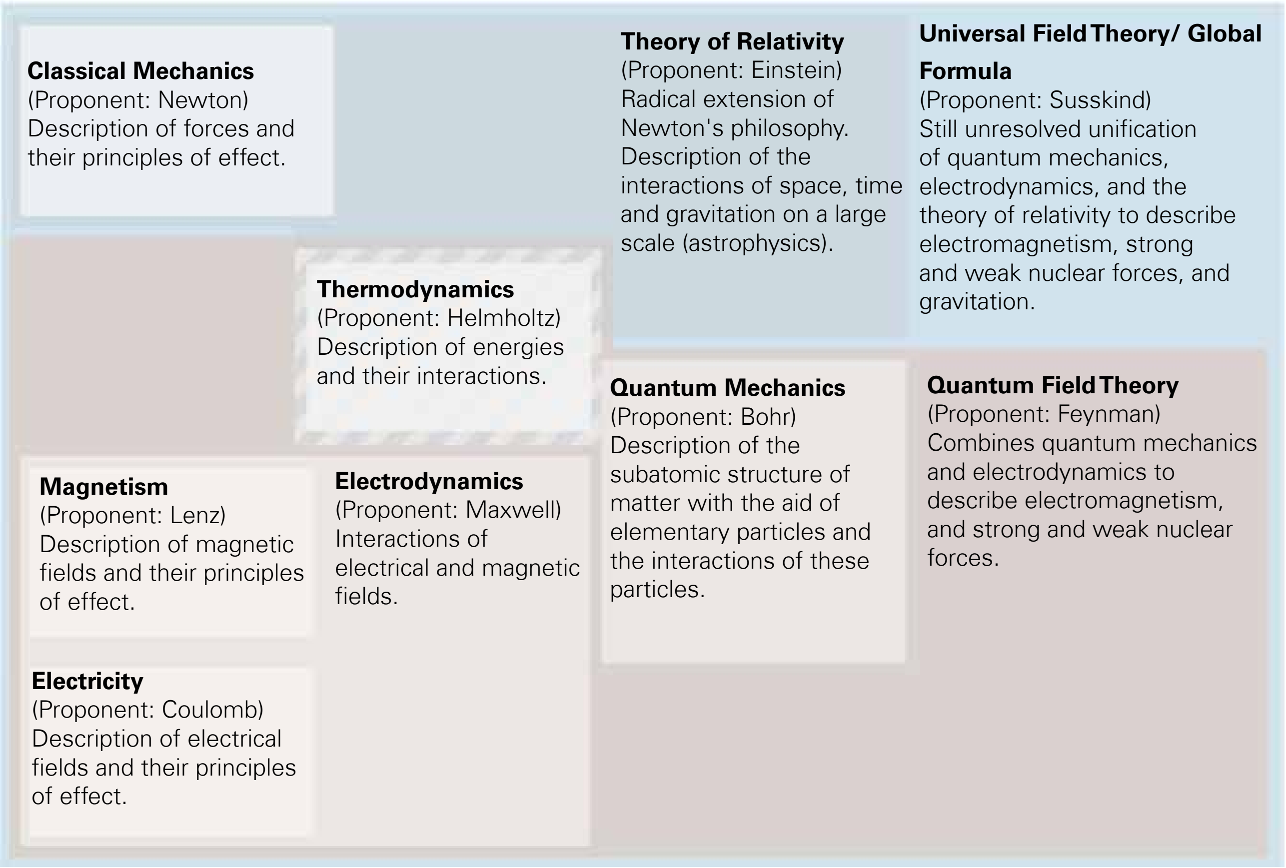
Additional shells are added in elements from higher periods (for example, sodium).

At a subatomic level, many of the electrical and electronic devices (computers, sensors, chip cards, etc.) that are used in automotive engineering function according to rules that are better described by quantum theory than by the classical theories. We should at least be aware that this theory exists and that it is particularly suitable for describing processes in the subatomic size range.

Even prior to Einstein, the trend in pure physics research was shifting towards combining all elementary variables in a unified field theory or "global formula". This effort may correspond to the alchemists' ancient dream of the all-explaining and eternal life-giving philosophers' stone.

From a modern point of view, the string or superstring theory (M theory) is a promising approach to a unified field theory. With this, success may be achieved by integrating gravitation into a new theory and placing quantum mechanics and the theory of relativity on a common mathematical footing.

The science dealing with the precise structure of matter and its origin remains exciting.



Classical Mechanics
(Proponent: Newton)
Description of forces and their principles of effect.

Theory of Relativity
(Proponent: Einstein)
Radical extension of Newton's philosophy. Description of the interactions of space, time and gravitation on a large scale (astrophysics).

Universal Field Theory/ Global Formula
(Proponent: Susskind)
Still unresolved unification of quantum mechanics, electrodynamics, and the theory of relativity to describe electromagnetism, strong and weak nuclear forces, and gravitation.

Thermodynamics
(Proponent: Helmholtz)
Description of energies and their interactions.

Quantum Mechanics
(Proponent: Bohr)
Description of the subatomic structure of matter with the aid of elementary particles and the interactions of these particles.

Quantum Field Theory
(Proponent: Feynman)
Combines quantum mechanics and electrodynamics to describe electromagnetism, and strong and weak nuclear forces.

Magnetism
(Proponent: Lenz)
Description of magnetic fields and their principles of effect.

Electrodynamics
(Proponent: Maxwell)
Interactions of electrical and magnetic fields.

Electricity
(Proponent: Coulomb)
Description of electrical fields and their principles of effect.

A simplified overview of the various physics theories.

s501_034

What is Matter?

Subatomic Variables Influencing Sensor Technology

Some sensor technology measurement processes are based on characteristics of the subatomic elements of matter — electrons, protons, quarks, etc. These are also referred to as quantum-mechanical characteristics of matter (electron spin, for example). The examples of these concepts used in this SSP are simplified for easier understanding.

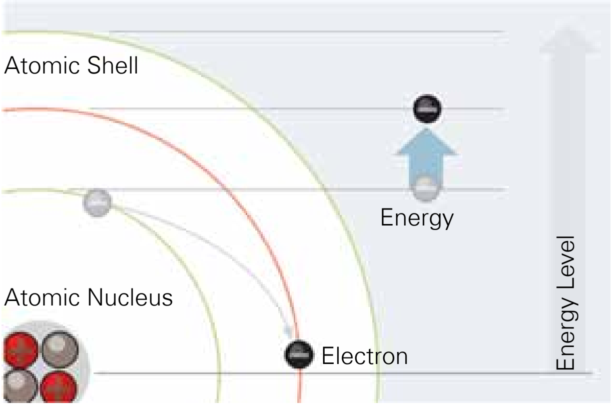
Normally, all physical systems including atoms and their components attempt to take on a state that uses as little energy as possible. A low-energy state is more thermodynamically stable than a higher-energy state. This behavior is used in some measurement methods, such as tomography, by artificially supplying particles with energy so that they make the transition to an excited higher-energy state. To return to the more stable lower-energy state, these particles must rid themselves of their "surplus" energy by emitting radiation or by changing their quantum characteristics. This can be measured using specific sensors.

Example of an electron:

An atom's electrons are distributed among certain "stable" energy levels or shells. These are referred to as "permitted" energy levels at which, according to Bohr, the electrons can continue to orbit without collapsing into the nucleus.

A suitable energy supply can be used to excite the electrons to jump to a higher "permitted" energy level. This process is called a quantum leap. The quantum leap has transferred the electron to an energy-richer and thermodynamically less favorable state.

The excited electron attempts to rid itself of the energy as quickly as possible by emitting electromagnetic radiation so that it can return to the lower and more stable energy level. The radiation that is emitted can be qualitatively and quantitatively measured using special sensors. The data can be used to draw conclusions regarding the measurements.



