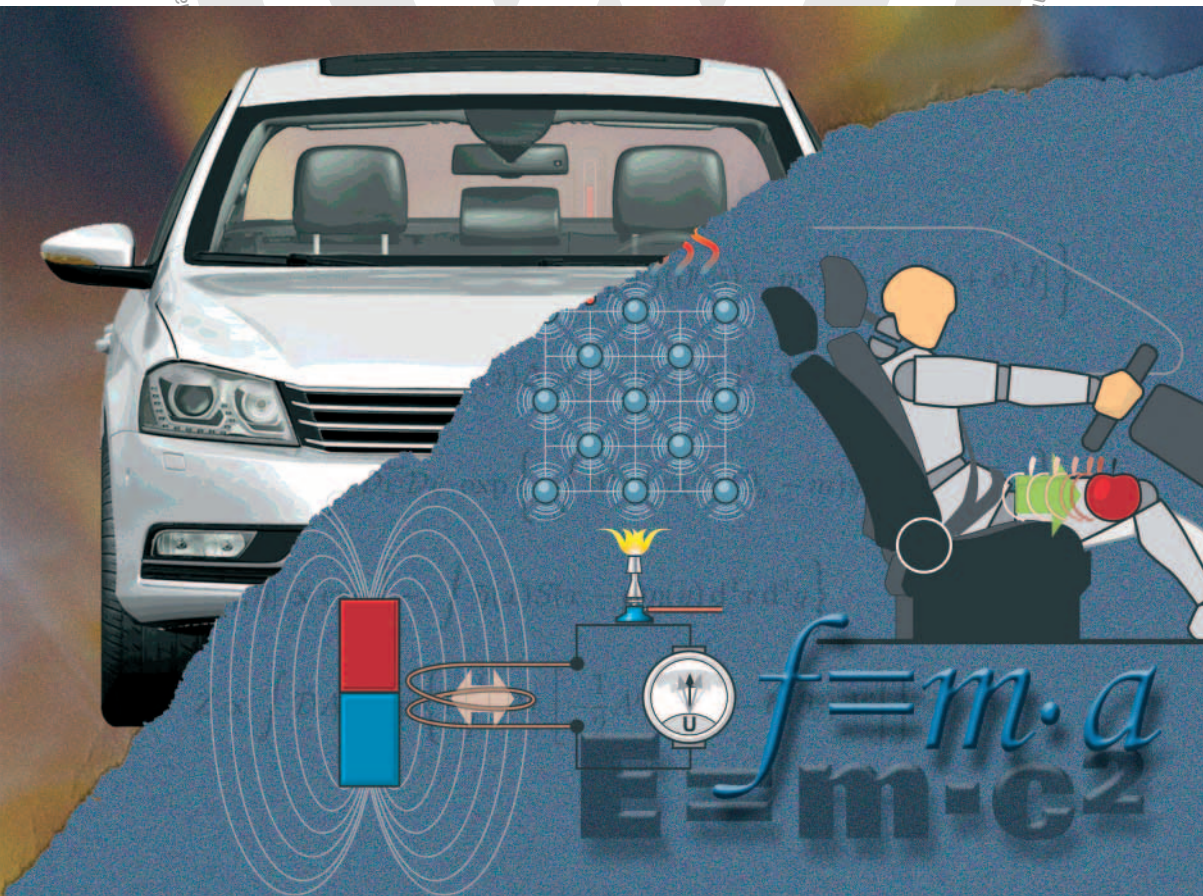




Technology Self-study Programme 501

Vehicle Sensor Technology
Physical Principles



In automotive engineering, increasingly high standards of safety, operation and comfort are leading to increasingly complex systems. Depending on their task, these systems require a vast amount of information, which is supplied to them by sensors. The result is an almost incalculable number of different sensor types and sensor designations.

However, all of these sensors and the way in which they function are based on a limited number of physical principles and physical measurement processes.

The objective of the self-study programmes on vehicle sensor technology is to explain these different measurement processes and their physical principles clearly and vividly and to associate them with the different sensor types. The system employed in these booklets is intended to make it easier for you to recognise the sensors installed in the vehicle systems and to assess what information they supply to the system based on the different laws of physics. The self-study programmes on the vehicle sensor technology are therefore designed as a central reference work which is intended to help you understand complex vehicle systems and support you in fault finding.

This self-study programme on the physical principles employed in vehicle sensor technology will help you to brush up on the knowledge you acquired at school. Amongst others, terms concerning central theories of physics such as quantum mechanics or relativity occur repeatedly; these are given little consideration or are disregarded entirely in school. We are not concerned with explaining these theories in precise mathematical terms here, however, as this would exceed both the scope and the point of this booklet. The intention is to inform you that these important theories exist and to convey the central importance which these often very abstract concepts have for the technology which surrounds us.

The self-study programme presents the design and function of new developments! The content will not be updated.

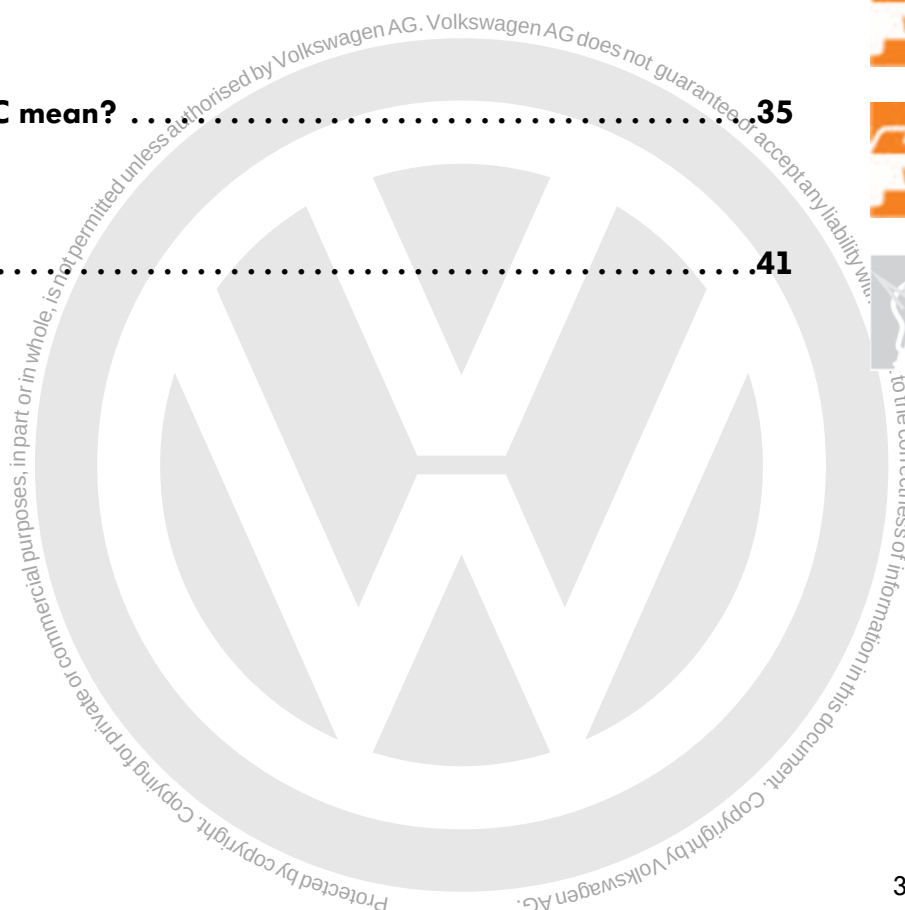
Current testing, setting and repair instructions can be found in the provided service literature.



**Important
note**



Introduction	4
What is motion?	6
What is energy?	14
What is matter?	20
What is magnetism?	26
What are electromagnetic waves?	30
What is sound?	34
What do U, I, R and C mean?	35
Glossary	41





Structure of the vehicle sensor technology series

The self-study programmes on the vehicle sensor technology are likely to encompass three booklets:

- Vehicle Sensor Technology - Physical Principles
- Vehicle Sensor Technology - Measuring Methods
- Vehicle Sensor Technology - Sensor Technology

These three booklets are based on each other and together form a reference work on the topic of vehicle sensor technology or sensors in automotive technology.

The series has been split into three parts to limit the number of pages in a booklet to a manageable level.

On the contents of the vehicle sensor technology series

This, the first booklet in the vehicle sensor technology series, explains physical principles which are vital to understanding the ways in which the different sensors function. Wherever possible, an attempt will be made to explain this using images and to forego an account of the mathematics on which the physics is based.

The majority of the models which are used describe the current knowledge of physics in vastly simplified and thus incomplete form. If you already have an extensive knowledge of basic physics, this first section can be skipped or used to refresh your existing knowledge.

The booklet entitled "Vehicle Sensor Technology - Measuring Methods" deals with the different measurement processes implemented by the sensors. The descriptions in the second booklet require knowledge of the principles explained in this booklet.

Finally, the "Vehicle Sensor Technology - Sensor Technology" booklet provides an overview of the different types of sensors currently used in automotive engineering and relates them to the measurement processes presented in the second booklet. What its signal can be used for, how the sensor is structured and how it functions with reference to the measurement process are described for each sensor.

What does sensor technology mean?

In technical terms, sensor technology refers to the knowledge and the application of sensors to control and regulate technical systems. A sensor is a gauge used to register specific physical characteristics and convert these into an electronically usable signal. A sensor is therefore the interface between the external world and the interior of the system for a specific measurement variable.



The vehicle's senses

To clarify the meaning of sensor technology in automotive engineering, comparison with the physiological sensors of a biological system such as man is appropriate.

Among other things we have six senses and have specific gauges for each of these senses.

For our optical sense (seeing), we have two eyes with photosensitive sensors which enable us to recognise colours and levels of brightness.

The individual sensors are already wired in such a way in the eyes that they are outstandingly suitable for recognising patterns. Age-dependent, experience-based evaluation of the optical data in the brain enables us to roughly estimate the distances, speeds and movements of objects in our environment.

Our acoustic sense (hearing) registers sound waves. Our sense of balance enables us e.g. to walk upright and, as a by-product, makes us sensitive to acceleration.

In the truest sense of the word, the pressure-sensitive gauges used in our sense of touch enable us to grasp our environment. Temperature sensors inside us and in our skin form our sense of temperature and warn us of excessively high or low temperatures which may harm our body.

We 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 these. We can classify our sensitivity as strong, less strong or weak, but we have no concrete and thus comparable measurement data. The meaningfulness of a biological system's physiological sensors is therefore extremely individual and difficult to compare with others.

The situation is completely different in the case of technical sensors.

With its multitude of control systems and driver assistance systems, a modern vehicle has significantly more senses than those with which we are born. Temperatures, rotational speeds, proximities, speeds, torques, pressures, distances, substance quantities and much more besides are registered using technical sensors and converted into concrete, comparable measurement results.

They enable the systems to evaluate measurement variables and derive control processes from these.

What is motion?

In addition to the apparently simple question of what motion actually is, the reason for or cause of motion is primarily important. This is where the terms force, acceleration and torque come into play.

Absolute and relative motion

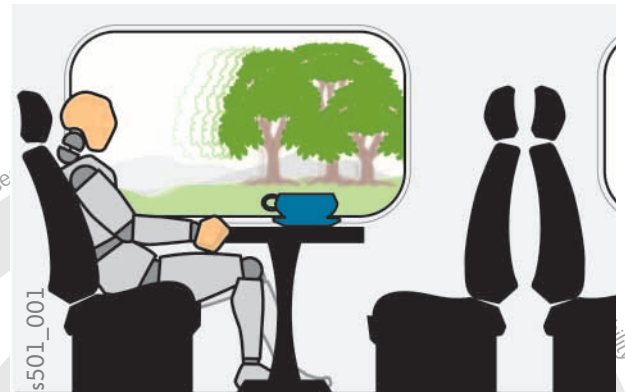
We no longer talk about absolute motion in the physical sense.

This was considered to be the movement of an object with reference to the surrounding, absolute space (the universe). However, this is also relative motion according to the current view: that of an object relative to the reference system of the universe.

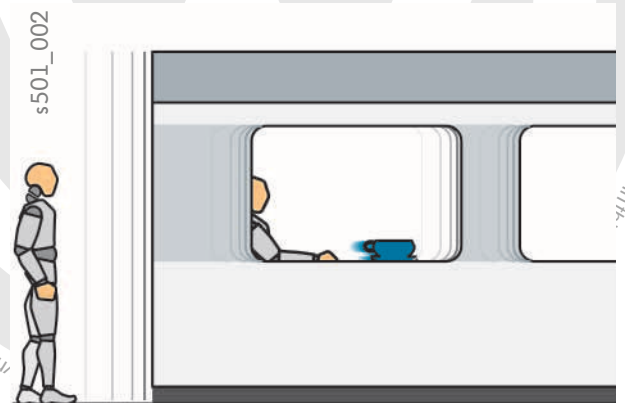
However, motion can be described in the reference not only to the surrounding space, but also to the observer or to another object. Depending on which reference system (inertial system) is used, motion is observed in different ways.

To the passenger in the train, a cup of coffee standing on the table in a moving train appears to be at rest, whilst an observer on the station platform believes it to be in motion. For a further observer at the centre of the Milky Way, the cup, passenger and first observer are underway quite quickly (at approx. 961,200 km/h) in our galaxy. When asked what the speed of the cup is, the first would reply 0 km/h, the second e.g. 250 km/h and the third approx. 961,200 km/h. These are three different statements, all of which can be checked and all of which are true at the same time.

