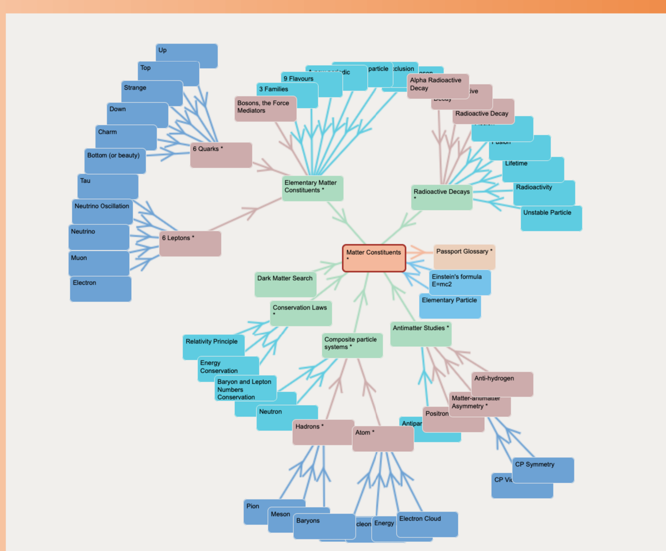
PASSPORT TO THE INFINITE

The Infinite Glossary: Matter Constituents

All the "Infinite Glossary" items are somehow linked. However, some links are stronger and more directs than others... Here are those related to the description of matter, from the atom down to its fundamental constituent, from the known properties of particles described in the standard model of particle physics to the questions opened by antimatter, neutrino properties and the mysterious dark matter and dark energy.



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Matter Constituents	Large groups of atoms or molecules form the bulk matter of everyday life. Depending on temperature and other conditions, matter may appear in any of several states: solids, liquids, gases, and plasmas. At the most fundamental level, however, matter is composed of elementary particles known as quarks and leptons.
Einstein's formula E=mc2	Einstein's famous formulae associates the mass, M, and the invariant energy, E, of a particle: E=Mc2, where c is the light speed in vacuum. As simple as the expression may be, the equation has profound consequences. First, mass is only a specific form of energy and can be expressed in energy units; then, the mass-energy equivalence means that, theoretically, one substance can be produced from the other. Given the high value of the c2 factor, mass contains a tremendous amount of energy.
Elementary (particle)	A particle with no internal structure, which makes up all the other composite particles: it is indivisible, its properties do not reflect the existence of any simpler object that it might contain. The "elementary" status of a particle can be questioned at any time, as it depends on the precision of the experiments. As science progressed, the atom, then the nucleus, then the protons/neutrons were first considered as elementary. Today, quarks seem to be. But for how long?
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.
	Elementary Matter Constituents
3 Families	The 12 fundamental particles known to date are sorted in three groups of four, called families. The first family is related to ordinary matter: it includes electrons, up and down quarks that make up protons and neutrons, and the neutrino associated with the electron. The other two families are built on the same model: a heavy "cousin" of the electron (muon or tau), two quarks (one whose properties are similar to the up quark's, the other rather close to the down quark), and a neutrino.
6 Leptons	A class comprising six of the twelve elementary particles (electron, muon, tau, and their associated neutrinos) known to date, which are not affected by the strong interaction. Three of them (electron, muon, tau) have en electric charge, the other three (neutrinos) are neutral.

6 Quarks	Quarks are elementary components of matter. Six types of quarks were discovered, that each has an associated antiparticle, called an antiquark. Since they are subjected to the strong interaction, quarks can never be found isolated: they are always bound together in quark-antiquark pairs or in groups of three through the strong interaction.
9 Flavours	In particle physics, a characteristic used to differentiate the types of leptons and quarks. Leptons (electron, neutrino) have 3 flavours (associated with the electron, the muon, and the tau), and quarks have 6 flavours (up, down, strange, charm, bottom, top). flavours are used to distinguish particles that only differ by their masses, while their other properties (electric charge, etc.) are similar.
A new periodic table ?	The periodic table is an ordered arrangement of the chemical elements showing similar chemical properties. It is now understood by the atom structure: elements and isotopes differ by the number of protons and neutrons of their nucleus. The similarities with the “families” of elementary particles is striking, but no equivalent sub-structure was identified up to now. Why three families? Why four types of particles? How to explain the huge mass gaps between the lightest and the heaviest particles? Many questions remain open.
Boson, the Force Mediators	Particles carrying fundamental interactions between particles of matter, often called “force mediators”. The electromagnetic force is transferred between two charged particles through the exchange of photons, resulting in the attraction or repulsion of the two entities, depending on their respective electric charges. Mediators of the weak force are the Z and W bosons, mediators of the strong force are gluons. The Higgs boson is a totally new type of boson (see standard model).
Bottom (or beauty)	One of the six quarks in the Standard Model, and the second heaviest. Studying the "b" quark helps us better understand the differences between matter and antimatter.
Charm	The name given by physicists to the fourth of the six quarks known to date. The "c" quark was discovered at the end of 1974 in the United States. It had been predicted a few years earlier in order to make sense of experimental observations for which no explanation could be found in a model that included only three light quarks: up, down, and strange quarks. This discovery, known as the "November revolution", has shown that quarks are a central piece in our understanding of the infinitely small.