By supplying energy, the electron is raised to a higher energy level (quantum leap).

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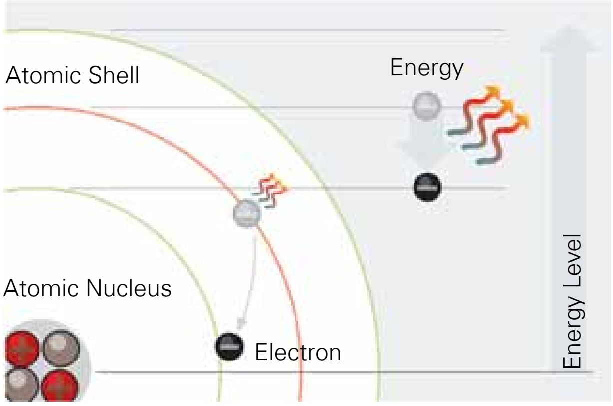

To return to the lower energy level, the electron emits energy.

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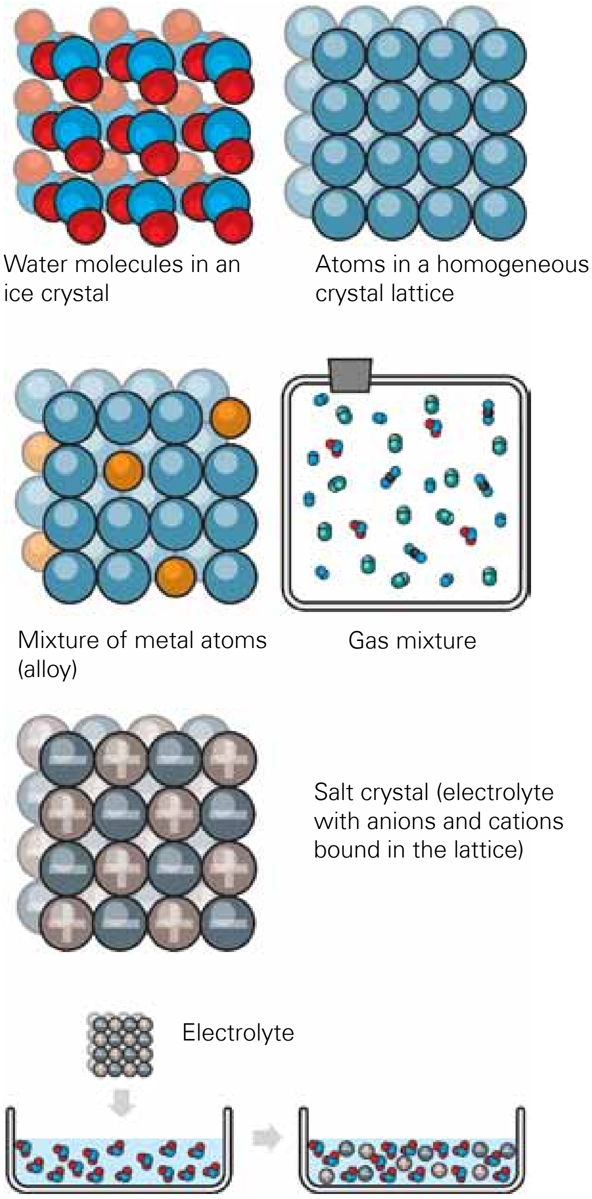
Mixtures, Compounds, Elements, and Ions



Water molecules in an ice crystal

Atoms in a homogeneous crystal lattice

Mixture of metal atoms (alloy)

Gas mixture

Salt crystal (electrolyte with anions and cations bound in the lattice)

Various forms of matter.

Atoms or elements can be integrated into matter in various ways. Matter may be homogeneous, consisting of a single type of atom. Under standard conditions of 68°F and 14.5 psi (20°C and 1 bar), these atoms form a solid in a lattice structure (such as carbon), or a gas (like helium), or a liquid (like bromine). Atoms can also form chemical bonds with other types of atoms. Different types of atoms bonded together are called molecules.

Molecules may be composed of just a few atoms, such as water (H_2O) for example, or a very large number of atoms such as protein molecules.

Matter may also be heterogeneous. That means it can consist of a mixture of elements, a mixture of elements and compounds, or a mixture of various compounds.

If we want to describe matter or its behavior, it is important not to confuse these three terms:

- Element
- Compound
- Mixture

If an atom or molecule loses one or more electrons, or takes on additional electrons from other atoms, the electrically charged particles that occur are called ions.

If electrons are added, a negatively charged ion, an anion, is created.

If the atom or molecule loses electrons, a positively charged particle, a cation, is created.

Many metal salts (electrolytes) can be broken down into cations and anions by being dissolved in water.

What is Magnetism?

Types of Magnetism

Magnetism is a part of electrodynamics. It describes a dynamic effect that can be observed in moving electrical charges, in conductors through which current flows, and between magnetized or magnetizing objects. Magnetism is based on the magnetic characteristics of elementary particles or the movement of electrical charges. The presence of magnetism is expressed in a force field, the magnetic field. Depending on their orientation and strength, magnetic fields can intensify, weaken, or neutralize each other entirely.

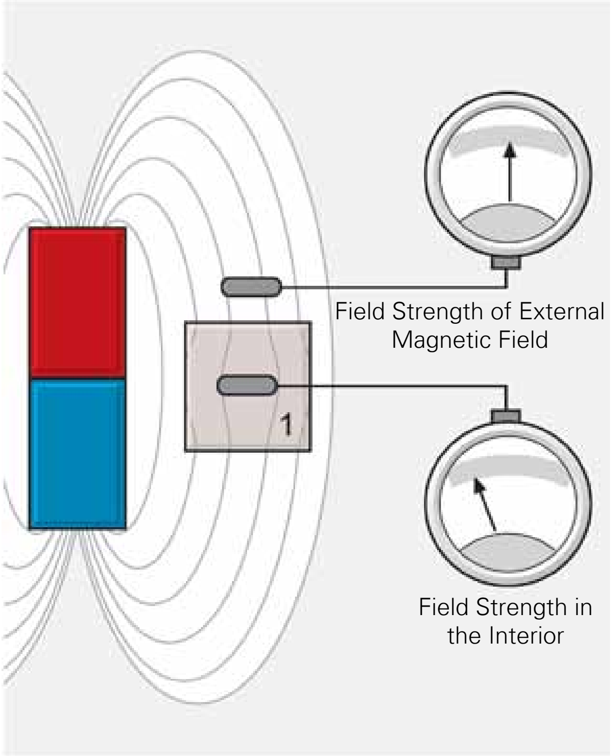
Five different types of magnetism occur in solids:

- Diamagnetism
- Paramagnetism
- Ferromagnetism
- Ferrimagnetism
- Antiferromagnetism

In this SSP we intend to briefly explain only the first three types of magnetism. Interactions of these types of magnetism play a role in certain measurement processes in sensors such as inductive and Hall senders.

Diamagnetism

A substance is called diamagnetic if it weakens a magnetic field that penetrates it. This effect occurs because the magnetic field induces a current in the electron shells of the substance's atoms. This current in turn generates a magnetic field. Due to Lenz's law, this "internal" magnetic field is opposed to the external magnetic field and the strength of the external magnetic field is reduced in the interior of the substance. Diamagnetism occurs in all substances (atoms, molecules, ions) that do not have any single (unpaired) electrons in their shells.



Diamagnetic substances (1) weaken an external magnetic field in their interior.