It is, therefore, important to specify the reference system when describing motion.

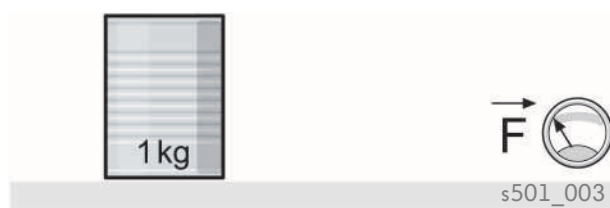


For the observer in the "train" reference system, the cup remains at rest in relation to the observer and the reference system.

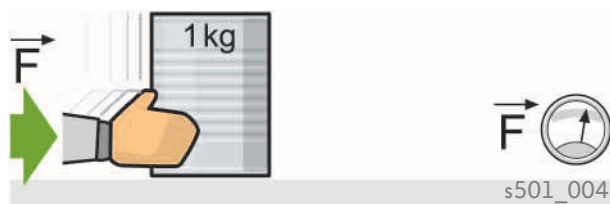


For the observer on the station platform, the cup, together with the train and passengers, is in motion in relation to him and another reference system, the "station".

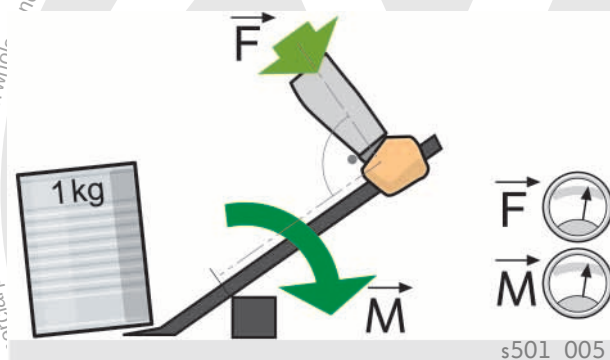
Force and torque



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



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



If a force (F) acts via a lever arm, a torque (M) occurs.

There are a number of forces which have fixed definitions and which play a role in describing sensors.

In the following, we will briefly examine:

- Gravitational force,
- Inertial force,
- Centrifugal force,
- Centripetal force and
- Coriolis force.

Forces or torques cause motion. A force is a targeted physical variable which can deform or accelerate a body. If the force acts on a lever arm, i.e. with reference to a fulcrum, torque is obtained as a physical variable.

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 or a torque changes the state of motion i.e. its speed or its direction changes. Mathematically, a force is described as the product of the mass of the body on which it acts and the acceleration which this undergoes due to the force (Newton's 2nd law).



What is motion?

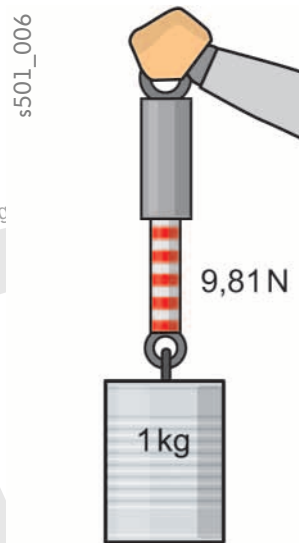
Gravitational force

For us on earth, gravitational force is caused primarily by the mass of our planet. Gravitation acts towards the centre of the earth. Each object in the earth's sphere of influence experiences this force. However, it decreases by the square of the distance from the earth.

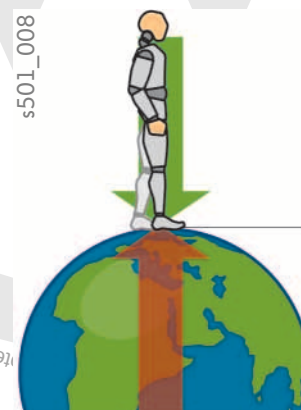
According to Newton's second law, the acceleration which a falling body experiences can be mathematically derived from gravitational force. This acceleration is 9.81 m/s^2 . In free fall to the earth, we therefore accelerate each second at a speed of 9.81 m/s if we disregard other influencing variables such as friction or lift.

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 "actio = reactio" or "lex tertia" (Newton's third law).

Newtonian mechanics can be used to describe gravitation, as we experience it, to a sufficient degree of accuracy and to derive it mathematically. Only when describing the behaviour of very large masses such as those which occur in the case of neutron stars or black holes can the observations no longer be described with sufficient accuracy using Newton's laws. In addition, Newton was unable to state how gravitation occurs and the rules according to which it functions.



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



According to Newton's 3rd 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).

Based on Albert Einstein's general theory of relativity, gravitation is not regarded as a force which 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 not all objects interact with each other on an unchangeable, static stage, i.e. the space surrounding us, but that the objects also influence the stage, just as the stage also influences the objects.

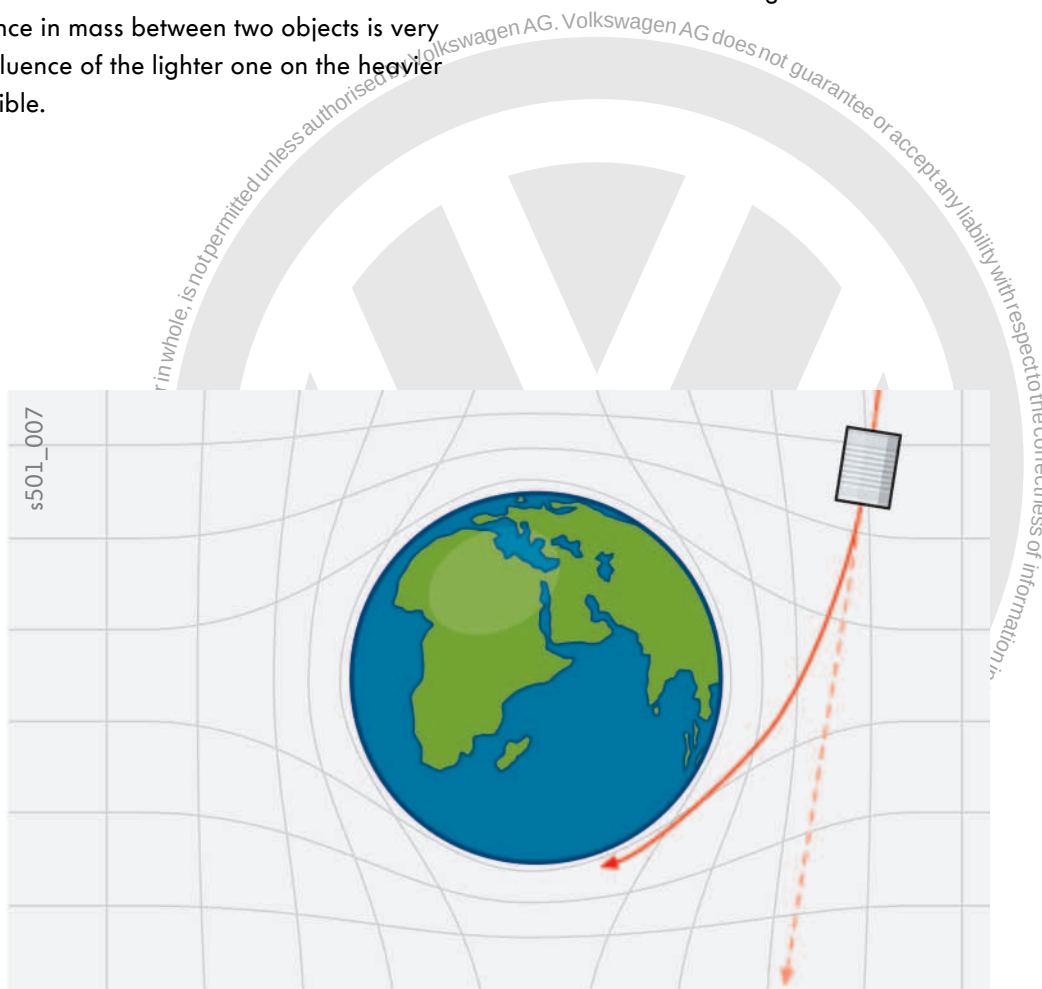
In extremely simplified form, this means that all objects which have a mass generate a disturbance or curvature in the structure of this space-time at their location. The greater the mass, the more the space-time structure is "bent".

If the difference in mass between two objects is very great, the influence of the lighter one on the heavier one is negligible.

This means that, in comparison with the influence which the earth exercises on an aeroplane, that of the aeroplane on the earth is negligibly small.

If another object encounters such a curved area on its way through the universe, it is diverted towards the object of great 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 depart from the curved area again. If the strength and direction of the object's own motion are not sufficient, the lighter object crashes into the object with the greater mass. In contrast to Newton's definition, 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 light object moving on a linear course to deviate from its path.

What is motion?

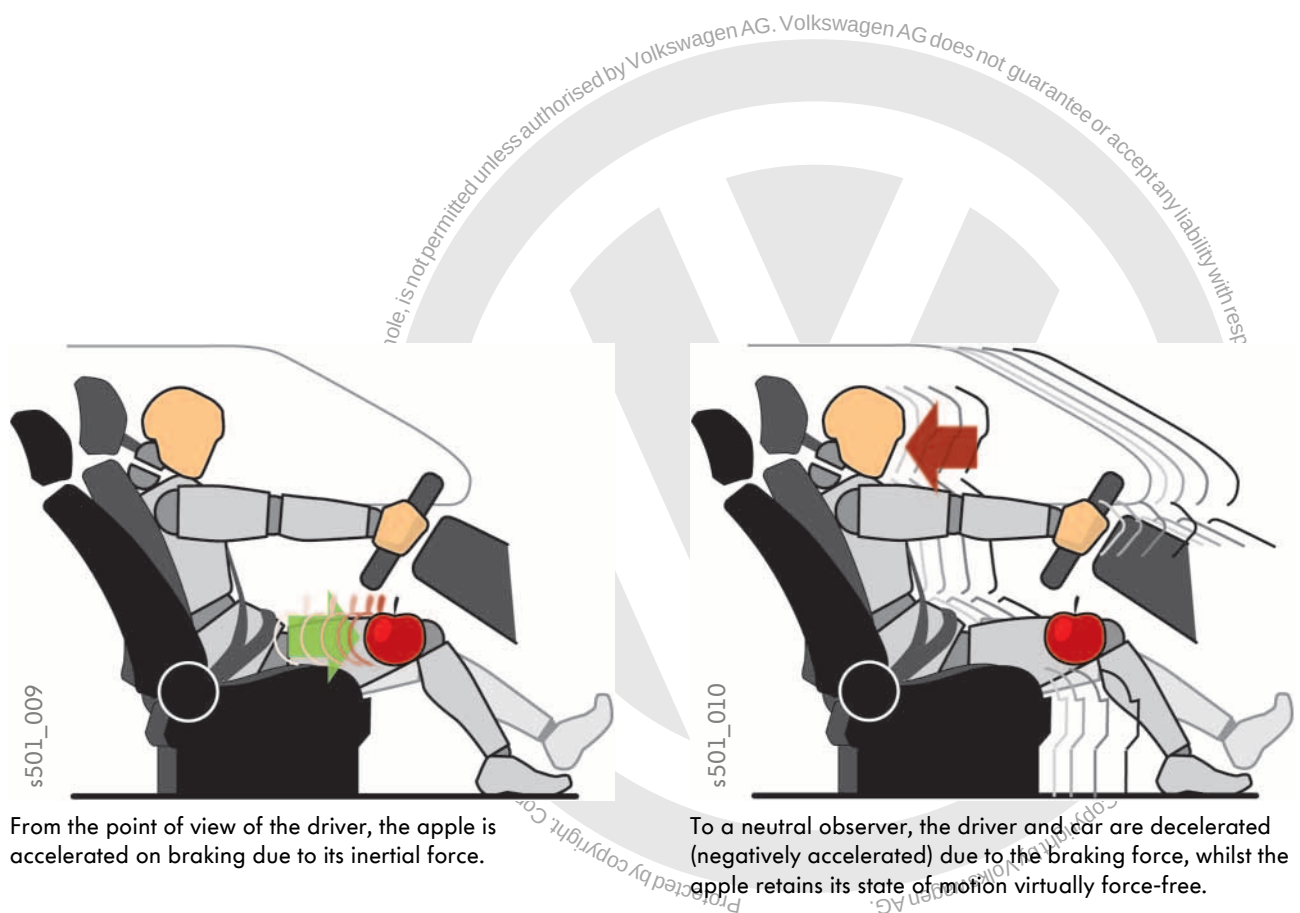
Inertial force

Inertial forces are also called apparent forces. Centrifugal, centripetal force and Coriolis force also number amongst the inertial or apparent forces. The term apparent force refers to the fact that the description of the force's action 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 lying next to you on the passenger seat in the 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 whilst you are restrained by the seat belt. From your point of view, the apple's state of motion changes whilst yours remains the same.

A force which leads to the apple's moving in the car reference system must therefore act. This is the inertial force. It is also referred to as inertia or a body's effort to retain its state of motion.

