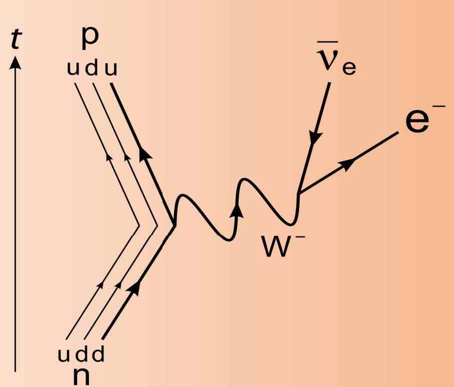
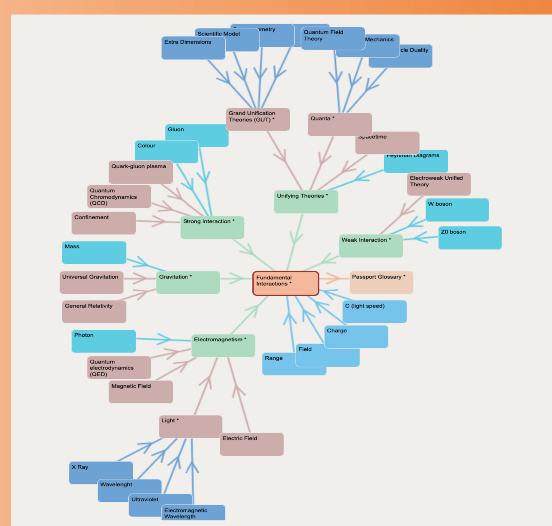
The Infinite Glossary: Fundamental Interactions

All the “Infinite Glossary” items are somehow linked. However, some links are stronger and more directs than others... Here are those related to the four known forces known today, and how they are described (as interactions between matter and fields) in the Standard Model of Particle Physics. Open questions about gravitation and the process of unifying theories are also included.





Translated from ‘Glossaire’, Passeport pour les deux infinis, *IN2P3/Dunod, https://pass2i.ijclab.in2p3.fr/ (French); updated with ICHEP2024 conference (https://ichep2024.org) for IPPOG*

Fundamental Interactions	
C (light speed)	The invariable and unsurpassable speed limit for all physical signals. In vacuum electromagnetic waves (and, therefore, photons) travel at light speed. The value of this physical constant, denoted c (for celerity), was set at 299,792,458 km/s in 1983.
Charge	The sensitivity of a particle to a fundamental interactions. They are respectively called electric charge for the electromagnetic interaction, weak isospin for the weak interaction, and colour for the strong interaction. If the charge of a particle is null the particle is insensitive to the corresponding interaction. If its is not, the higher the charge the stronger the effect. For example, electrons have an electric but no strong charge, meaning that the strong interaction does not affect them.
Field	A physical quantity that has a value in every point in space, e.g. temperature, pressure, or flow rate of a river. A field may vary in space – a torrent's flow changes when the riverbanks narrow or if there is a waterfall – and in time – in case of rising waters or drought. The concept of field is essential to describe the wave-related aspects of particle physics. The concept is also useful to study continuous media (macroscopic properties of solids, fluids, etc.).
Range	The range of an interaction is the typical distance over which its action is appreciable. Gravitation and the electromagnetic interaction have infinite range, while the ranges of strong and weak interactions are restricted to subatomic distances.
Standard Model of Particle Physics	A theory that describes strong, weak and electromagnetic interactions, as well as all of the fundamental particles known to date. Devised in the 1970s, the Standard Model is currently consistent with all the experimental tests for which predictions are available. The last missing component, the Higgs boson, was discovered at CERN in 2012.