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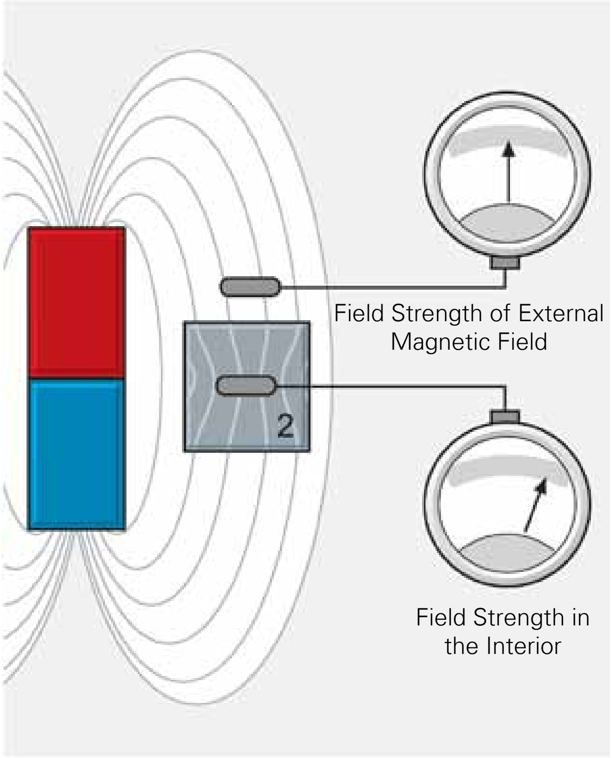
Paramagnetism



Paramagnetic substances (2) intensify an external magnetic field in their interior.

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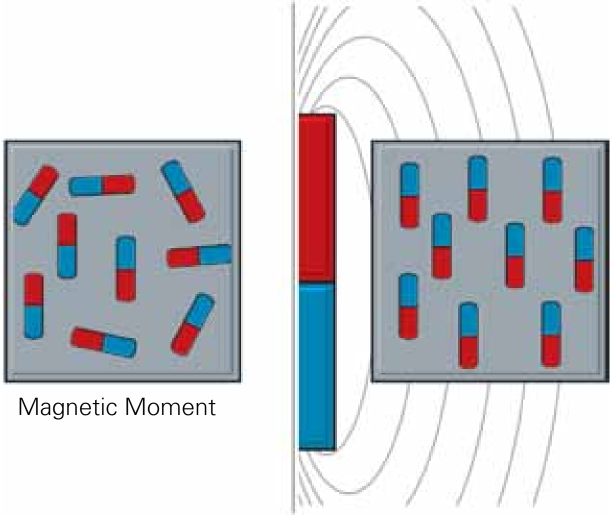
A substance is called paramagnetic if it intensifies a magnetic field that penetrates it.

This effect occurs because the components of the substance (atoms, molecules, ions) possess magnetic characteristics. The substance does not show its own internal magnetic field because its magnetic field does not have order and neutralizes itself.



The magnetic moments of the paramagnetic substance's components are oriented to the external magnetic field.

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If an external magnetic field is applied, the components of the substance are oriented parallel to the external magnetic field. The strength of the external magnetic field increases in the interior of the substance. If the external magnetic field is removed, the paramagnetic substance's internal magnetic field collapses as the components' parallel orientation is dissolved.

Because this temporary orientation of the substance's components is temperature-dependent, paramagnetism decreases as the temperature increases. This is due to the fact that the components (atoms, molecules, ions) begin to oscillate more intensively at their lattice sites as the temperature increases, and cannot then be oriented easily in a magnetic field.

What is Magnetism?

Ferromagnetism

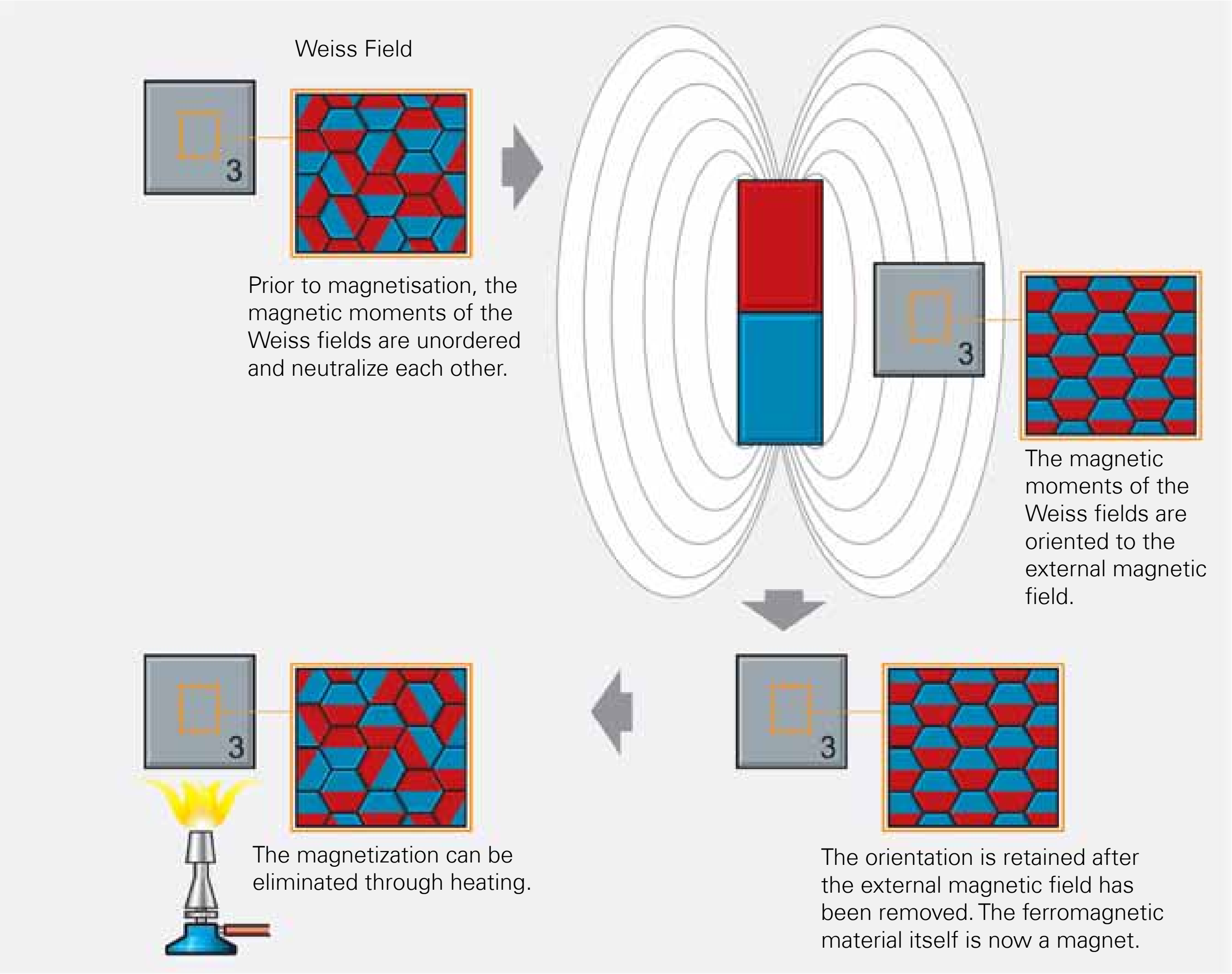
A substance is called ferromagnetic if it retains magnetic orientation after an external magnetic field has been removed. The substance is magnetized and reveals the characteristics of a permanent magnet.

As in the case of paramagnetism, the substance's individual particles possess their own magnetic moment.

In ferromagnetic substances these particles and their magnetic moments are already aligned in parallel in small areas of the substance, called Weiss fields.

On the whole, these fields' magnetic moments neutralize each other, with the result that the substance does not initially appear to be magnetic. If an external magnetic field is applied, the Weiss fields become aligned parallel to the external magnetic field and the substance itself has a magnetic field.