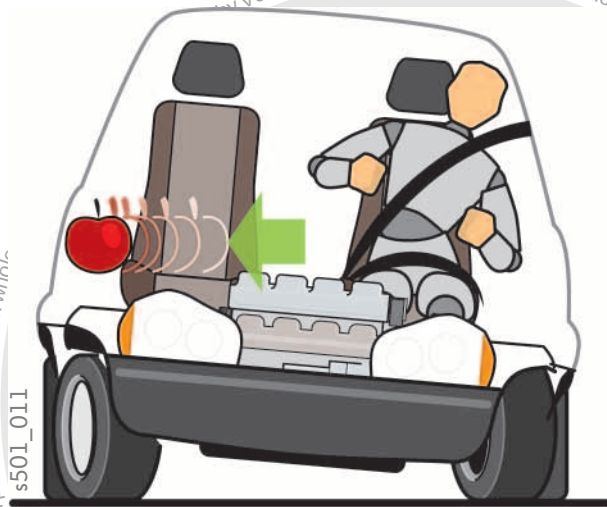
The process is different from the perspective of the observer that you pass on the road when you brake: you undergo negative acceleration due to a force, the braking force, because you are firmly connected to the braking car via the seat belt. During this, the apple continues to fly off at constant speed because no braking force is acting on it. From this point of view, your state of motion changes whilst that of the apple remains the same. The observer does not need any inertial force to explain the behaviour of the apple.



Centrifugal force

If a rotating reference system is observed from a position within the system, a force which pulls an object located together with the observer in the reference system outwards appears to exist.

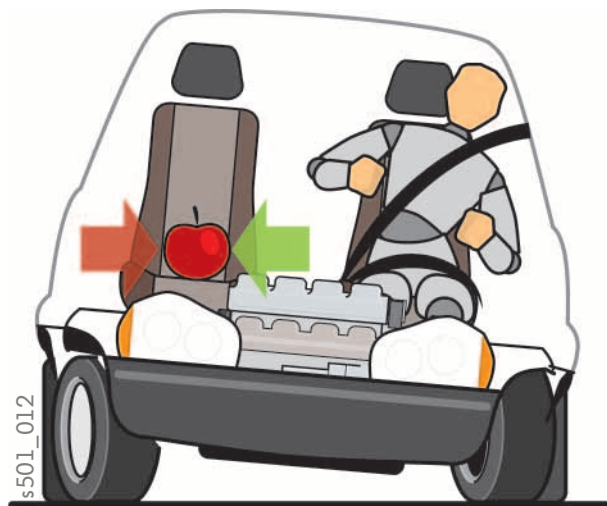
We will remain with the example of the apple on the passenger seat in the car. As soon as you drive into a curve, the apple on the seat moves outwards from the centre of the curve, whilst you counteract this pull via the seat belt and your physical posture. From your point of view, the apple is accelerated outwards by the centrifugal force.



From the point of view of the driver, who is located in the same reference system along with the apple, a force which accelerates the apple outwards must exist on cornering.

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. A counterforce must therefore exist for each acting force in this case. 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.



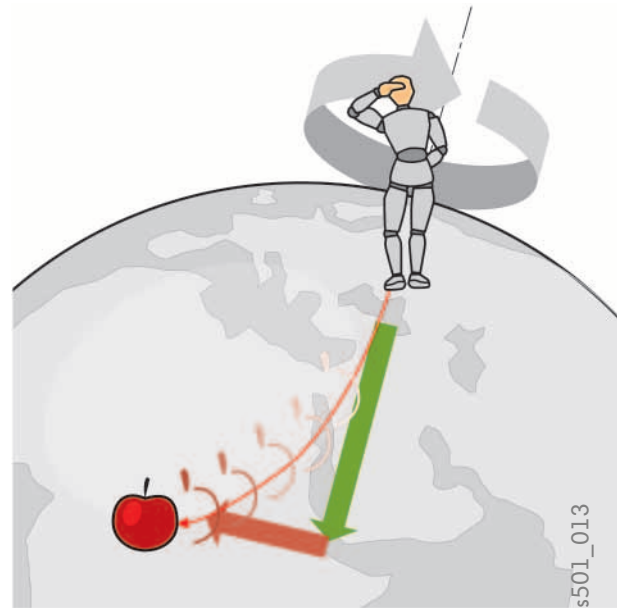
So that the apple can remain at rest during cornering from the point of view of an observer, an opposing centripetal force (red) of the same magnitude as the centrifugal force (green) pulling the apple outwards must exist.

What is motion?

Coriolis force

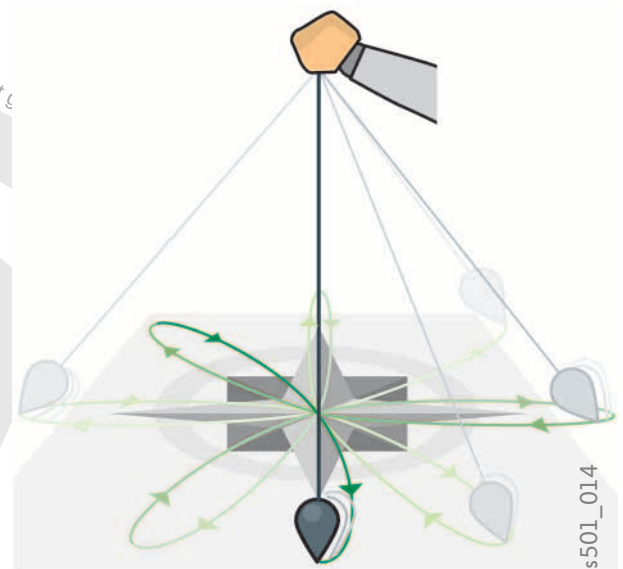
The Coriolis force is also an inertial or apparent force. It occurs when describing motion relative to a rotating reference system. It acts during both vertical and horizontal motion of a body within this reference system, and is dependent on the rotational direction of the reference system, etc. If the earth is used as the reference system, the Coriolis force acts on all moving objects on the earth and is caused by the earth's rotation.

The Coriolis force therefore plays an important role in the occurrence of weather.



For the observer on the earth, a force which diverts the apple, which is thrown in a straight line, must exist: the Coriolis force.

The effect of the Coriolis force can be visualised using a swinging pendulum (Foucault pendulum). In the northern hemisphere, the Coriolis force causes the pendulum to divert to the right during its movement. The pendulum's plane of oscillation is therefore shifted clockwise, resulting in the patterns of movement registered by the Foucault pendulum. In sensor technology, the Coriolis force plays a role e.g. in the measurement of yaw rates or mass flows.



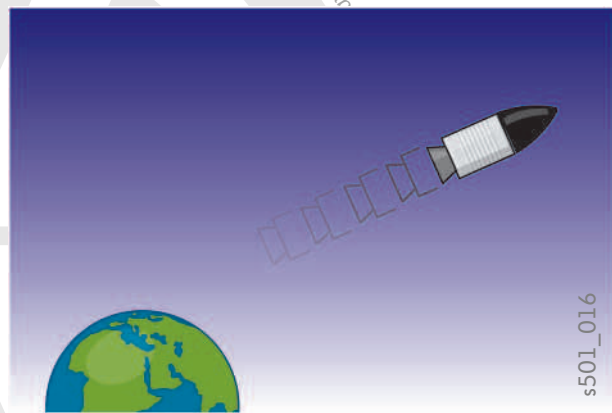
The effect of the Coriolis force can be shown using the Foucault pendulum. The pendulum's plane of oscillation rotates 360° once in 24 hours. As a result of this, the pendulum describes a pattern of overlapping ellipses.

Uniform and non-uniform motion

We refer to a uniform motion when a body moves at a constant speed. If further acceleration takes place so that the body's speed changes, this is non-uniform motion. If this acceleration is constant, the resulting motion is called a 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.



After the rocket motor has been shut off, the rocket glides through space without further acceleration.
It now flies with uniform motion at a constant speed, insofar as other effects such as gravitational influences are disregarded.



The laws of Newtonian mechanics are usually sufficient to obtain adequately precise results to describe all processes on the earth which occur in the order of magnitude perceptible in our daily lives. Only in the case of very large and very small masses (black holes, elementary particles) and at very high speeds (close to the speed of light) are Newton's laws no longer sufficient to obtain results which correspond to the observations.

Einstein's general or special theory of relativity is then used for large masses and high speeds, whilst quantum mechanics are employed to describe very small masses and high speeds.

What is energy?

At the very latest, the vast amount of energy which is bound in matter became clear when the first atomic weapon tests were conducted.

And Einstein's world famous equation $E=mc^2$ makes it clear for all that mass and energy are equivalent.

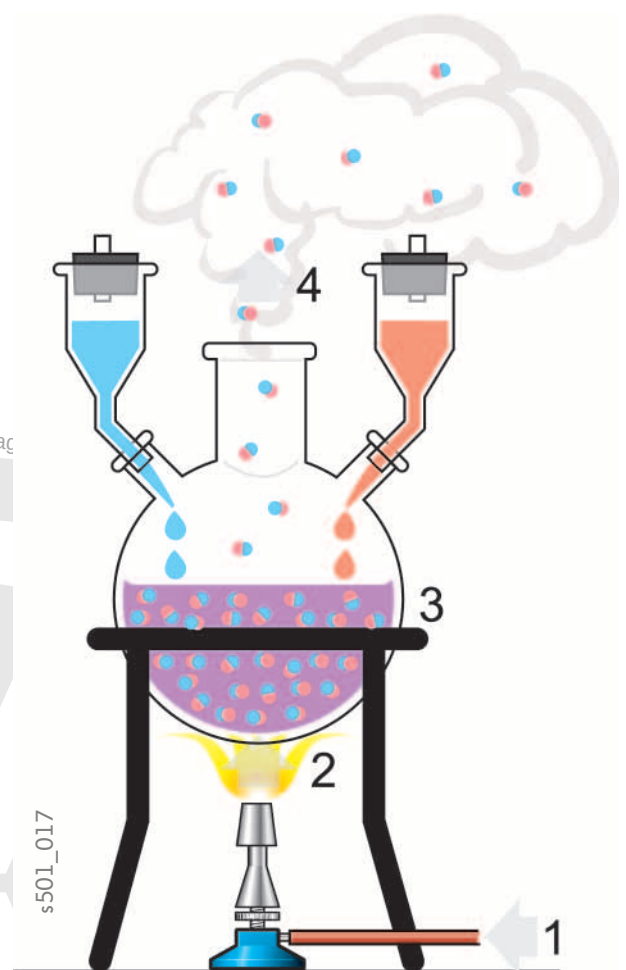
In classical mechanics, energy is understood as a physical variable which is capable of performing work.

Depending on which branch of the natural sciences is concerned, different definitions are used for energy or forms of energy.



Forms of energy

Different terms for energy may therefore be based on the fact that different things are investigated. The kinetic energy which a body contains due to acceleration will necessitate a definition or physical derivation which differs from that of a description for the energy which has to be applied to create or break a chemical bond. Irrespective of the individual definition of a form of energy, in the final analysis, all forms of energy can be converted into each other (at least mathematically). They are therefore equivalent like the mass and energy in Einstein's formula. In terms of practical applicability, however, this equivalence is limited, as side-effects or interactions usually lead to "energy devaluation" (apparent energy losses) or conversion to another form of energy is technically impossible or too complex.



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 vapour molecules

Potential energy & its siblings

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

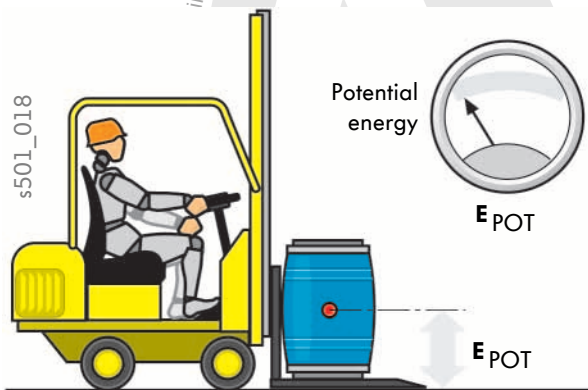


Potential energy

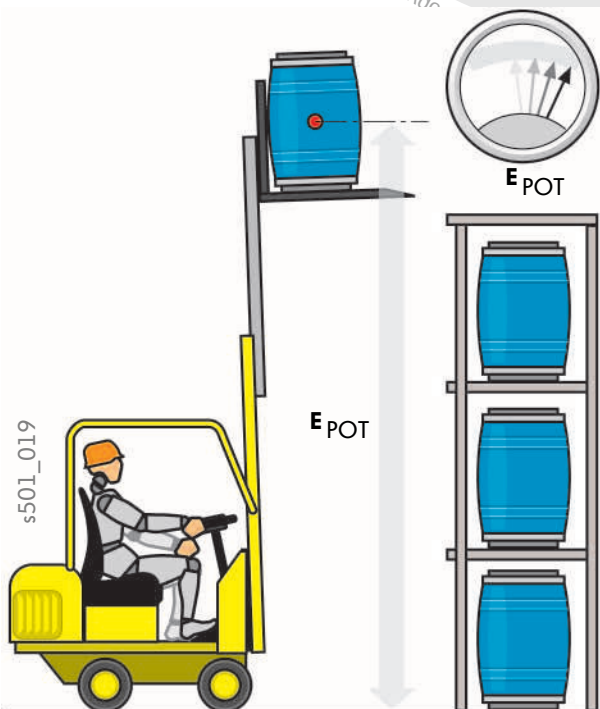
If a body which is at rest on the floor is lifted up e.g. with a fork-lift truck and placed onto a shelf, where it is again at rest, its amount of potential energy has increased by the energy which the fork-lift truck brought to bear as work whilst lifting.