Electro-magnetism	A theory introduced by Maxwell in 1864 which unifies electricity and magnetism. Although the two phenomena manifest very differently in experiments, they have a common origin. In addition to unveiling the nature of light, this theory introduced a new constant – light speed in vacuum – whose universality was incompatible with classical mechanics. The problem was eventually resolved by Einstein's theory of special relativity in 1905.
Electric field	A field created in all points of space by the presence of electric charges. If an electric charge is placed in an electric field, it is subjected to a force proportional to the electric field and to the value of its charge and is accelerated (gain energy) or repelled (lose energy).
Electromagnetic wave	A variation of the electric and magnetic fields caused, for instance, by the alternating movement of electric charges. Characterised by its frequency (or its wavelength), The visible light is a fraction of electromagnetic waves. Classified by ascending frequency, electromagnetic waves are called radio waves, microwaves, infrared waves, red waves, yellow waves, green waves, blue waves, violet waves, ultraviolet waves, X-rays, and gamma rays. In vacuum, they travel at light speed, c.
Light	In classical physics light is described as an electromagnetic radiation, i.e. a wave corresponding to the linear propagations of a magnetic field and of an electric field. In quantum physics light can be described in two ways, either as the propagation of an electromagnetic radiation (variation of electric and magnetic fields), or as the emission of a zero-mass particle called a photon, whose energy is proportional to the wave frequency.
Magnetic field	A field which is created in all points of space by moving electric charges and/or by the variation of an electric field over time. Since Maxwell's work, electric and magnetic fields can be described in a single formalism, the electromagnetic field. If an electric charge is placed in a magnetic field, the Lorentz force will bend its trajectory. The curvature of its path is proportional to the particle energy and to the inverse of the field.
Photon	The elementary grain of light, often noted γ. For particle physicists, electromagnetic waves are made up of photons whose energy is proportional to the wave frequency. The photon carries the electromagnetic interaction. Thus, two electrically charged particles attract or reject each other by exchanging protons.

Quantum electrodynamics (QED)	QED, or Quantum Electrodynamics, is a fundamental theory in physics that describes how light and matter interact. It combines quantum mechanics and special relativity to describe the particles interactions using complex probability amplitudes. QED is considered one of the most successful theories in physics due to its precise predictions and extensive experimental verification.
Ultraviolet	A radiation of electromagnetic waves whose wavelengths range from 10 nm (X-ray limit) to 400 nm (visible-light limit). For the associated photons, these limits correspond to the respective energies of 120 eV and 3.1 eV.
Wavelength	A physical value, homogeneous to length, that is used to characterise periodical phenomena. A wave is a physical phenomenon which propagates and is identically reproduced slightly later in time and slightly further in space. Wavelength is the shortest distance between two strictly identical points of a wave at a given time. When an electromagnetic wave propagates in vacuum, wavelength is inversely proportional to frequency.
X-ray	A high-frequency electromagnetic wave whose wavelength ranges from approx. 5 picometers to 10 nanometers. The energy of these photons can vary from a few eV (electronvolts) to tens of MeV. There are numerous applications to X-rays, including medical imagery and crystallography.
Gravitation	The interaction responsible for the reciprocal attraction of massive bodies. General relativity currently stands as the best description of gravitation. The universal law of attraction, elaborated by Isaac Newton at the end of the 17th century, is an excellent approximation in everyday life. At microscopic scales, gravitation is the weakest of the four fundamental interactions and has a negligible impact.
General relativity	A relativistic theory of gravitation, here considered as the effect of the bending of spacetime in the presence of a mass. General relativity draws on a geometrical perspective according to which the presence of matter alters the structure of space and time, and, therefore, the movement of massive objects. General relativity encompasses and replaces Isaac Newton's law of gravitation, which represents its limit for low speeds (compared with light speed) and weak gravitational fields.