This induced magnetic field is retained by the ferromagnetic substance even after the external magnetic field has been removed. The substance can be demagnetized again by heating or by mechanical impact, which removes the induced magnetic field.



Ferromagnetic substances (3) retain their magnetic characteristics even after the external magnetic field has been removed.

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What is Magnetism?

Magnetic Fields

A magnetic field can be generated by magnetic or magnetized materials, by electrical currents in electrical conductors, or by the temporal change in an electrical field.

The points at which a magnetic field enters and exits a magnetized substance are called poles. They are referred to as the north and south poles depending on their orientation to the earth's magnetic field. These poles are opposed to each other. This means that poles with the same orientation (north to north, or south to south) repel each other and poles with different orientations (north to south) attract each other.

Field Strength

A body's magnetic field is the area where the magnetic force acts. As the distance from the object causing the magnetic field increases, its strength or its effect decreases.

The strength of a magnetic field is described using two physical variables: the magnetic field strength and the magnetic flux density.

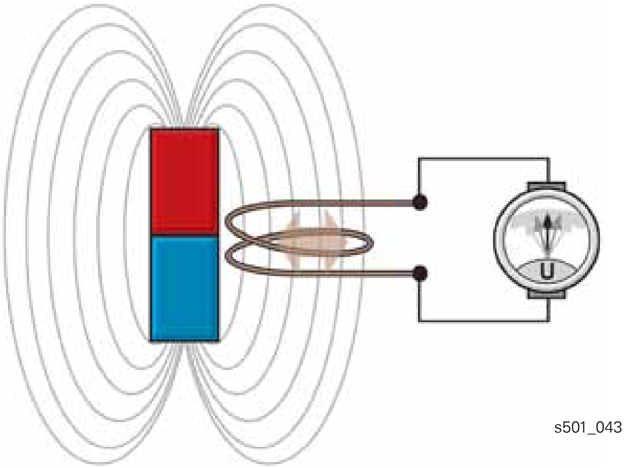
Induction

Because a moving electrical charge builds up its own magnetic field it will interact with an applied external magnetic field. This results in the moving charge experiencing a force.

This force that a magnetic field exercises on a moving electrical charge is called the Lorentz force. It acts perpendicular to the orientation of the magnetic field's lines of electrical flux and perpendicular to the electrical charge’s direction of movement.

When the Lorentz force acts on electrical charges in a conductor, a current is generated in the conductor. This process is called induction. It forms the basis of the function of generators.

Induction is also used in various sensor technologies.



When an electrical conductor is moved through a magnetic field, the Lorentz force that acts on the conductor's free electrons induces a current.

The result is a measurable electrical voltage in the conductor.

What are Electromagnetic Waves?

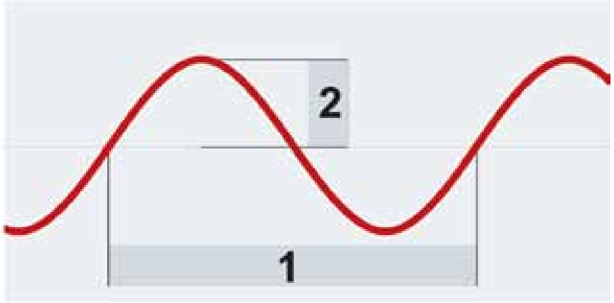
Electrodynamics

The field of physics that deals with electromagnetic waves and electromagnetic interactions is called electrodynamics. Electrodynamics is based extensively on the research conducted by James Clerk Maxwell in the 19th century. It was combined with quantum mechanics to form quantum electrodynamics in the mid-20th century.

Electrodynamics investigates and describes the interaction between electrical and magnetic fields. Both electrical fields (such as those within capacitors or coils) and magnetic fields (such as those around conductors and coils through which current is flowing) are bound to the object that generates them. This means that they can be detected only on that object and only have an effect there, not independent of it.

When electrical and magnetic fields interact with each other they generate electromagnetic radiation. No matter what object generates it, electromagnetic radiation expands in the form of waves at the speed of light, about 186,282 miles per second (300,000 km/s).

A wave is defined by the height of the wave (its amplitude) and the sequence of wave peaks and wave troughs (its wavelength). The frequency of a wave is obtained by observing the recurring sequence of the wavelength over a period of time, usually a second.



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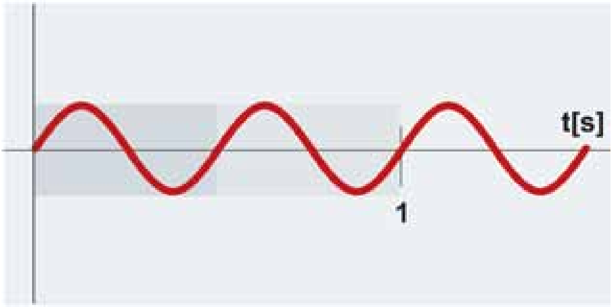
Electromagnetic waves are defined by their wavelength (1) and their amplitude (2).

Electromagnetic waves occur across an extremely wide range of wavelengths, from very short waves with a length of 10^{-15} m (0.000000000000001 m) to very long waves with a wavelength of 10^{7} m (10,000,000 m).

- The shorter the wavelength, the higher its frequency, and the higher its energy
- The longer the wavelength, the lower its frequency, and the lower its energy

All wavelengths shorter than 200 nm (0.0000002 m) are harmful to biological organisms.

Note: A nanometer (nm) is one-billionth (10-9) of a meter (m). The nanometer is customarily used as the unit of measure for the wavelength range of visible light, which is about 380 nm to 780 nm.



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The frequency of an electromagnetic wave is the number of wavelengths passing through a point in one second.

Frequency is specified in Hertz (cycles per second).

The wave shown above has a frequency of 2 Hertz — 2 wavelengths (oscillations) pass through a point in one second.

What are Electromagnetic Waves?

Different but so Similar: Heat, Light, and Radar

We can perceive heat and light directly through our senses. Radar is an electronic localization system. It determines the speed and the distance of an object from the radar source. We can render radar signals visible using electronic receiving equipment and monitors.

Although we perceive heat and light with different senses, both use electromagnetic waves as their transmission medium. Radar also uses electromagnetic waves, but in such a long wavelength range that our "built-in" senses are not able to perceive it.

Heat, or infrared radiation, lies in a wavelength range of 2.5 µm to 1 mm.

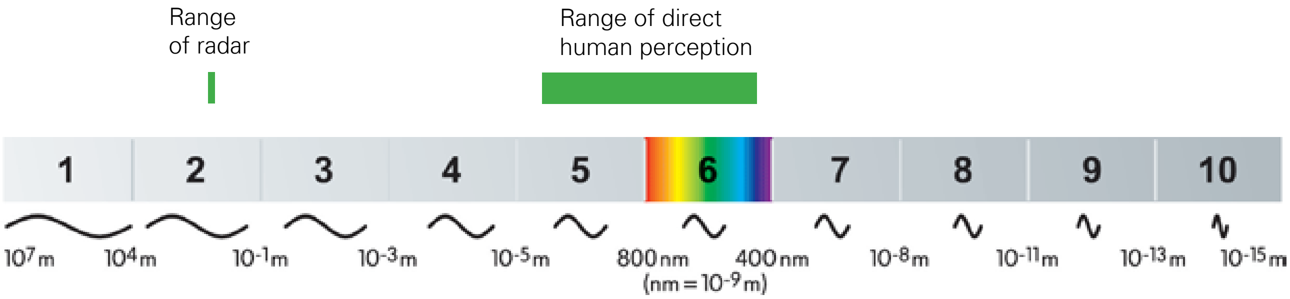
Note: A micrometer (µm) is one-millionth (10-6) of a meter (m).

The short wave end of this wavelength range is followed by the range of visible light, which extends from 380 nm to 780 nm.