This potential energy is described as the amount of energy added to a body due to its location with reference to a surrounding force field (usually a gravitational field/earth's gravitation).

If the location of the body changes in the direction in which the gravitation acts, i.e. it falls down, its potential energy decreases. If it gains height counter to the gravitational force, it increases. If the location of the body changes perpendicularly to gravitation, i.e. at the "same height" on 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.



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



Due to the work which the fork-lift truck performs when lifting the body, the latter's potential energy increases by an amount equivalent to the work.

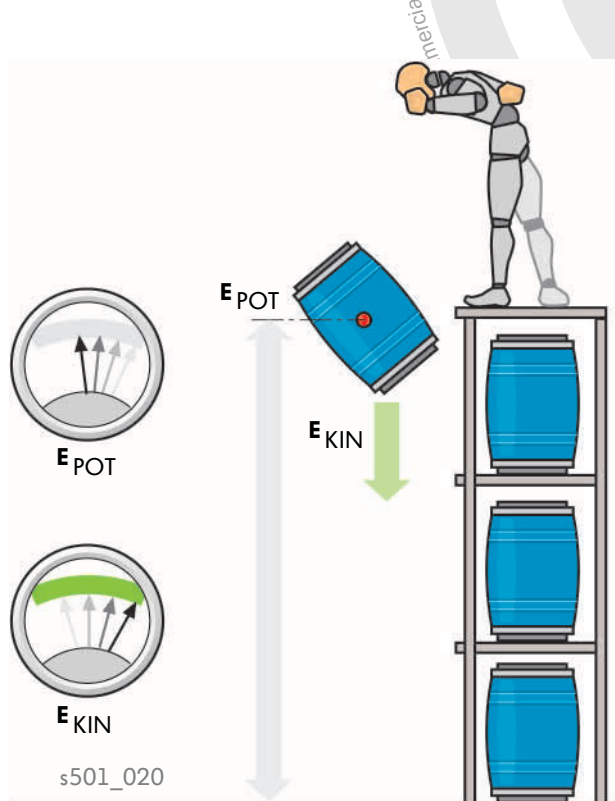
What is energy?

Kinetic energy

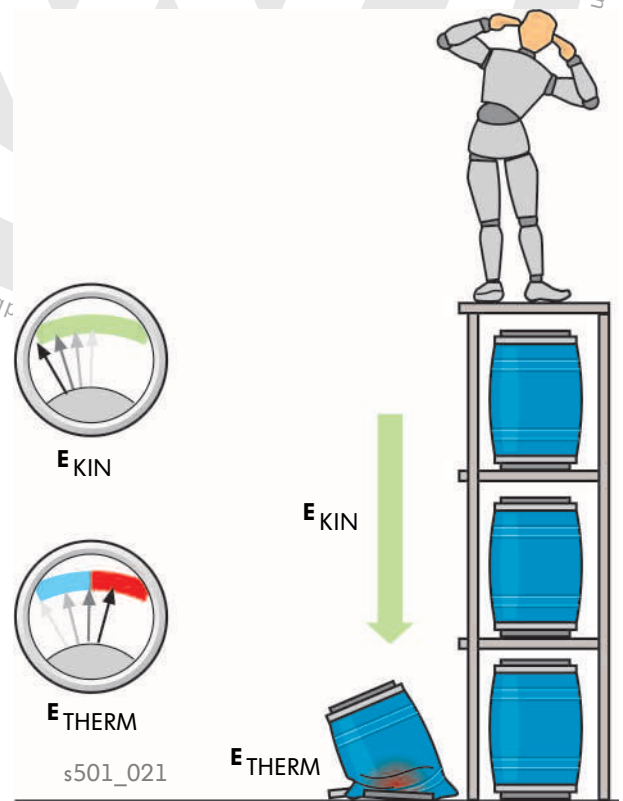
This is the energy "contained" in a state of motion. The more a body is accelerated and the higher its speed then becomes, the greater its kinetic energy. If no further forces act on the body and no energy losses occur, e.g. due to friction, its kinetic energy remains constant.

In this case, it continues to move without changing its speed.

If it loses speed due to e.g. friction, however, part of its kinetic energy is transformed into thermal energy.



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



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

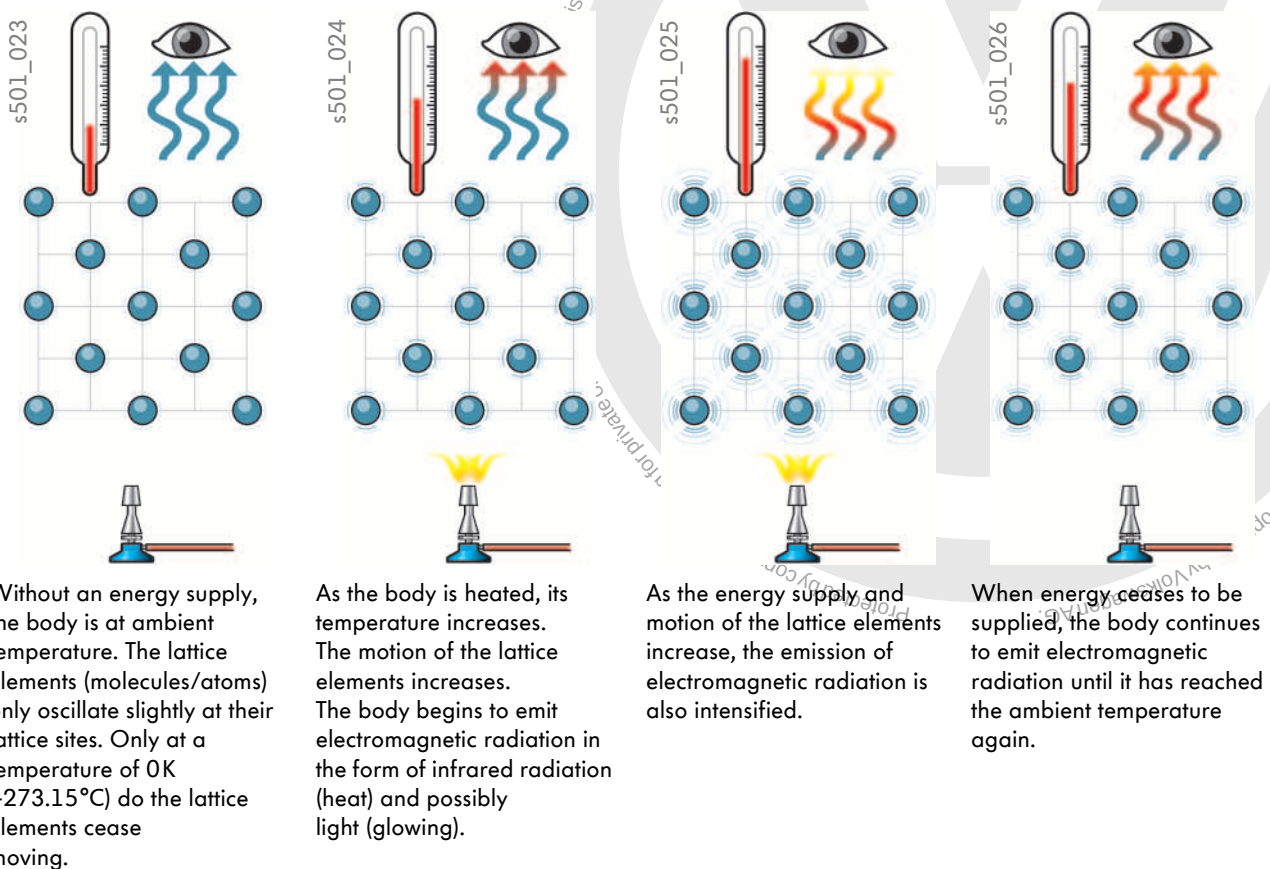
Thermal energy

Expressed in vastly simplified terms, thermal energy or heat energy is based on the motion of a body's atoms or molecules.

The more thermal energy that is transferred to the body, the more the atoms (molecules) begin to oscillate in their position in the body's structural lattice. Each heated body attempts to "get rid" of the thermal energy which has been supplied to it in order to return to a lower-energy and thus more stable thermodynamic state.

Amongst other methods, this is carried out by the atoms' dissipating the surplus energy into the environment in the form of electromagnetic radiation. Depending on the material's characteristics, we can feel this as thermal radiation and possibly see it in the form of glowing.

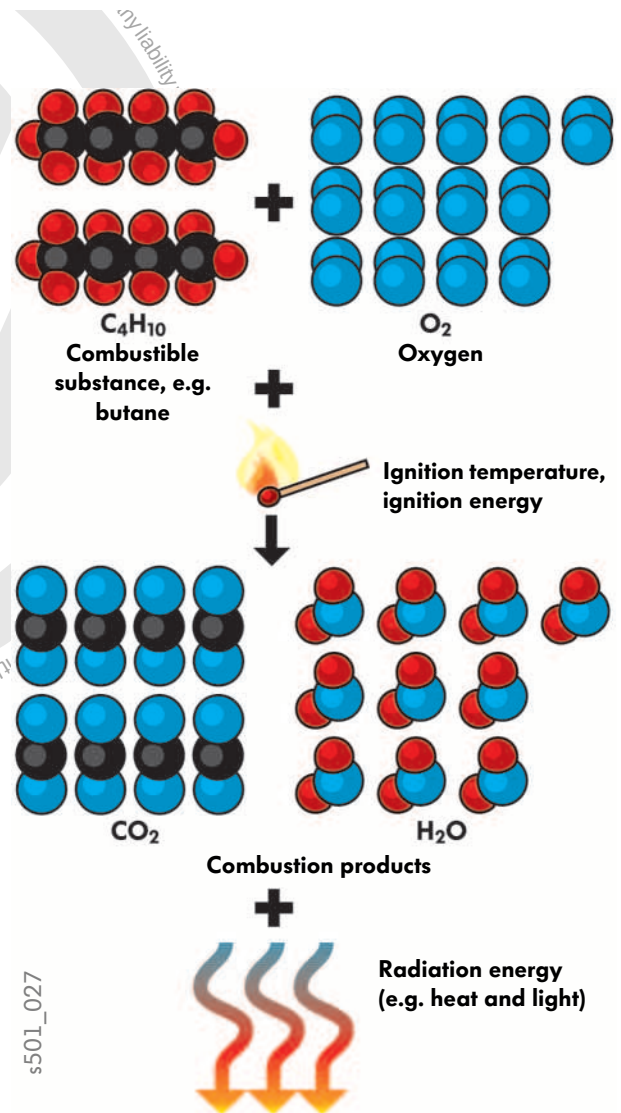
If the energy which is supplied exceeds a specific value for the material comprising the body, the atoms (molecules) are released from the body's structure. The material melts or evaporates. If a sufficiently high amount of thermal energy is supplied to a mixture of atoms (or molecules), in addition to other conditions, they may bond to form new molecules. In this case, thermal energy is transformed into chemical binding energy.



What is energy?

Chemical energy

Chemical energy or binding energy corresponds to the amount of energy which has to be expended to bond the involved substances (atoms or molecules). If these bonds are broken apart e.g. when fuel molecules are combusted, part of this binding energy is released again as thermal energy and can be used to carry out work (e.g. in the combustion engine).



Conversion of forms of energy and conservation of energy

As has been described, energy can be converted more or less completely into different forms. The statement that no energy can be lost during this is important. Regarded superficially, the conversion of chemical energy from fuel into kinetic energy in a combustion engine occurs incompletely. Energy is apparently lost. This merely appears to be the case though, as some of the chemical energy which is released is also converted into thermal energy and other forms of energy. However, the sum of all of these forms of energy must again correspond to the amount of the chemical energy.

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

It is essentially the case that the sum of all forms of energy contained in an enclosed system, i.e. a system from which no energy is able to escape due to interactions, is constant. No energy is lost. By the same token, none can be added (principle of the conservation of energy).