Down	The down quark is one of the two quarks that form neutrons and protons, along with the "up" quark. All of our surrounding matter consists of three fundamental particles: "u" quarks, "d" quarks, and electrons.
Electron	A massive, stable fundamental particle whose electric charge is opposite to the proton's. It is one of the three constituent of ordinary mater, along with the up and down quarks grouped into protons and neutrons. Electrons play an essential role in numerous physical phenomena, such as electricity, magnetism, chemistry, and thermal conductivity; Electrons radiate or absorb energy in the form of photons when they are accelerated.
Muon	A massive cousin of the electron. The muon shares the same properties, except for its mass, which is 207 times greater. It is not affected by the strong interaction, carries a negative electric charge equal to the elementary charge, and has a very short lifetime (2.2 μs at rest). Denoted μ^-, the muon has an antiparticle, denoted μ^+. On Earth, muons are produced by the decay of charged pions, which come from cosmic rays penetrating the upper atmosphere.
Neutrino	A fundamental particle produced by a decay caused by the weak interaction (e.g. beta radioactivity of unstable atomic nuclei). There are three different types of neutrinos, each associated with the electron, the muon, and the tau. Neutrinos were long thought to have zero mass. Recent experiments (based on the study of neutrinos' oscillations) have shown that their masses are very small compared to other particles, but not null.
Neutrino oscillation	A neutrino produced by the decay of another particle has a well defined flavour (electron, muon, or tau). However, if the neutrino propagates and the flavour is measured after a certain time, a different result may be observed. Quantum mechanics explains this startling effect: a neutrino is considered as the superposition of three waves which correspond to particles of different masses. The latter do not propagate at the same frequency, which alters the blend composition over time.
Strange	The third of the six quarks. Its name is inherited from the particles that were discovered during experiments on cosmic rays shortly after the end of the Second World War. Their signatures differed from those of the then-known particles, hence their "strange" nickname. Once quarks were discovered, these various behaviors were associated to the presence of a new quark in these particles, the "strange" quark.
Tau	The tau is the lepton in the 3rd family of fundamental particles. It is a cousin of the muon and the electron, but more massive.

Higgs boson	The last elementary particle of the Standard Model to have been discovered (2012), the Higgs boson differs from the bosons carrying interactions, and from the fermions composing matter. It is a fundamental element of the standard model, as it is central to the BEH mechanism through which particles acquire their masses. This is the reason why the detailed analysis of its properties is one of the primary objectives of the LHC physics programme.
Top	The most massive quark known to date. With a mass of 171 GeV/c2, the "t" quark is almost as heavy as a gold atom.
Up	The least massive quark, with a mass ranging from 1.5 to 4 MeV/c2. Together with down quarks, up quarks form protons and neutrons.
	Atoms and Composite Particles
Atom	Fundamental component of matter. Electrically neutral, the atom is formed by a positively charged nucleus containing protons and neutrons, around which electrons orbit in a number equal to the number of protons. The atom's stability stems from the forces governing these particles and their interactions. Atoms combine into molecules and form the basis of chemistry.
Baryon	A particle made up of three quarks, each of a different colour. The nucleus components, protons and neutrons, are baryons.
Electron cloud	All of the electrons orbiting around an atomic nucleus to form an atom. The term "electron cloud", which is purposedly rather vague, suggests that the electron position cannot be determined with absolute precision due to the quantum nature of the objects involved.
Energy levels	The electrons orbit around an atom nucleus on layers called shells, each being associated with a certain energy level. This structure, driven by quantum mechanics, helps us explain why some chemical reactions are "easy" and others "difficult", ionisation and the light emitted by atoms. Similarly, this shell model can be used to describe the organisation of protons and neutrons in a nucleus and determine whether such nucleus is stable or decays quickly.
Hadron	A composite particle that contains quarks and/or antiquarks, bound together by gluons. Other hadrons of different compositions, called exotic hadrons, have been recently discovered: tetraquarks (made up of two quarks and two antiquarks) and pentaquarks (made up of four quarks and one antiquark).