Radar lies beyond the long wave range of infrared radiation in a wavelength range of 1 mm to 10 m.

Our senses are unable to register electromagnetic radiation that lies below a wavelength of 380 nm. This includes UV, X-ray, and gamma radiation, which are so energy-rich that they can damage biological systems, among other things.

We are also unable to directly perceive electromagnetic radiation that lies above a wavelength of 1 mm, the terahertz, microwave, radio wave and low-frequency range.



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Pictured wavelength range of the electromagnetic spectrum (not in scale to the actual proportions the entire spectrum): low frequency waves (1), radio waves (2) microwaves (3), terahertz (4), infrared (5), visible light (6), ultraviolet (7), X-ray (8), gamma radiation (9), cosmic rays (10)

What are Electromagnetic Waves?

Wave, Particle, or Both?

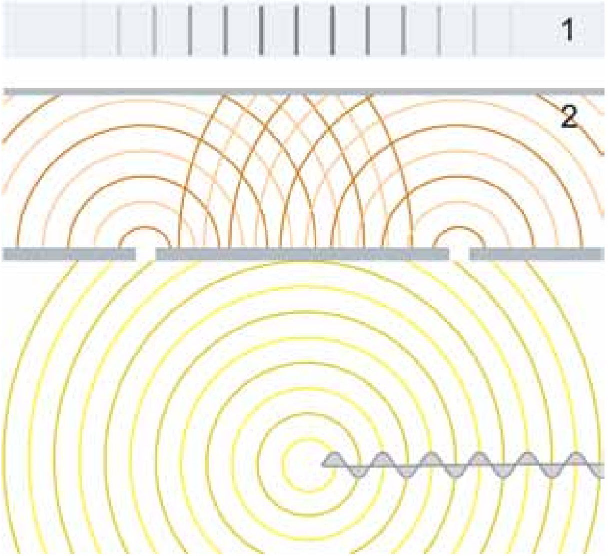
If what is emitted by a source of electromagnetic radiation is allowed to pass through two narrow parallel slits in a surface, interference patterns are formed on the side of the surface facing away from the source. These stripe patterns are typical of waves as they move through space.

At the point where electromagnetic radiation passes through a slit, a new wave front starts up and carries on in circles from the other side of the slit. This is the same effect as when a stone is thrown into a pond.

Because this experiment involves two slits, two wave fronts that interfere with each other start and move outwards from the slits.

The result of this interference is that:

- When two wave troughs or wave peaks encounter each other, their amplitudes are added and they intensify each other
- When a wave peak encounters a wave trough, their amplitudes neutralize each other
- Like the waves on a pond, stripe patterns show up on a projection surface positioned perpendicular to the direction of wave movement in the experiment



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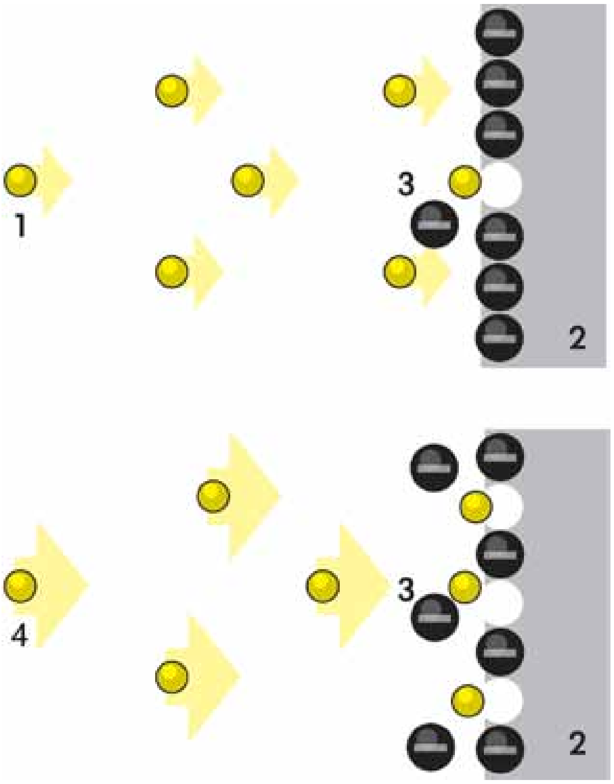
Characteristic stripe pattern (interference pattern) (1) on a projection surface (2) in the double-slit experiment

After researchers had successfully repeated this experiment many times, the opinion was formed that electromagnetic radiation behaves like a wave.

On the other hand, a phenomenon called the "photoelectric effect" cannot be explained satisfactorily with the characterization of light as a wave pattern. This phenomenon is characterized by the observation that when energy-rich electromagnetic radiation such as UV radiation is directed onto a metal surface, it causes electrons to be ejected from that surface. The number of electrons removed does not depend on the intensity (amplitude) of the radiation as one would expect, but rather on the frequency of the radiation.



The photoelectric effect depends on the frequency of the electromagnetic radiation.
Low-energy photons (1) are less successful in knocking electrons (3) out of the metal surface (2) than are high-energy photons (4).

The solution to the problem was provided by Albert Einstein based on Max Planck's theory of radiation.

Einstein defines electromagnetic radiation (light) as a sequence of energy packets (light quanta or photons). The higher the frequency of the radiation is, the higher the energy packets' energy.

A photon with high energy is more likely to knock an electron out of the metal surface than a photon with low energy. This is why the frequency of the radiation, not its intensity, determines the number of electrons that are released by the surface.

Einstein’s explanation of the photoelectric effect is shown in simplified form here. Electromagnetic radiation had a second character. Just as Newton had suspected long before Einstein, electromagnetic radiation (light) can be regarded as a stream of particles.

But which of the two views is correct? Does light consist of waves or particles? The answer is that light consists of both!

The characteristic of light that is revealed depends on the experiment. How it is seen is determined by the means used to examine it.

This view contradicts our common sense. Something cannot simultaneously have two different forms. For example, common sense tells us that the same piece of wood cannot have the shape of a sphere and the shape of a cube at the same time.

In the quantum-mechanical world of elementary particles, this "indeterminacy" is not a contradiction.

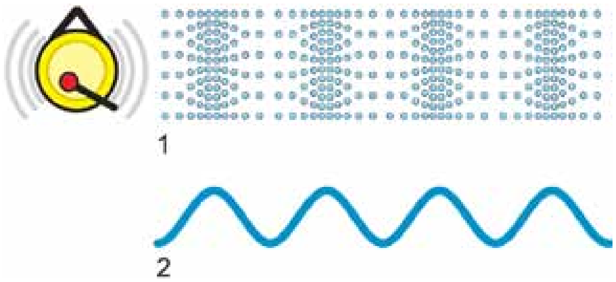
What is Sound?

Sound Waves

Like light, sound also has a wave character. A sound wave is a succession of pressure and density fluctuations in the surrounding medium through which the sound moves. This character becomes particularly clear when perceiving very deep sounds that are not only heard but also felt by the body.

For a medium to be able to transmit sound, it must have some elastic characteristics, like those of a gas or a liquid. Inelastic mediums do not transmit sound well and are better for use as soundproofing.

Unlike the speed of light, the speed of sound is not constant. Among other things, the speed of sound depends on the characteristics of the elastic medium through which it travels.

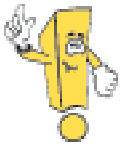


The pressure and density fluctuations between the molecules of the elastic medium (1) can be shown as a sound wave (2).

The denser and colder the elastic medium is, the better it transmits sound. The less dense and hotter the medium is, the poorer it transmits sound. This is why sound waves travel farther and faster in the sea than in air. The greater the motion of the components of a medium such as the gas molecules in the air, the less are sound waves supported.

Sound does not occur in a vacuum at all. There is no medium to support it. As huge as the explosion of a supernova is, an observer in the vacuum of space can see it but cannot hear it.