Mass	A general term which refers to two values intrinsic to a body: one quantifies the body's inertia (inertial mass), and the other one the body's contribution to the gravitational force (gravitational mass or gravity load). While these masses seem to be distinct, experiments have in fact verified that they were equal. Mass appears in all the calculations of classical physics. In special relativity, (invariant) mass expresses a body's energy.
Universal gravitation	The gravitation law, or the universal law of attraction, elaborated by Isaac Newton at the end of the 17th century, describes gravitation as one and only force responsible for the fall of bodies and of the celestial body movements. It describes the attraction between two bodies as a force proportional to the product of their masses and inversely proportional to the squared distance between them. It represents an excellent approximation of Einstein's general theory of relativity in most usual cases.
Strong interaction	One of the four forces existing in nature, along with electromagnetism, weak interaction, and gravitation. It is responsible for the confinement of quarks within hadrons and for the stability of an atomic nucleus. As the name suggests, it is the most intense force, even though its range is restricted to the subatomic world.
Colour	For the strong interaction, the charge (i.e. the fact of being affected by this force) is associated with a specific parameter that can take on 3 values. By analogy with the decomposition of white light, physicists refer to the charge as a "colour" and its 3 states are called "blue", "green" and "red". This description is enriched by "anticolours" to characterise the antimatter quarks, or antiquarks. A composite particle made of quarks, a hadron, is "white": the colours of its component sum up.
Confinement	Quarks are confined within hadrons through the strong interaction, which is also responsible for the cohesion of atomic nuclei. Confinement stems from a specificity of the strong interaction: the intensity of the interaction increases with the distance: the further two quarks are from each other, the stronger their bond! As a result, quarks cannot exist isolated, they are always associated with one or two other quarks within composite.
Gluon	The carrier of the strong interaction, which confines quarks in protons and neutrons. There are 8 types of gluons. Their masses and electrical charges equal zero, and they are subject to the strong interaction (for they carry a colour and an anticolour).

Quantum chromodynamics (QCD)	QCD, or Quantum Chromodynamics, is the theory in physics that describes the strong interaction. Developed in the early 1970s, QCD states that very short distances or, equivalently, at very high energies, quarks interact weakly and behave almost as free particles (property called asymptotic freedom). As quarks move apart, the force between them becomes stronger, effectively preventing the separation of individual quarks (phenomenon known as color confinement).
Quark-gluon plasma	If a very high amount of energy is provided to quarks, the particles become so agitated that they can break loose of the strong interaction and leave the hadrons. This deconfinement would produce a new form of matter called plasma, in which quarks and gluons (carriers of the strong interaction) are free particles. QGP is believed to have existed just after the Big Bang and can be created in high-energy heavy-ion collisions, such as those performed at the Large Hadron Collider (LHC) at CERN.
Weak interaction	The weak interaction is responsible for part of the decay of radioactive nuclei and occurs only within an atomic nucleus. It a major role in the energy production processes taking place in the centre of stars, including the Sun. The bosons carrying the weak force are called Z0 and W. Their are massive, which explains why the range of the interaction is small and also why producing and studying them requires high energy accelerators.
Electroweak theory	A single theoretical and mathematical framework covering electromagnetism and the weak interaction, despite their apparent differences: the former has an infinite range, while the effect of the latter does not range beyond the atomic nucleus. The apparent difference is understood as the consequence of the mass difference between the mediators : the photon is massless, whereas the W+, W- and Z0 bosons are heavy. The unification becomes visible only at high energies.
W boson	With a charge of +1 or -1, the W boson can change the identity of particles that undergo weak interactions, for example in radioactive decays. CERN announced its discovery in 1983. Since then, experimental physicists have continued to compare measurements of W boson properties with theoretical predictions, particularly the mass, with increasingly higher precision.
Z boson	The Z boson is a neutral elementary particle. Like its electrically charged cousin, the W boson, the Z boson carries the weak force. Its existence was suggested in 1958 in the context of the unification of the electromagnetic and weak interactions, and was a cornerstone of the standard model development. After a major experimental effort, CERN was able to gradually