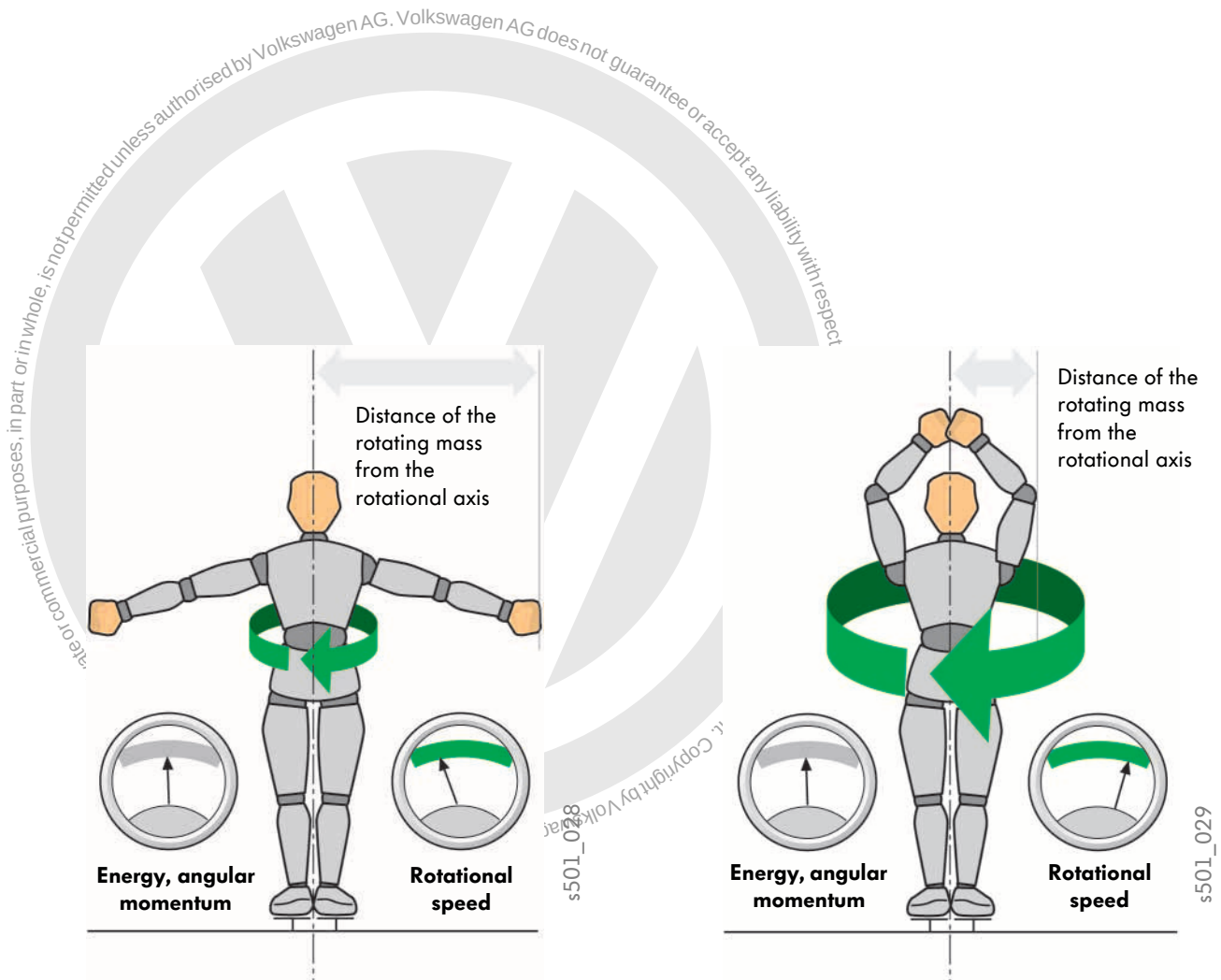
Example of angular momentum

The conservation of energy may also lead to the fact that a body's behaviour or movement appears to change without any external influence. An ice skater performing a pirouette can be used as an example to analyse this. In this example, angular momentum is regarded as a form of kinetic energy.

If the skater begins the pirouette with his arms outstretched and subsequently pulls his arms in towards his body, his rotational speed increases without other forces acting externally to increase acceleration.

The ice skater gives himself a certain angular momentum when he starts his pirouette.

This angular momentum is dependent on the mass of the skater, the rotational speed and the distance between the rotating mass and the rotational axis. If the ice skater reduces the distance from the rotational axis by pulling his arms in, the two other influencing variables must change accordingly to guarantee energy conservation or conservation of the angular momentum. The ice skater's weight remains the same, so his rotational speed has to increase to compensate the decrease in distance.



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

What is matter?

If we follow Einstein's $E=mc^2$ equation, matter can be perceived as "solidified", tangible energy. However, this does not explain what matter actually is.

Even the ancient philosophers assumed that all things around us are comprised of certain types of the same basic substances. What these basic substances were, however, 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, and Anaximenes attributed everything to gas (air). Empedocles pronounced the conciliatory theory that all things consisted of fire, water, earth and air. Empedocles' opinion was upheld well into the Middle Ages, and led in the field of alchemy to attempts 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 represented the opinion that everything was formed from the same types of atom, units of matter which cannot be broken down any further. This roughly corresponds to our present concept of matter.

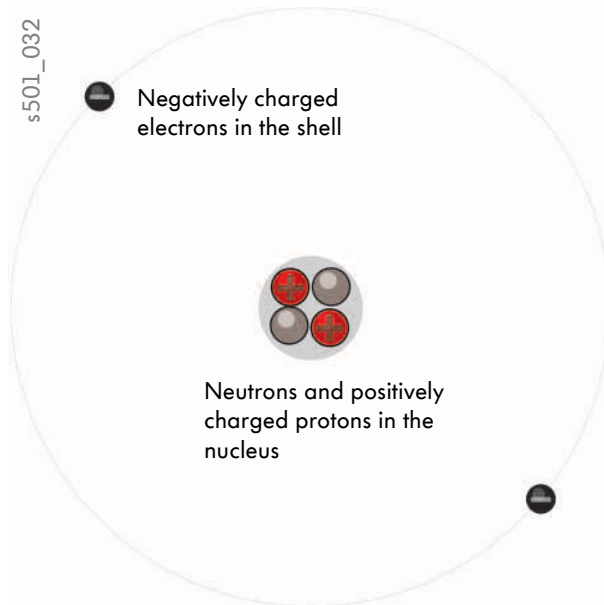
However, it was demonstrated that Democritus' atoms could in fact be broken down further, with the result that current theories regarding the structure of matter look deep into the atom and define new, minute elementary particles.

There is not just one "type of atom" (element) which makes up matter with the aid of elementary particles though; instead, there are now 118 elements, although only the first 83 of these are stable. The other 35 elements are radioactive, i.e. they break down into other types of atom whilst 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 (particle accelerator).



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

Basic structure of elements



Structure of an atom using helium as an example

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

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Excerpt from the periodical table of elements

The elements of the 8 main groups are shown up to the 5th period.

Depending on the design of the periodical table, the internationally applicable abbreviation (e.g. Be for beryllium), the atomic number (at the top left of the box in this case) and the atomic mass (bottom centre here) are specified in each box.

Each atom consists of the elementary components of electrons, protons and neutrons. These in turn consist of even smaller elementary particles (quarks, bosons, muons, etc), which have to be disregarded here.

Protons and neutrons form the nucleus and thus the centre of an atom's mass, which is very, 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 is therefore an extremely minute and heavy nucleus with a great deal of "nothing" surrounding it.

Protons carry a positive elementary charge, electrons a negative elementary charge. Neutrons have no electrical charge. So that an atom can be electrically neutral, it has the same number of protons and electrons.

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 periodical table of elements (iso = same, topos = location). The periodical table of elements structures all types of atom according to the number of protons in their nucleus (atomic number) and according to their chemical bonding behaviour, which is determined by the atom's outer electrons (valence electrons). Elements cannot be broken down any further by chemical processes, therefore corresponding extensively to Democritus' concept of atoms as the smallest components of matter.



What is matter?

There have been and still 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. In this case, the protons and neutrons can be imagined together 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 one special effect or rather its failure to materialise:

According to classical electrodynamics, a charge carrier running on a circular track emits electromagnetic radiation, i.e. it loses energy. Due to the law governing the conservation of momentum, this should lead to the electron's collapsing into the nucleus; however, this obviously does not occur as we would not otherwise exist.

Niels Bohr therefore developed the concept that the electrons must have special shells or energy levels at which they emit no 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 no longer describes elementary particles such as electrons as concrete particles, specifying a location and a velocity, but in the form of highly-complex probability functions, because location and velocity can no longer be determined simultaneously within this order of magnitude (Heisenberg uncertainty principle). The statement is therefore no longer "Here is an electron and it has this velocity" but "An electron may perhaps be here, and if this is its location, I cannot determine its velocity there".

Relationships which are clear to us, such as cause and effect, also lose their clarity at quantum level. This 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".

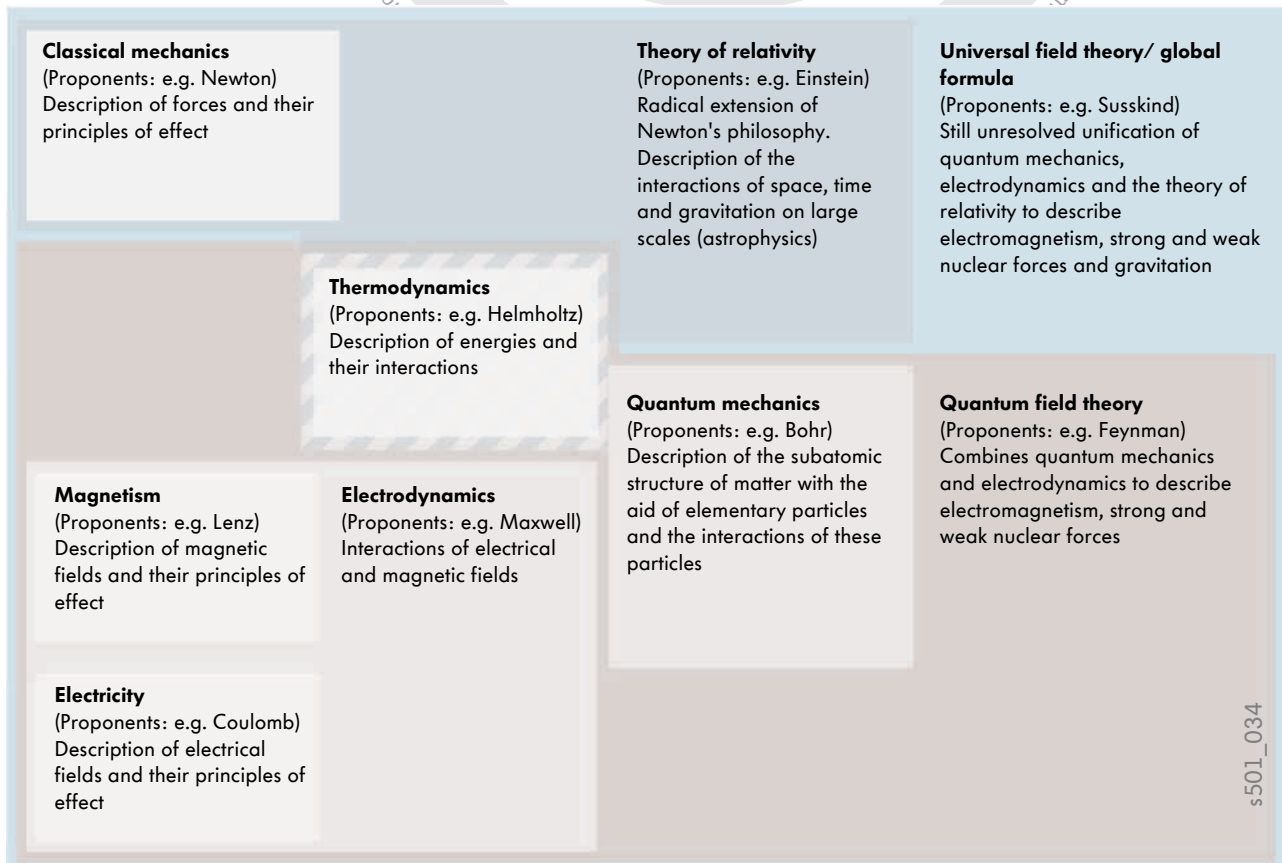
According to the shell or planet model, an atom's electrons orbit the nucleus like planets orbit the central body. The model of a carbon atom is portrayed here as an example, with 6 protons and 6 neutrons in the nucleus plus 6 electrons in the shell. In this case, a specific number of electrons assume a defined, "stable" electron orbit (electron shell), in which 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). Further shells are added in elements from higher periods (e.g. sodium).

At subatomic level, a great many electrical and electronic devices (computers, sensors, chip cards, etc.) which are a matter of course for us today and are used in automotive engineering nevertheless function according to rules which are described better by quantum theory than by the classical theories. We should therefore 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 perhaps 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 perhaps also be achieved in 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 therefore remains exciting.



Vastly simplified overview of the various physics theories.

What is matter?

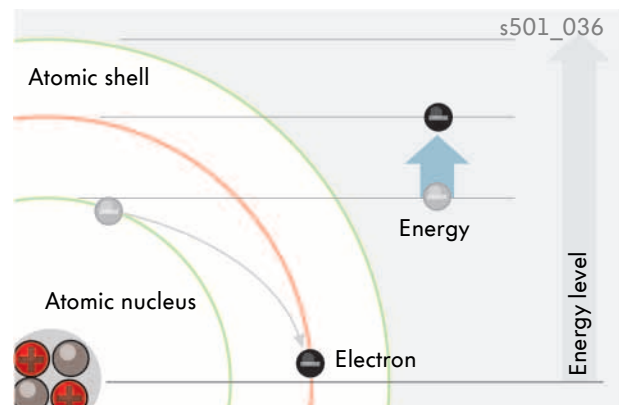
Subatomic variables influencing sensor technology

Certain of the measurement processes described in this series 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, e.g. electron spin. Describing and explaining all of the facets of these characteristics here would exceed the scope of this series by far. Only the following vast simplification is therefore provided here. Under normal circumstances, all physical systems (e.g. atoms or their constituents) attempt to assume a state which is as low in energy as possible, as this is thermodynamically more stable than a higher-energy state. This behaviour is used in certain measurement methods, e.g. tomography, by artificially supplying particles with energy so that they make the transition to an excited, energetically higher state. To return to the more stable state, these particles then attempt to rid themselves of their "surplus" energy by emitting e.g. radiation or changing their quantum characteristics.