In the earth's atmosphere at a normal atmospheric pressure of 14.5 psi (1 bar) and a temperature of 68°F (20°C), sound travels at a speed of about 1125 feet (343 meters) per second. The frequency range of the sound we can hear lies between about 16 Hz and 20 kHz depending on our age and the state of our hearing.



Note: Infrasonic sound refers to sound waves with a frequency lower than our hearing range. Ultrasonic sound refers to sound waves with a higher frequency than we can hear.

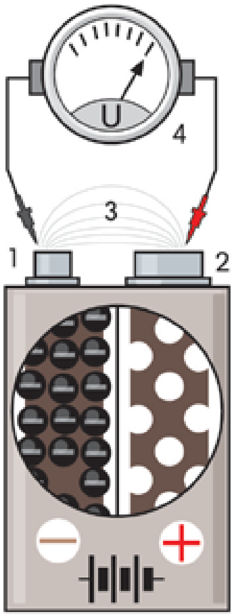
What Do U, I, R, and C Mean?

Electrical Terms

Certain terms from electrical science will crop up time and again in the descriptions of sensor technology and its measurement. These terms will be briefly explained in the following.

Voltage, Current, and Resistance

The relationship between voltage (U), amperage (I), and electrical resistance (R) are explained in Ohm's law. This law states that in an electrical circuit, its resistance is in direct proportion to its voltage and its amperage (current) is in inverse proportion to its voltage. But what do these terms mean?



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Due to the potential difference between the anode (1) and cathode (2), an electrical field (3) exists between the two terminals. Battery voltage (U) can be measured between the two terminals using a voltmeter (4).

Voltage

Voltage is also referred to as the potential difference. A voltage source such as a battery has a negative terminal (anode) and a positive terminal (cathode).

If the battery is not yet spent, a potential difference exists between the two terminals and a negative electrical potential is present at the anode. Stated more simply, there are too many electrons at the anode. They are waiting to carry out work in an electrical consumer.

In contrast, a positive electrical potential is present at the cathode. Again to simplify, the cathode needs electrons.

The greater the difference between the negative and positive electrical potentials, the higher the voltage supplied by the battery.

An electrical field exists between the two battery terminals because of this difference in potential.

The voltage value specifies how much work or energy is necessary to move a charge carrier (in this case an electron in an electrical conductor) within this electrical field. Voltage can be described as the energy content of an electrical charge that it can release in a consumer, or its capacity to perform work in the consumer.

Note: The electrical unit of voltage is the volt.

The conventional international abbreviation for voltage is "U".

What Do U, I, R, and C Mean?

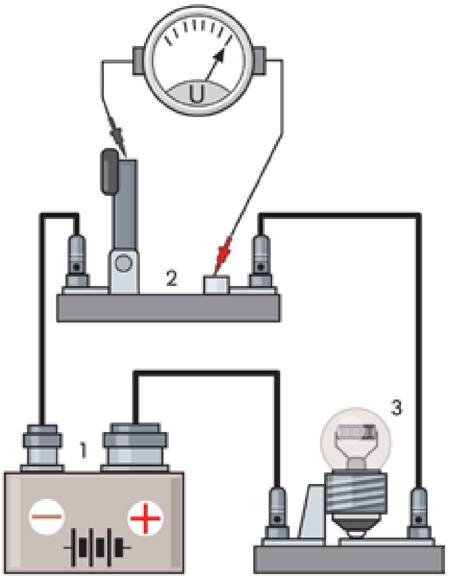
Current and Amperage

Consider what happens if the two terminals of a battery are connected by an electrical conductor (short-circuited). The electrical charge carriers, the electrons, begin to flow through the conductor from the anode (negative) to the cathode (positive) due to the force of the electrical field that exists as a result of the voltage.

As a rule, a battery is not simply short-circuited. The electrical energy that is stored in a battery is normally used to carry out work equivalent to the voltage in an electrical consumer such as an electric motor or a bulb.

Let us take a closer look at the example of a bulb.

A switch and a bulb are connected in series to a battery using electrical cables. As long as the switch is open no current flows, but the circuit voltage can be measured at the two contacts on the switch.



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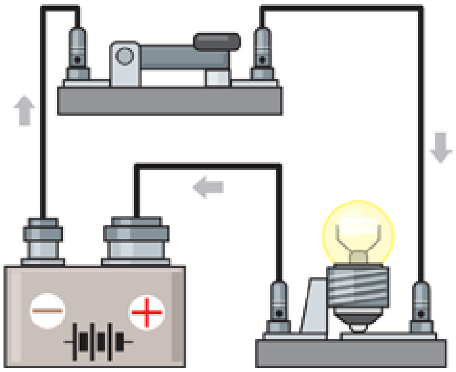
Test set-up with battery (1), switch (2) and bulb (3) as an electrical consumer with the switch open.

If the switch is closed, the electrons flow from the battery through the switch to the bulb, and from there back to the battery. This is due to the voltage and the related electrical field. The battery functions as a sort of "electron pump".



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When the switch is closed, an electrical current flows through the circuit.

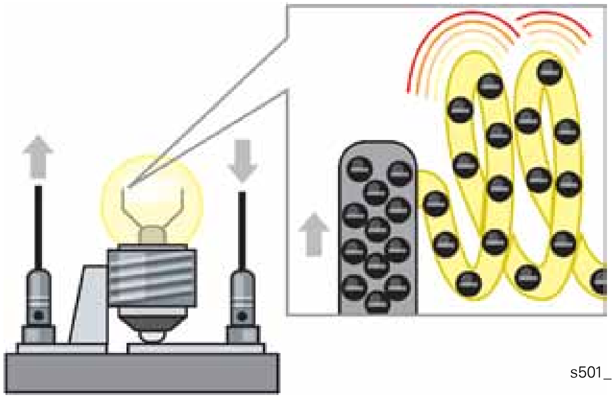
The quantity of electrons (charge carriers) that make their way to the consumer per unit of time determines the intensity of the current.

The higher the number of electrons per unit of time, the more electrical energy is transmitted, and the more work can be carried out by the consumer of the energy.

The intensity of the current is measured in amperes.

Note: The conventional international abbreviation for the amperage is "I".

The level of the amperage in a circuit depends on the voltage (potential difference) and the characteristics of the electrical cables that are used. The larger the cable cross-section and the higher the conductivity of its conductor, the higher the amperage can be at the specified voltage.



Due to the high electrical resistance of the filament, the bulb begins to light up.

What does this mean for our bulb?

The electrons are set in motion to the bulb once the switch has been closed and the electrical current is flowing. The bulb contains a very thin wire (coiled filament) that has a much higher electrical resistance than the other wires connecting the components.

In grossly simplified terms, a higher resistance means that fewer electrons are able to pass through the conductor at the same time. This causes the wire in the bulb to heat up as the electrons are "pumped" through it.

The thin wire emits this thermal energy in the form of electromagnetic radiation (light and heat). The bulb lights up.

The electrons perform work in the bulb filament wire in order to pass through it. They lose energy while doing so before they return to the battery cathode.

What Do U, I, R, and C Mean?

Electrical Resistance and Conductivity

Electrical resistance is related to voltage and amperage. This was recognized and expressed in a mathematical formula by Georg Simon Ohm. The unit of electrical resistance is named after him.

Resistance is a measure of the voltage that is necessary to achieve a specific amperage in an electrical conductor.

Resistance is determined by the electrical characteristics of the conductor through which the charges flow. The resistance value depends on the temperature, the cross-section of the wire (the diameter of the conductor), and a material characteristic called "specific resistance".

Electrical resistance can also be understood as the reciprocal value of electrical conductivity, another characteristic of materials.

The conductivity of a material specifies its willingness to "permit" a charge to be transported through its electrons.