Meson	A particle formed by a quark of a given colour and an antiquark of the associated anticolour. Pions are mesons, for instance.
Neutron	A subatomic particle made of 2 down quarks and 1 up quark. It has a neutral electric charge and its mass equals 939 MeV/c2. The neutron decays after fifteen minutes, on average, when the particle is isolated. However, it is stable when found in atomic nuclei, together with protons.
Nucleon	A generic term for the components of an atomic nucleus, i.e. protons and neutrons, each made of 3 quarks. The number of nucleons per atom is generally noted "A" and is called the mass number.
Nucleus	The atomic nucleus refers to the area located at the centre of an atom and made up of protons and neutrons. The nucleus (10-14 m) is about 10,000 times smaller than the atom (10-10 m) but concentrates almost all of its mass.
Pion	The least massive type of subatomic particles made of a quark and an antiquark (called mesons). There are three types of pions, all with a very short lifetime. Two of them carry an electric charge equal to the elementary charge (π+ and π-); they share the same mass and same lifetime, and only differ by the sign of their charge. The lifetime of the neutral pion (π0), which is slightly less massive, is far shorter than the lifetime of the charged pions.
Proton	A subatomic particle carrying an elementary electric charge. It is made up of two up quarks and one down quark, which are bound together by the strong interaction. The proton is a stable particle forming the basis of atomic nuclei.
	Radioactive Decays
Alpha radioactive decay	A type of radioactive decay, noted α, in which an alpha particle (helium nucleus), is emitted.
Beta radioactive decay	A type of radioactive decay, noted β, in which a beta particle (an electron or a positron) is emitted. If an electron (a negatively charged particle) is emitted, the emission is called beta minus (β–) decay; if a positron (a positively charged particle) is emitted, the emission is called beta plus (β+) decay. The weak interaction is at the origin of this form of radioactivity. For instance, a neutron turns into a proton by emitting an electron and an antineutrino.

Decays and Radioactivity	In particle physics, an unstable particle decay is the spontaneous process of one unstable subatomic particle transforming into multiple lighter particles. A radioactive decay is the process by which an unstable atomic nucleus is transformed into a lighter nucleus accompanied by the emission of particles or radiation. Both have the same origin and are governed by the strong and weak forces.
Fission	The decay of a heavy nucleus into several smaller fragments under the effect of a collision with a neutron. The mass of the reaction products is inferior to the mass of the initial nucleus. Missing mass M is not lost, it converts into energy E (carried away by the reaction products) through Einstein's formula E=Mc2. The factor c2, a gigantic number, explains why fission nuclear reactions are significant sources of energy used in various applications, be they civil or military.
Fusion	During a fusion reaction, two light nuclei combine into a heavy nucleus and a proton or a neutron. Part of the initial mass is converted into energy during the process. For instance, fusion reactions are the source of the energy the sun generates and radiates towards the planets of the solar system, including the Earth.
Gamma Radioactive Decay	Gamma decay is the emission of electromagnetic radiation of an extremely high frequency i.e. very high energy, giving out excess energy in order to stabilize the unstable nucleus. Unlike the two other types of decay, it does not involve a change in the element.
Lifetime	An unstable body decays to form more stable entities. The exact decay time is random but the law of probability governing this phenomenon is well known. Its mathematical expression depends on a single parameter called lifetime. On average, the higher the lifetime, the longer the unstable body takes to decay. Lifetime can greatly vary from one body to another: a fraction of a second for the muon, some 15 minutes for an isolated neutron, over 4 billion years for the Uranium-238 nucleus.
Radioactivity	A natural phenomenon during which unstable atomic nuclei transform ("decay"). They emit energy in the form of various radiations, to decay into more stable nuclei that have lost part of their mass. The emitted radiations are called, depending on the case, α rays (Helium nuclei), β rays (electrons or positrons), or γ rays (energetic photons).
Unstable Particle	The primary components of ordinary matter, e.g. the proton or the electron, are stable. But most pf the particles created in high energy collisions are unstable, and spontaneously transform (decay) into lighter ones. The particles in the final state may themselves be unstable and subject to further decay, until only stable particle remain. In collider experiments the final set of particles is analysed to reconstruct the initial particle properties.