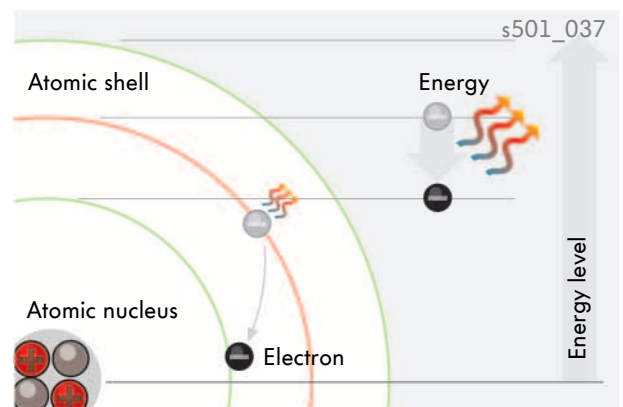
This can then be measured with the aid of suitable sensors.

Example of an electron:

If we remain with the shell model of the atomic structure, an atom's electrons are distributed amongst certain "stable" energy levels or shells. This refers to what are also called "permitted" energy levels at which, according to Bohr, the electrons are able to orbit without collapsing into the nucleus. A suitable energy supply can therefore be used to excite the electrons to jump to a higher, "permitted" energy level. As this process, called a quantum leap, has transferred the electron to an energy-rich and therefore thermodynamically less favourable state, the excited electron attempts to "rid itself" of the energy as quickly as possible by emitting electromagnetic radiation and thereby return to the lower and thus more stable energy level. The radiation which is emitted can be qualitatively and quantitatively determined using suitable sensors, and the data which are obtained can be used to draw conclusions regarding the object to be measured.

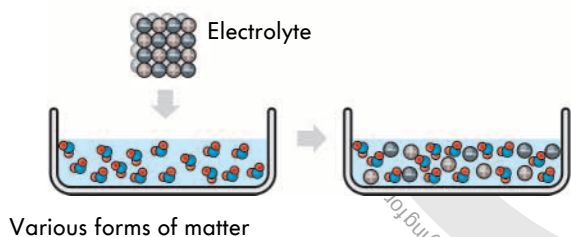
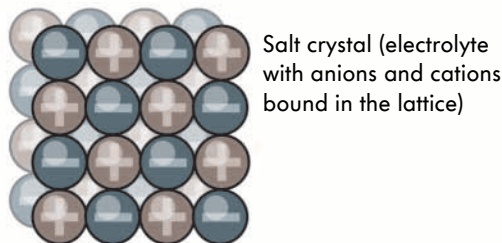
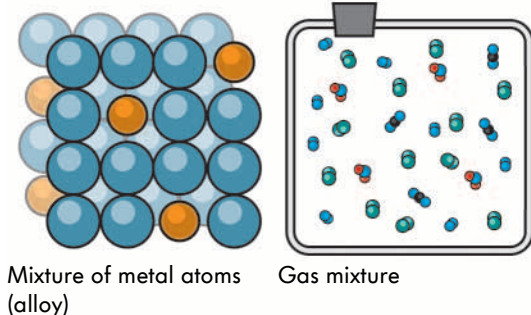
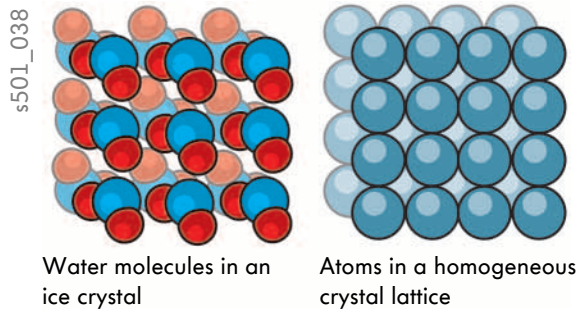


By supplying energy, the electron is raised to a higher energy level (quantum leap).



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

Mixtures, compounds, elements and ions



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 (20°C, 1 bar), these atoms form a solid in a lattice structure (e.g. carbon) or a gas (e.g. helium) or a liquid (e.g. 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, e.g. water (H₂O), or a very large number of atoms (e.g. protein molecules).

And finally, matter may also be heterogeneous, i.e. consisting 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 behaviour, it is important not to confuse these three terms - element, compound and mixture.

If an atom or molecule loses one or more electrons or takes these from other atoms, the electrically charged particles which 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 e.g. by being dissolved in water.



What is magnetism?

Magnetism is a sub-area of electrodynamics. It describes a dynamic effect which can be observed in moving electrical charges, conductors through which current flows and between magnetised or magnetising objects. Magnetism is based on the magnetic characteristics of elementary particles and/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 neutralise each other entirely.

Ferromagnetism & co.

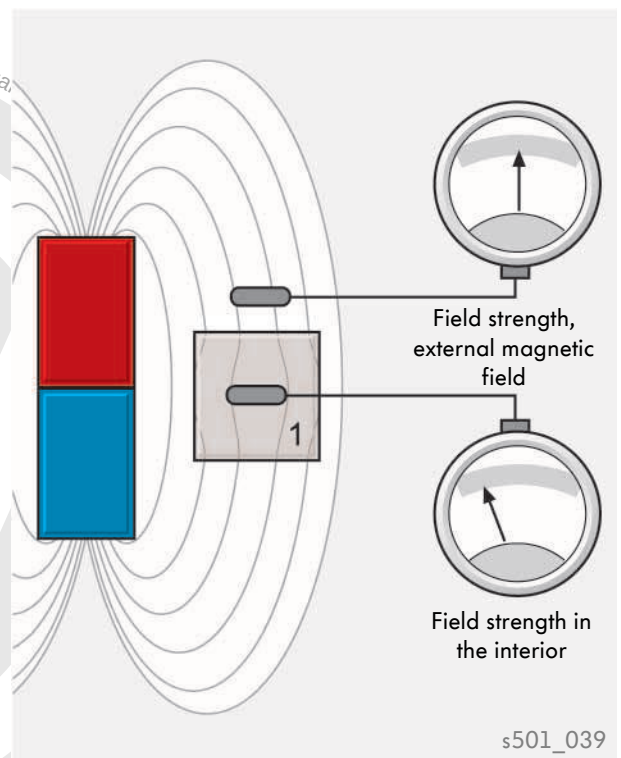
Five different types of magnetism occur in solids:

- Diamagnetism
- Paramagnetism
- Ferromagnetism
- Ferrimagnetism
- Antiferromagnetism

At this point, we only intend to briefly explain the first three, as magnetic interactions play a role in certain measurement processes in sensors (e.g. inductive senders, Hall senders).

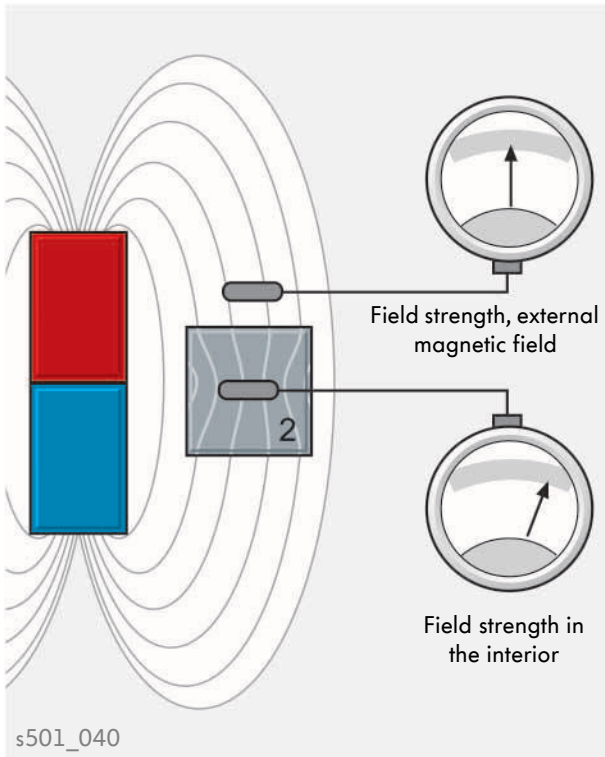
Diamagnetism

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

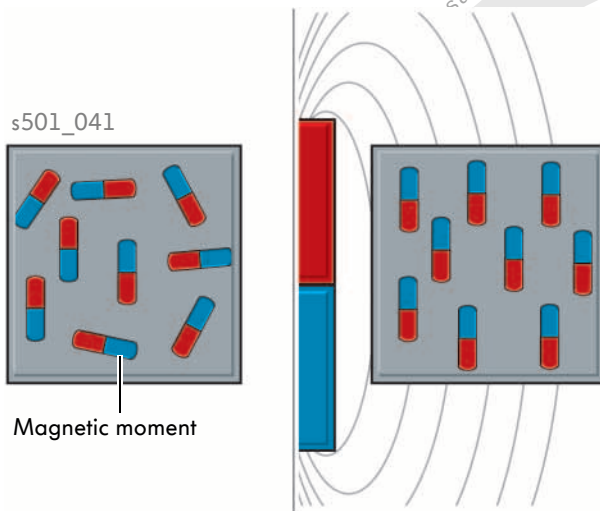


Diamagnetic substances (1) weaken an external magnetic field in their interior.

Paramagnetism



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



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

A substance is called paramagnetic if it intensifies a magnetic field, which penetrates it, in its interior.

This effect occurs because the constituents of the substance (atoms, molecules, ...) themselves possess a magnetic moment. However, the substance does not show its own internal magnetic field, as the constituents' magnetic moments are unordered without an external magnetic field and statistically neutralise each other.

The constituents are only oriented parallel to the external magnetic field as a result of the external magnetic field. The strength of the external magnetic field therefore increases in the interior of the substance. If the external magnetic field is removed, the paramagnetic substance's internal magnetic field collapses again, as the constituents' orientation is dissolved.

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



What is magnetism?

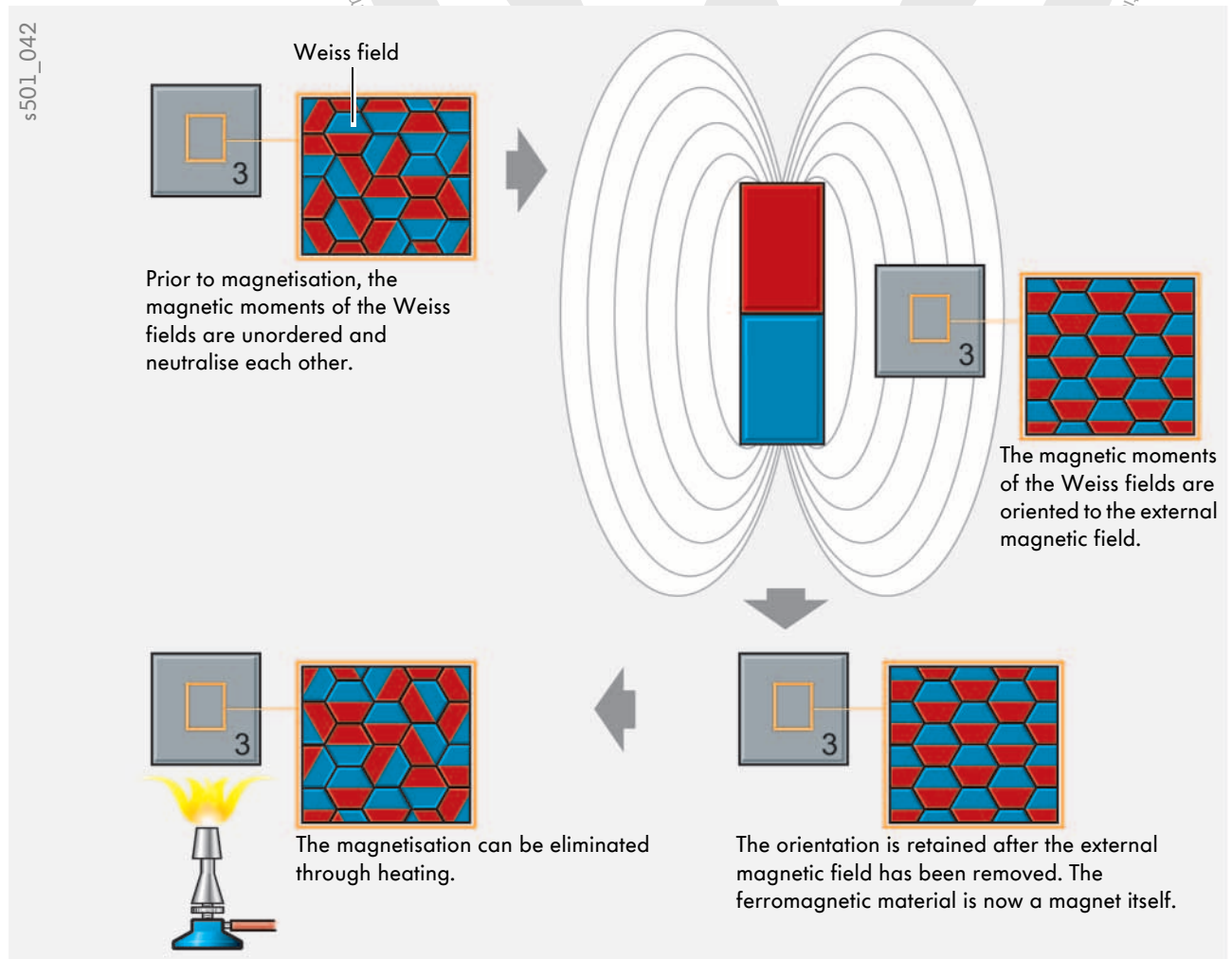
Ferromagnetism

A substance is called ferromagnetic if its constituents retained the magnetic orientation after an external magnetic field has been removed. The substance is therefore magnetised 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, however, these particles and their magnetic moments are already aligned in parallel in small areas of the substance, called Weiss fields.