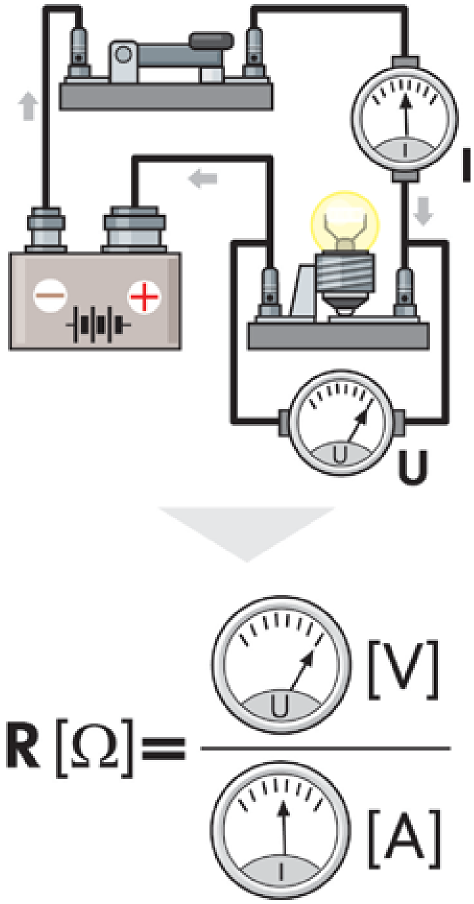
Let’s use metal as an example. If the electrons in the material are not bound to individual atomic nuclei but are instead "distributed" throughout the entire metal lattice, an electrical current can easily run through the material. This is because there are many "free" electrons that can be accelerated in the conductor by the electrical field built up due to the voltage.

Such a material has a high conductivity and, due to the reciprocal value, a low specific resistance.

Because resistance depends on temperature, it is a good measurement variable to determine temperature.

Note: The conventional international abbreviation for resistance is “R”.

The standard unit of measure for resistance is the Ohm (Ω).



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The electrical resistance (R) of a component can be calculated from measured amperage (I) and voltage (U).

If the resistance and the voltage are known, the amperage can be calculated.

If the resistance and the amperage are known, the voltage can be calculated.

Materials in which the electrons are firmly bound to the relevant atoms in the form of chemical (covalent) bonds are extremely unwilling to release their electrons for charge transportation.

These materials have low conductivity and a high specific resistance. They are called poorly conductive or nonconductive materials, or insulators. This does not mean that these materials are completely unable to transport any charges at all. A great deal of energy, in the form of heat for example, has to be pumped into them to transform them into a state that is electrically conductive (ionized plasma).

In many materials this energy value (ionization temperature, transition temperature) is relatively easy to achieve. One example of this would be the ionizing of a gas that is non-conductive under normal conditions in a bulb.

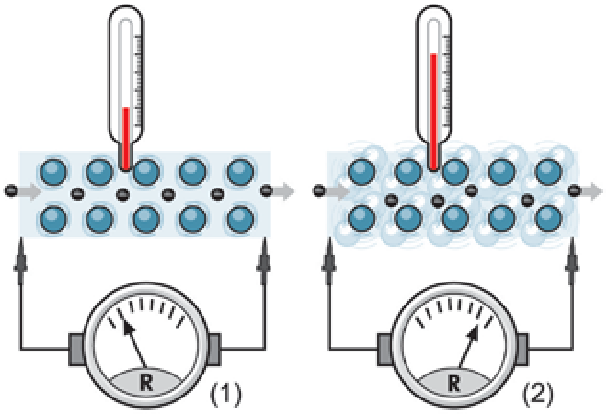
A material's conductivity and also its electrical resistance depend on temperature. This can be easily seen in metals. As the temperature of the metal rises, the atoms increase oscillation at their lattice sites. The electrons also collide with increasing frequency. All this activity at the atomic level inhibits charge transportation through the conductor. The resistance increases.

As the temperature falls, the resistance of metals and semiconductors decreases, because the movement of the atoms in the lattice slows as the temperature drops.

At a low specific threshold temperature the charge can be transported without any loss of electrical energy. This is called superconducting. This effect usually occurs only at extremely low temperatures close to absolute zero (0 K; -459.67°F; -273.15°C).

The behavior of non-metals in terms of their electrical resistance or conductivity is slightly different or completely the opposite to that of metals.

The temperature dependency of resistance is used in temperature sensors. Ohm's law can also be applied to determine voltage or amperage.



Temperature dependency of electrical resistance:

Slight movement of the metal atoms at their lattice sites leads to slight electrical resistance (1).

If the movement of the metal atoms increases along with the temperature, the resistance also increases (2)

What Do U, I, R, and C Mean?

Capacity and Dielectric Material

Capacity is a measure of the ability of a charge storage device to store an electrical charge.

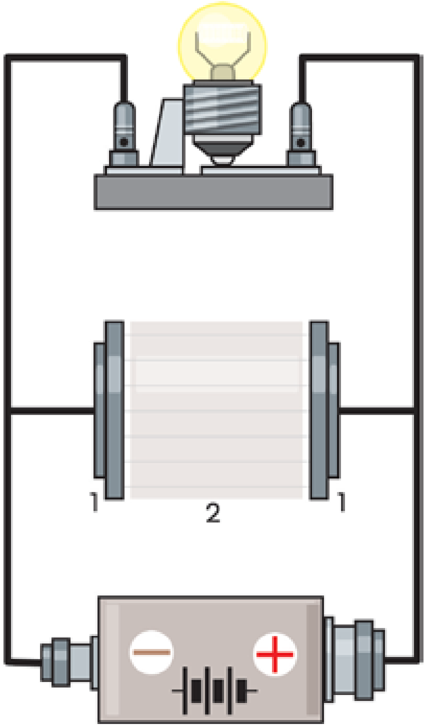
Capacity is proportional to the quantity of the charge and inversely proportional to the voltage applied to the capacitor.

The simplest form of charge storage device is the plate-type capacitor. A plate-type capacitor has two conducting plates positioned opposite each other.

A small charge can be stored without any additional material between the plates, but storage capacity can be increased or changed by positioning a suitable dielectric material between them.

This dielectric material consists of a poorly conducting or non-conducting, non-metallic substance. In addition to the physical characteristics of the dielectric material, capacity also depends on the surface area of the capacitor plates and the distance between them.

If the two plates are connected in an electrical circuit, the capacitor is charged. This means that an electrical field builds up between the capacitor plates. No electrical current flows through the capacitor in the sense that charge carriers (electrons) flow through it, but the current flow continues downstream of the capacitor in order to do work like causing a bulb to light up.



Simplified illustration of the structure of a plate-type capacitor in an electrical circuit:

When the electrical circuit is made, electrical energy is stored in an electrical field between two capacitor plates (1).

A dielectric material (2) between the capacitor plates can be used to influence the storage capability of the capacitor.

This phenomenon is based on a physical characteristic called electrical flux. Electrical flux occurs due to the change in the electrical field when the capacitor is charged.

If the voltage source is removed, the energy stored in the "charged" capacitor causes the current to continue to flow for a period of time. The bulb remains lit until the capacitor is completely discharged.

Note: The conventional international abbreviation for capacity is “C”.

The standard unit of measure for capacity is the Farad (F).

In sensor technology, pressures and humidity are measured using special capacitive sensors.

Glossary

André-Marie Ampère
10.01.1775 - 10.06.1836
French physicist and mathematician
The physical unit of electrical current is named after him: ampere.