Baryon and Lepton Numbers Conservation	This law requires that the total baryon and lepton numbers are the same before and after an interaction occurs. To determine the total baryon number, every baryon is assigned +1 for matter, –1 for antimatter, and 0 for all other particles. The same applied for the electron-lepton, muon-lepton and tau-lepton numbers. These laws are used to easily identify which decay is forbidden for a given unstable particle and their origin is an open question.
	Conservation Laws
Conservation Laws	Conservation laws are critical to an understanding of particle physics. Strong evidence exists that energy, momentum, and angular momentum are all conserved in all particle interactions. Just as electric charge is conserved in all electrostatic phenomena, the charges associated to other interactions are. These are by no means the only conservation laws in particle physics.
Energy conservation	There are many types of energy: kinetic energy, heat, potential energy, mass energy, etc. While these properties seem very distinct at first, they are in fact multiple sides of a same reality, energy, which is overall conserved during any physical phenomenon. For instance, when the fission of a heavy nucleus produces lighter nuclei the missing mass is not lost, it has been converted into kinetic energy. Energy conservation is a fundamental principle in physics.
Relativity Principle	Principle which states that the laws of physics are the same in any inertial referential (a referential where an object that is not subjected to any force is either immobile, or in a uniform, linear translation movement). This implies that two experiments prepared identically in two inertial referentials give the same results.
	Antimatter Studies
Antihydrogen	The simplest antiatom: the antihydrogen nucleus is an antiproton, around which one single antielectron orbits. Its properties are studied in details at CERN, in the Antiproton Decelerator (AD) facility: very low energy antiprotons and antielectrons are combined and stored in magnetic traps in the center of experiments which verify if the laws of physics are the same as for atoms.
Antimatter	The "mirror image" of matter – which forms almost all of the observable Universe. Just as matter is composed of particles, antimatter is composed of antiparticles.

Antiparticle	The theory describing the infinitely small states that each particle is associated with a "mirror" particle, called antiparticle. This has been confirmed by experiments. A particle and its antiparticle share many properties. In particular, they have the same mass but have opposite charges. If enough energy is available, particle-antiparticle pairs can be produced. But the antiparticle will annihilate if it crosses matter.
CP symmetry	CP-symmetry states that the laws of physics should be the same if a particle is interchanged with its antiparticle (C-symmetry) while its spatial coordinates are inverted ("mirror" or P-symmetry). While the strong interaction and electromagnetic interaction seem to be invariant under the combined CP transformation operation, further experiments showed that this symmetry is slightly violated in certain types of decay.
CP violation	The Big Bang should have produced equal amounts of matter and antimatter, and there should have been total cancellation of both, resulting in a sea of radiation in the universe with no matter. Since this is not the case, after the Big Bang, physical laws must have acted differently for matter and antimatter. The violation of Charge conjugation and Parity symmetry (CP) is a subtle effect observed in the decays of certain particles revealing Nature’s preference for matter over antimatter.
Matter-antimatter Asymmetry	The Big Bang should have created equal amounts of matter and antimatter in the early universe. Matter and antimatter particles are always produced as a pair and, if they come in contact, annihilate one another, leaving behind pure energy. But today, everything we see from the smallest life forms on Earth to the largest stellar objects is made almost entirely of matter. One of the greatest challenges in physics is to figure out why.
Positron	The antiparticle of the electron is the first antimatter particle to have been predicted (by Dirac in 1927) then discovered (by Anderson in 1932). The electron and the positron share many properties (e.g. their mass), but have opposite electric charges. Positrons are used in medical application (PET) and can be accelerated as beams to produce electron-positron collisions.
	Dark Matter Search
Dark Matter	Dark matter is a currently unknown substance to which astrophysicists refer to explain the rotation speeds of stars and the formation of the Universe's structures. Its gravitational effects indicate that it accounts for 25% of the Universe's energy balance, five times more than ordinary matter. This new form of matter could consist of stable and electrically-neutral particles predicted in many theories. Unraveling the nature of dark matter is one of the greatest interdisciplinary challenges.