On the whole, though, these fields' magnetic moments neutralise each other, with the result that the substance does not initially appear to be magnetic. If an external magnetic field is now applied, the Weiss fields are aligned parallel to the external magnetic field so that the substance itself now also has a magnetic field.

This is retained even after the external magnetic field has been removed. The substance can be demagnetised again by heating or mechanical impact.



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

On fields and field strengths

A magnetic field can be generated by magnetic or magnetised materials, by electrical currents in electrical conductors or by the temporal change in an electrical field. Fine iron chips can be used to visualise magnetic fields on a surface. The points at which a magnetic field enters and exits a magnetised substance are called poles, and are opposed to each other. They are referred to as the north and south poles depending on their orientation with reference to the earth's magnetic field. This means that poles with the same orientation (north and north, south and south) repel each other and poles with different orientations (north and south) attract each other.

The term "field" and induction

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

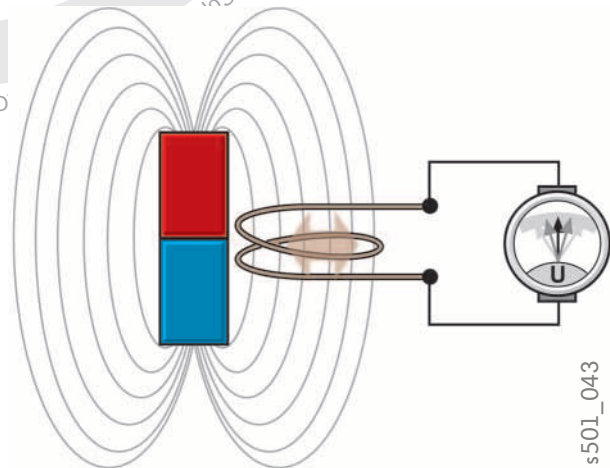
The strength of a magnetic field is described using two physical variables: the magnetic field strength and the magnetic flux density.

Because moving charges build up their own magnetic field, interaction with an external magnetic field takes place, resulting in the moving charge's experiencing a force.

This force, which a magnetic field exercises on moving electrical charges, 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 charges' direction of movement.

If the Lorentz force acts on electrical charges in a conductor, a current is generated in the conductor. Called induction, this process forms the basis of the function of generators.

Induction is also used in various sensor technologies.



If an electrical conductor is moved through a magnetic field, the Lorentz force which acts on the conductor's free electrons induces a current, resulting in the occurrence of a measurable electrical voltage.

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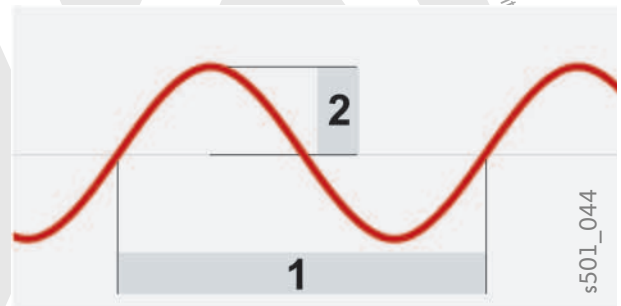


What are electromagnetic waves?

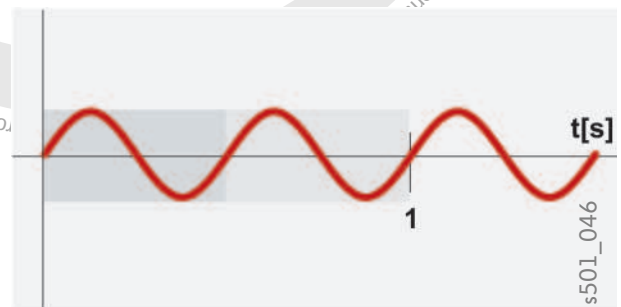
We haven't been surrounded by electromagnetic waves or fields just since the invention of mobile phones. Only the amount has increased. The field of physics which deals with electromagnetic waves and electromagnetic interactions is called electrodynamics. It is based extensively on the research conducted by James Clerk Maxwell in the 19th century, and was combined with quantum mechanics to form quantum electrodynamics in the mid-20th century.

The interaction between electrical and magnetic fields is investigated and described in the field of electrodynamics. Both electrical fields (e.g. in capacitors or coils) and magnetic fields (e.g. around conductors and coils through which current is flowing) are bound to the object which generates them. This means that they can be ascertained only on that object and have an effect only there, but not independently of it. If electrical and magnetic fields interact with each other, this leads to the creation of something which expands in space at a speed of approx. 300,000 km per second (speed of light), irrespective of the object which generates it. This is electromagnetic radiation, which expands in the form of waves.

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



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



The frequency is the number of wavelengths passing through a point per second, and is specified in Hertz. The wave shown above has a frequency of 2 Hertz, i.e. 2 wavelengths (oscillations) pass through a point per second.

Electromagnetic waves occur in a gigantic range of wavelengths. This ranges 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 and thus the higher its frequency, the higher the wave's energy is. The longer the wavelength and thus the lower its frequency, the lower the wave's energy is. All wavelengths shorter than 200 nm (0.0000002 m) is harmful to biological organisms.

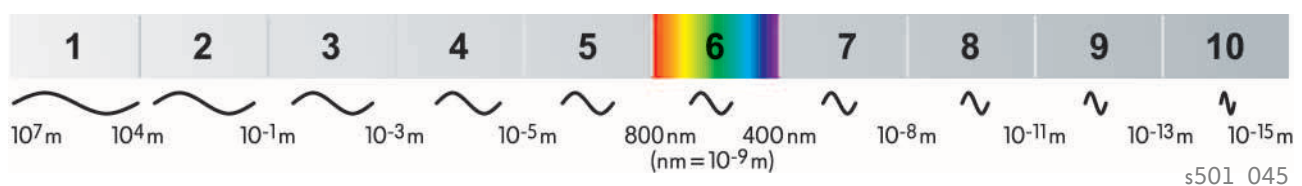
Different but so similar: heat, light and radar

We can perceive heat and light directly through our senses. Radar is an electronic localisation system which determines the speed and the distance of an object from the radar source and which we can render visible using corresponding technical aids (radar system with monitor).

Although we perceive heat and light in completely different manners, both are based on electromagnetic waves as their transmission medium. Radar also makes use of electromagnetic waves, but in such a long wavelength range that our "built-in" senses are unable to perceive it.

Heat, or infrared radiation, lies in a wavelength range of $2.5\mu\text{m}$ to 1mm .

The short wave end of this wavelength range is followed by the range of visible light, which extends from 380nm to 780nm . Radar lies beyond the long wave range of infrared radiation in a wavelength range of 1mm to 10m . Our senses are unable to register anything which lies below a wavelength of 380nm . This includes UV, X-ray and gamma radiation, which are so energy-rich that they can damage biological systems, among other things. And we are unable to directly perceive everything which lies above a wavelength of 1mm , the terahertz, microwave, radio wave and low-frequency range.



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)

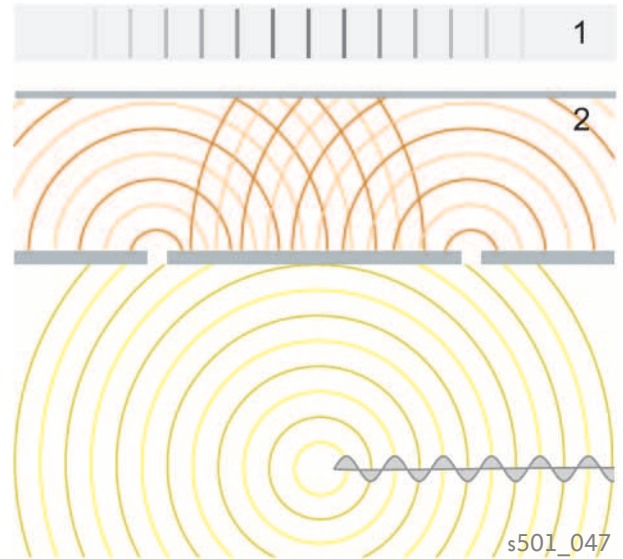
What are electromagnetic waves?

Wave, particle or both?

If what is emitted by a source of electromagnetic radiation is allowed to pass through two narrow, parallel slits, interference patterns are formed on the side facing away from the source. These stripe patterns are typical for wave propagation.

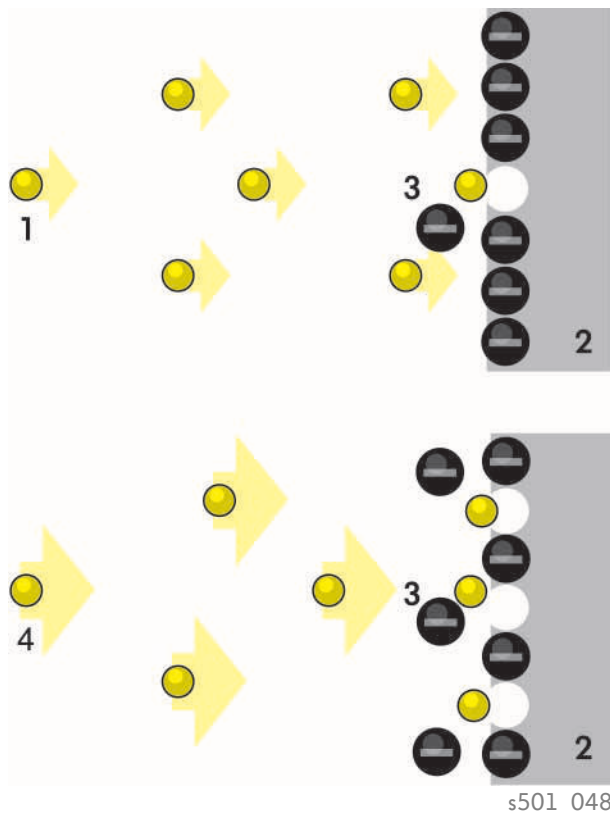
Where the electromagnetic radiation passes through a slit, a new wave front propagates in circles from the other side of the slit, in precisely the same way as when a stone is thrown into a pond. Because this experiment involves two slits, two wave fronts which interfere with each other propagate from the slits. Interference means that when two wave troughs or wave peaks encounter each other, their amplitudes are added, i.e. they intensify each other. But when a wave peak encounters a wave trough, they neutralise each other.

Like the waves on a pond, stripe patterns occur on a projection surface positioned perpendicular to the direction of propagation in the experiment.



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

After researchers had successfully repeated this electromagnetic radiation experiment many times, the opinion that electromagnetic radiation behaves like a wave was formed. On the other hand, a phenomenon called the "photoelectric effect" cannot be explained satisfactorily with the wave character of light. This involves the observation that energy-rich electromagnetic radiation (e.g. UV radiation) directed onto a metal surface causes electrons to be ejected from the metal surface. However, the number of emitted electrons is not dependent on the intensity (amplitude) of the radiation, as should be assumed, but on the frequency of the radiation.



The solution to the problem was provided by Albert Einstein on the basis of 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 which are released. Thus, Einstein explained the photoelectric effect, portrayed in vastly simplified form here, and electromagnetic radiation had a second character: just as Newton had suspected before Einstein, it can be regarded as a stream of particles.



Dependence of the photoelectric effect 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 high-energy photons (4)

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

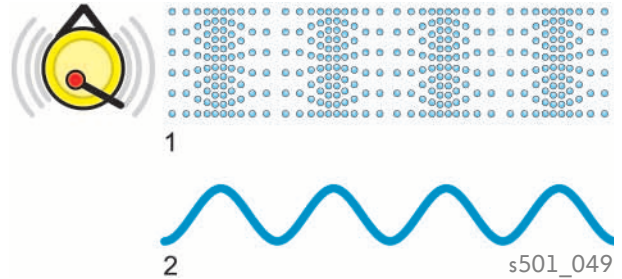
Which of the characters of electromagnetic radiation displays depends on the experiment. The light "decides" which character to display only when one examines it with the appropriate means. This view contradicts our common sense. Something cannot simultaneously have two different forms. The same piece of wood cannot be given the shape of a sphere and a cube at the same time. In the quantum-mechanical world of elementary particles, however, this type of "indeterminacy" is not a contradiction.

What is sound?

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 is propagated. This character becomes particularly clear when perceiving very deep sounds which are not only heard but also felt by the body.

So that a medium is able to conduct sound, it must possess corresponding elastic characteristics like e.g. a gas or a liquid, as the relevant medium would otherwise be better for use as soundproofing. The propagation velocity of sound is not constant like the speed of light. Amongst other aspects, it is dependent on the characteristics of the elastic medium through which the sound moves.



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 propagate further and faster in the sea than in air.