Anaximenes of Miletus
Approx. 585 BC - approx. 526 BC
Greek natural philosopher

Niels Bohr
07.10.1885 - 18.11.1962
Danish physicist
1913 Development of the Bohr atomic model based on the work of Planck and Einstein
1922 Nobel Prize for physics
1922 Explanation of the structure of the periodic system on the basis of Sommerfeld's extended atomic model

Charles August Coulomb
14.06.1736 - 23.08.1806
French physicist
Founder of electrostatics and magnetostatics

Democritus
Approx. 460 BC - approx. 370 BC
Greek natural philosopher

Empedocles
5th century BC
Greek natural philosopher, physician, politician, priest and poet

Albert Einstein
04.03.1879 - 18.04.1955
German, later American, physicist
1905 Publication of the special theory of relativity
1916 Publication of the general theory of relativity
1921 Nobel Prize for physics
1932 Emigration to the USA (Princeton)
His search for a universal field theory remained fruitless up to his death.

Michael Faraday
22.09.1791 - 25.08.1867
English natural scientist, chemist and experimental physicist
Faraday was the first to discover and describe electromagnetic induction.
The unit of measure for the capacity of capacitors is named after him: Farad.

Glossary

Richard Phillip Feynman
11.05.1918 - 15.02.1988
American physicist
1965 Nobel Prize for physics for his work on quantum electrodynamics

Werner Heisenberg
05.12.1901 - 01.02.1976
German physicist
1927 Formulation of the Heisenberg uncertainty principle
1930 Publication of the document "Physical principles of quantum theory"
1932 Nobel Prize for physics

Hermann Ludwig Helmholtz
31.08.1821 - 08.09.1894
German physiologist and physicist
1847 Publication of the book "On the conservation of force"
1867 Publication of a manual on physiological optics

Heraclitus of Ephesus
Approx. 520 BC - approx. 460 BC
Greek natural philosopher from Ephesus

Heinrich Rudolf Hertz
22.02.1857 - 01.01.1894
German physicist
1886 Discovery of the photoelectric effect
The research conducted by Hertz provided the basis for the development of wireless information transmission (telegraphy, radio). The physical unit of frequency is named after him: Hertz.

Heinrich Lenz
12.02.1804 - 10.02.1865
German-Baltic physicist
Lenz carried out research in the field of electrical manifestations such as induction and resistance.

Leucippus
5th century BC
Greek natural philosopher

James Clerk Maxwell
13.06.1831 - 05.11.1879
Scottish physicist
1860 Formulation of the kinetic theory of gas
1864 Publication of the Maxwell equations on electricity and magnetism
Prediction of the value of the speed of light

Isaac Newton
20.03.1643 - 31.03.1727
English mathematician, natural scientist and alchemist; head of the Royal Mint in London
1687 Publication of "Philosophia Naturalis Principia Mathematica", in which Newton defines his laws of mechanics
1704 Publication of "Opticks", in which his research into the field of optics was summarized
The physical unit of force is named after him: Newton.
Newton assumed the particle character of light even prior to Einstein.

Georg Simon Ohm
16.03.1789 - 06.07. 1854
German physicist
1826 Definition of Ohm's law
The physical unit of electrical resistance is named after him: ohm.

Max Planck
23.04.1858 - 04.10.1947
German physicist
1899 Introduction of Planck's quantum of action
1918 Nobel Prize for physics
1929 Publication of "Das Weltbild der neuen Physik" (The Philosophy of New Physics)
Head and subsequently honorary president of the Kaiser-Wilhelm Institute for the promotion of science (subsequently renamed the Max-Planck Institute), co-founder of quantum mechanics

Ernest Rutherford
30.08.1871 - 19.10.1937
New Zealand physicist
1902 Hypothesis of the radioactive decay of elements
1908 Nobel Prize for chemistry
1911 Derivation of the Rutherford atomic model
1918 Discovery of the proton

Leonard Susskind
1940 -
American physicist
Co-founder of the string theory

Thales of Miletus
Approx. 624 BC - 546 BC
Greek mathematician from Miletus, natural philosopher, astronomer, politician and engineer

Count Allesandro Guiseppe Antonio Volta
18.02.1745 - 03.03.1827
Italian physicist
The physical unit of electrical voltage is named after him: volt.

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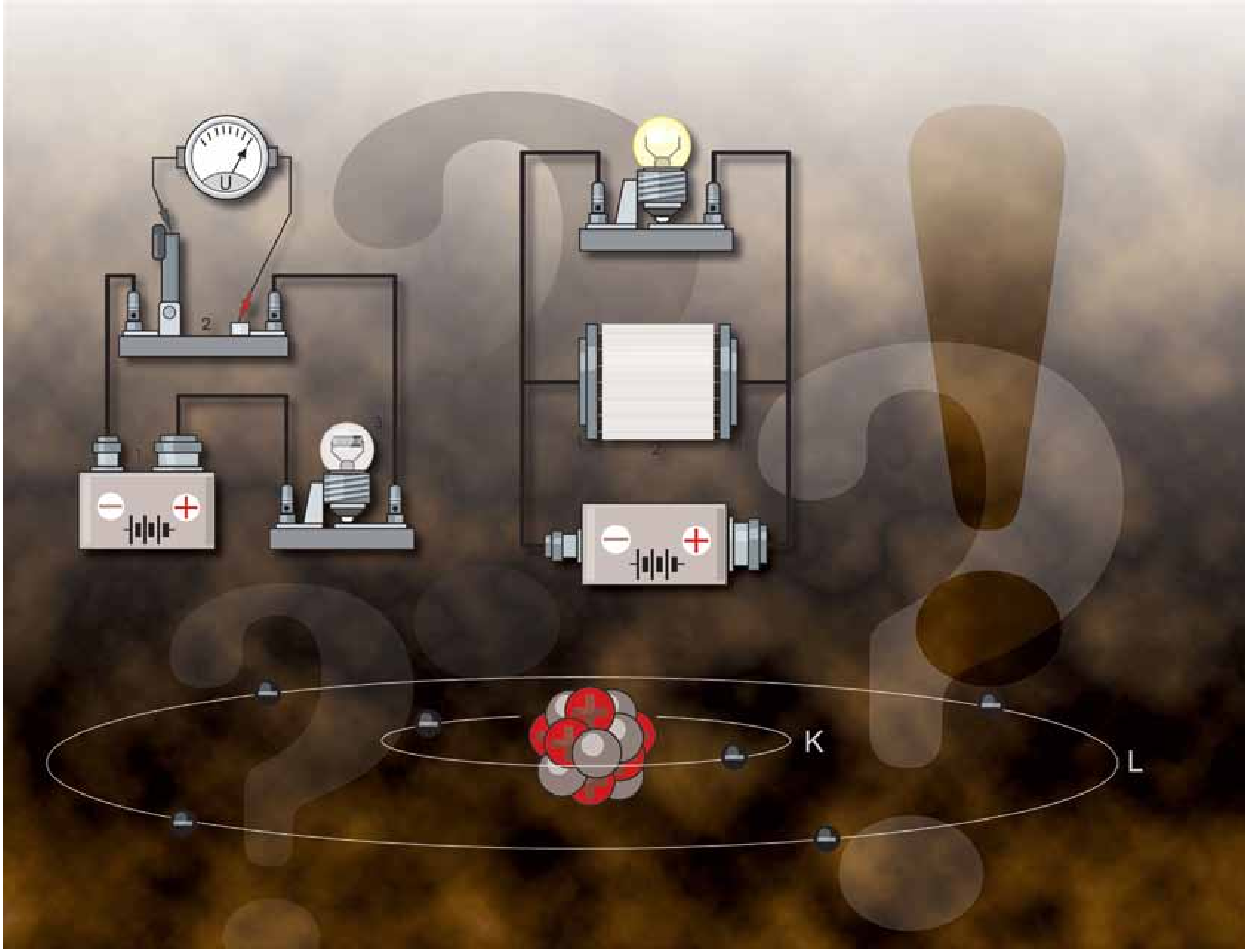
Or, E-mail:

concierge@volkswagenacademy.com



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