	confirm this hypothesis between 1973 and 1983, and study the Z0 in details.
Unifying Theories	In the 1860s, James Clerk Maxwell recognized the similarities between electricity and magnetism and developed his theory of a single electromagnetic force. A similar discovery came a century later, when theorists began to develop links between electromagnetism, with its obvious effects in everyday life, and the weak force, which normally hides within the atomic nucleus. Pushing the concept a step further, theorists even contemplate the possibility of unifying all fundamental forces into one.
Extra Dimension	Some theories draw on additional space dimensions, particulary those which try to unify gravitation and the other three forces affecting fundamental particles (electromagnetic, weak, and strong forces). These dimensions would explain why gravitation looks so weak compared to the other three, and be small enough to have escaped detection in our experiments until now. While a sign of their reality remains to be found, no fundamental principle precludes such extra dimensions.
Feynman Diagram	Pictorial representation of the mathematical expressions describing the behavior and interaction of subatomic particles, named after physicist Richard Feynman who introduced them. The calculation of probability amplitudes in theoretical particle physics requires the use of complicated integrals over a large number of variables. Feynman diagrams can represent these integrals graphically and theoretical physicists have increasingly turned to this tool to help them undertake critical calculations.
Grand Unification Theories (GUT)	Unification of theories about observable fundamental phenomena of nature is one of the primary goals of physics. After Isaac Newton's unification of gravity and astronomy and the success of the electroweak theory, the process of "unifying" forces continues today. "GUT" models including the strong force predict that the proton is not stable, and are not confirmed. Adding gravity requires to unify quantum mechanics and general relativity into a single theory called quantum gravity,
Quantum (plur. quanta)	A quantum (a Latin word meaning "how many") is the smallest indivisible unit which can be gained, lost or exchanged, regarding energy, movement quantity or mass. The concept is fundamental in quantum theory, which was introduced in the early 20th century and led to quantum mechanics. This theory opposes the classical mechanics, which states that energy and other physical properties can be exchanged in arbitrarily small amounts.

Quantum field theory	The quantum field theory stems from the alliance of quantum mechanics and special relativity. In this framework particles are elementary excitations of a more fundamental object: a field, that takes on different values at various points in spacetime. For the water on an ocean, elementary excitations are waves propagating on the surface. In quantum mechanics, the height of the waves can take only certain precise values (they are "quantised") and these "elementary waves" are particles.
Quantum mechanics	The field of physics which describes the fundamental phenomena at atomic scales, thus complementing classical physics, which addresses the macroscopic scales. Quantum mechanics helps explain phenomena such as superfluidity, superconductivity or the photoelectric effect. Quantum mechanics principles break with classical physics principles by abandoning the idea that physical quantities (such as position and speed) are perfectly determined and predictable to reason in terms of probabilities.
Scientific model	Physicists design and develop "models" to describe a scientific theory related to given phenomena. A model is generally based on a theory (a series of hypotheses) and on a set of parameters obtained from experimental data and/or observations. Computer simulations can sometimes be used to test a model's reliability. If it is found to be sufficiently reliable, the simulation can even be used to predict what would happen if the initial parameters were different.
Spacetime	The space we live in comprises three dimensions: every movement can be decomposed into three distinct movements upwards/downwards, left/right and forwards/backwards. Since Einstein's theory of relativity, time has been added to form the four-dimensional spacetime. The time coordinate differs fundamentally from the other three: while backward movement is possible in space, time only goes forward. However, time is relative, just as space: time elapses differently from one observer to the other.
Supersymmetry	One of the current theories suggested to extend the particle Standard Model, which, in particular, predicts twice the number of fundamental particles through a new "supersymmetry" – hence the name of this model family, often abbreviated as "SUSY". This additional property solves some of the Standard Model theoretical "gaps", especially regarding the Higgs boson and the question of particles' masses. Today SUSY still remains a mere hypothesis which the LHC tries to confirm or infirm.

Theory	In physics a theory generally refers to the mathematical support, derived from a small collection of fundamental principles and equations, which is used to predict phenomena that can be observed experimentally. A theory, which has a broad scope and is tested extensively, is usually distinguished from a model, which has a narrow application field and reproduces data more qualitatively than quantitatively.
Wave Particle Duality	A wave is the propagation of a disturbance, which causes a reversible variation of physical properties on its way. For instance, sea waves influence water levels. In quantum mechanics, fundamental particles may in certain cases be assimilated to waves, and vice versa. This property of quantum objects explains why the elementary grain of light, the photon, can behave both as a wave and as a particle. Depending on the circumstances, one or the other of these two aspects will be put to the fore.