This means that, the greater the intrinsic motion of the medium's constituents is (e.g. in the case of gas molecules), the more extensively sound waves are "braked".

Sound is unable to propagate in a vacuum, i.e. when a medium is absent.

This means that, as gigantic as the explosion of a supernova is, an observer in space's vacuum can merely see it. It cannot be heard with the ears in space.

In the earth's atmosphere at a pressure of 1 bar and a temperature of 20°C, sound propagates at a speed of approx. 343 metres per second.

For humans, the frequency range of audible sound lies between approx. 16 Hz and 20 kHz depending on the age of the person and the state of his or her hearing.

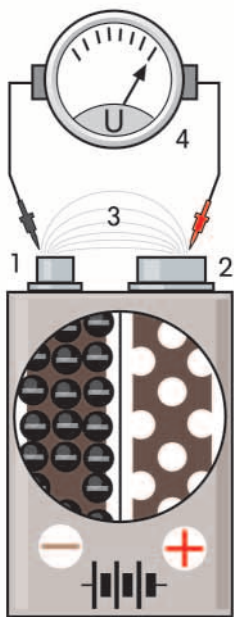
Infrasonic sound refers to sound waves with a frequency lower than our hearing range; ultrasonic sound refers to sound waves with a correspondingly higher frequency.

What do U, I, R and C mean?

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

The triumvirate of voltage, current and resistance

Voltage (U), amperage (I) and electrical resistance (R) are related via Ohm's law. This law states that the electrical resistance is proportionate to the voltage and the amperage is inversely proportionate. But what do these terms mean?



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

Electrical voltage

This is also referred to as the potential difference. A voltage source such as e.g. 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. This means that a negative electrical potential is present at the anode; expressed figuratively: a "surfeit of electrons is waiting" to carry out work in an electrical consumer.

In contrast, a positive electrical potential is present at the cathode, i.e. "electrons are awaited" there. The greater the difference between the two electrical potentials, the higher the voltage which the battery supplies. An electrical field exists between the battery's two terminals due to this potential difference.

In this case, the voltage value specifies which work or energy is necessary to move a charge carrier (e.g. an electron in an electrical conductor) within this field. Voltage can therefore also be understood as the energy content of an electrical charge which it can release in a consumer, or its capacity perform work in a consumer.

The electrical unit of voltage is volt. The conventional international abbreviation for voltage is "U".



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What do U, I, R and C mean?

Current and amperage

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 to the cathode due to the force of the electrical field which exists as a result of the voltage.

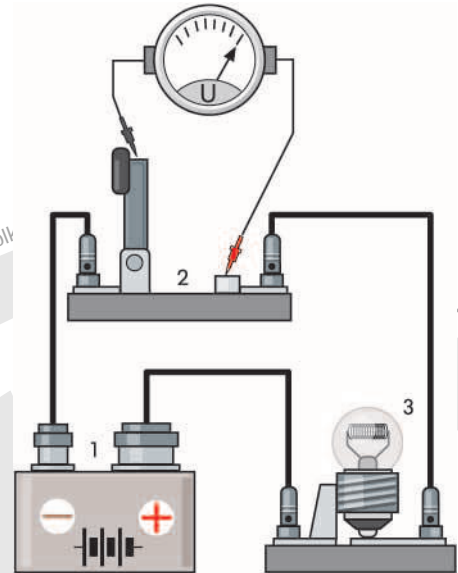
As a rule, however, a battery is not simply short-circuited; instead, the electrical energy which is stored in a battery is used to carry out work equivalent to the voltage in an electrical consumer such as an electric motor or a bulb.

Let us take a closer look at the example of a bulb: A switch and a bulb are connected to the battery using electrical cables. As long as the switch is not closed, no current flows, but the current circuit's voltage can be measured e.g. at the two contacts on the switch.

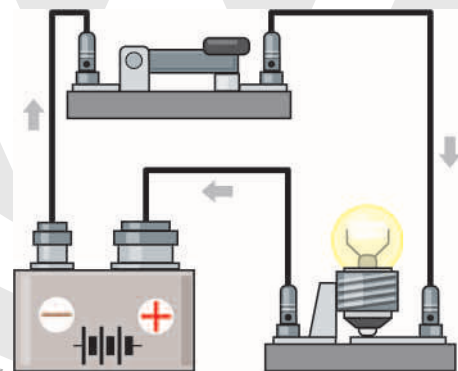
If the switch is closed, the electrons flow through the switch from the battery to the bulb, and from there back to the battery, due to the voltage and the related electrical field. Expressed figuratively, the battery therefore functions as an "electron pump". The intensity of the current, i.e. the quantity of electrons (charge carriers) which make their way to the consumer per unit of time, is measured in amperes.

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 conventional international abbreviation for the amperage is "I".

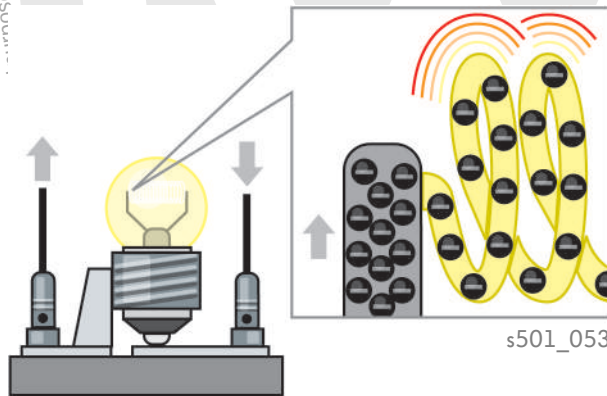


Test set-up with battery (1), switch (2) and bulb (3) as an electrical consumer with the switch open.



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

The level of the amperage depends on the voltage and the characteristics of the electrical cables which are used. The larger the cable cross-section and the higher the conductivity of the 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), which has a very 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 when the electrons are "pumped through" it.

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

The bulb lights up.

Expressed simply, the electrons perform work in the bulb's wire in order to pass through it, and lose energy whilst doing so before they return to the battery's cathode.



What do U, I, R and C mean?

Electrical resistance

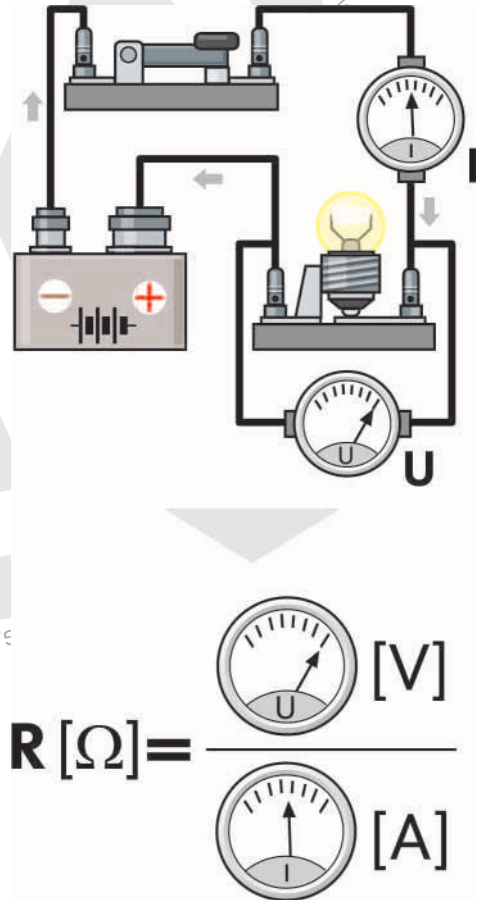
In mathematical terms, the electrical resistance represents a relationship between the voltage and amperage. This was recognised and expressed in a mathematical formula by Georg Simon Ohm. The unit of electrical resistance is named after him. Physically, the resistance is a measure of the voltage which is necessary to achieve a specific amperage in an electrical conductor.

The electrical resistance is caused by the electrical characteristics of the conductor through which the charges (e.g. electrons) flow. The resistance value is dependent on the temperature, the cross-section of the wire (i.e. the diameter of the conductor) and a material characteristic called the "specific resistance". This can be understood as the reciprocal value of conductivity, another material characteristic.

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

If, as in the case of a metal for example, the electrons in the material are already delocalised, i.e. they 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 because there are many "free" electrons which are accelerated in the conductor by the electrical field built up due to the voltage.

The material has a high conductivity and, due to the reciprocal value, a low specific resistance. Due to its temperature dependency, the resistance is a suitable measurement variable for measuring temperature.



The electrical resistance (R) of a component can be calculated by measuring the amperage (I) and voltage (U). If, on the other hand, e.g. the resistance and the voltage are known, the amperage can be derived from these.

If, however, the electrons are firmly bound to the relevant atoms in the form of chemical (covalent) bonds, these are extremely unwilling to release the electrons for charge transportation.

These materials therefore have low conductivity and a high specific resistance. They are called poorly or non-conductive materials or insulators if their conductivity is very, very low in relation to the environment.

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, simply has to be pumped into them to transform them into a state which is electrically conductive (ionised plasma).

In many materials, this energy value (ionisation temperature, transition temperature) is relatively easy to achieve, e.g. when ionising a gas, which is non-conductive under normal conditions, in a bulb.

A material's conductivity and therefore also its electrical resistance are temperature-dependent.

This can be easily visualised in the case of metals:

as the temperature rises, the atoms begin to oscillate increasingly at their lattice sites, and the electrons also collide with increasing frequency.

In total, these movements increasingly inhibit charge transportation through the conductor.

The resistance increases.

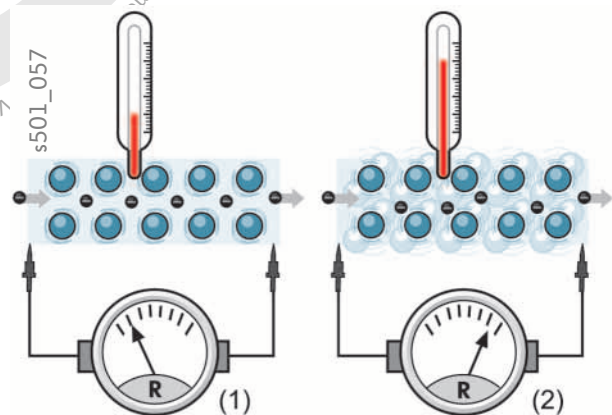
As the temperature falls, the resistance of metals and semi-conductors decreases, as the movement of the atoms in the lattice continues to decrease as the temperature drops.

As of a specific threshold value, the charge can then be transported practically without the loss of electrical energy.

This is called superconducting. However, this only usually occurs at very low temperatures which lie close to absolute zero (0K; -273.15°C).

The behaviour 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, for example, in temperature sensors. Ohm's law, however, can also be applied to determine voltage or amperage.



Temperature dependency of the 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?

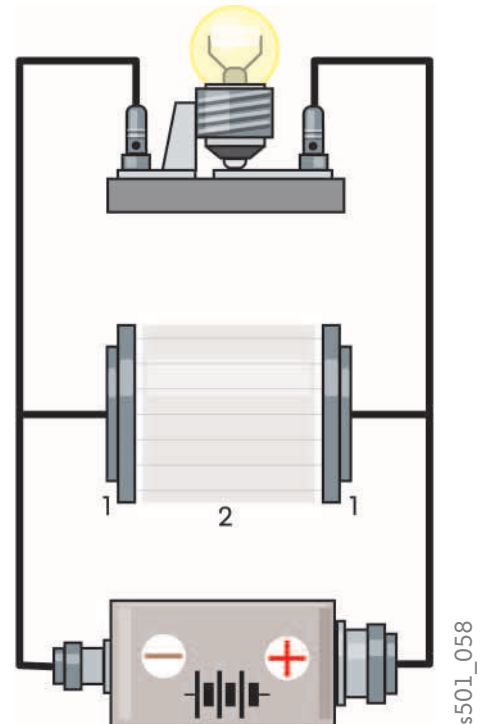
Capacity and dielectric material

The capacity is a measure of a capacitor's capability to store an electrical charge.

The unit for capacity is Farad; the conventional international abbreviation is "F". The capacity is proportional to the quantity of the charge and inversely proportional to the voltage applied to the capacitor.

The simplest form of such a charge storage facility is the electrical plate-type capacitor.

A plate-type capacitor is structured in such a way that two conducting plates are located opposite each other. Whilst a charge can also be stored without an additional material, which is positioned between the two plates and is called a dielectric material, the capacitor's storage capability can be increased or changed by selecting a suitable dielectric material. A capacitor's dielectric material consists of a poorly or non-conducting, non-metallic substance. In addition to the characteristics of the dielectric material, the capacitor's capacity is also dependent on the area of the capacitor plates and the distance between the capacitor plates.



Simplified illustration of the structure of a plate-type capacitor: 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.

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 form that charge carriers (electrons) flow through it. However, the current flow continues downstream of the capacitor in order e.g. to cause a bulb to light up. This phenomenon is based on a physical characteristic which is called electrical flux. The 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 and the bulb therefore remains lit until the capacitor is completely discharged. In sensor technology, for example, pressures or humidity are measured with the aid of special capacitive sensors.

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 periodical 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 physical unit of the capacity of capacitors is named after him: Farad



Glossar

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 into 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
summarised

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 of Volta

18.02.1745 - 03.03.1827

Italian physicist

The physical unit of electrical voltage is named after him: volt



