Matter and elementary particles. Interactions and qualities

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The elementary interactions of nature are discussed, based on the structure of the atom. Elementary particles are categorized by their qualities, especially their spin and statistic, but as well charge and compound forms among others. The connection to CP-behaviour and to the different elementary interactions is discussed, as well as some open questions and ideas in modern elementary particle physics.

• The atom and interactions

Matter is what suffers a change by means of forces and the trajectory of which can be analyzed by classical means. In modern physics, the trajectory is not defined and the quantum state is used. Moreover, mass does not have to possess a mass, since mass is no longer an intrinsic characteristic, and it can be described as particles or waves. It is often spoken about fields of matter as it is spoken about temperature or electro-magnetic fields. The way it changes and reacts is a consequence of symmetries and interactions that form the unities of nature we now know.

Democritus and Leucippus in the Ancient Greece believed matter to be dividable and dividable until a certain point, where one should have reached the length of the “atom” (atomo—atomos: undividable). This “atoms” should interact and form more complex systems we then see, as if they were some kind of Lego or puzzle pieces. Many atom types should exist, with different shapes and size, so that through inter-connecting with each other, many types of macroscopic particles appear. The latter one is still, in principle, the thought behind of the theory of nuclear physics and elementary particles. Modern atoms have different size and different capabilities to interact with different kinds of other atoms. The conjuncture of atoms leads to compounds and molecules, and so to all microscopic particles we know. The way each atom acts with the others is given especially through the nuclear forces, giving and

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1 In this work, little about supersymmetry and supergravity is said (i.e. the theoretical connection between bosons and fermions that says, every fermion should have a (supersymmetric) bosonic partner and every boson a fermionic one, so to achieve a more symmetric theory for generalizing the SM, even in direction of a gravitaitonal theory). Analogously, Dark Matter is only quickly referred, although it is basically supposed not to be baryonic or leptonic and contribute at most to all matter in the universe.

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I try here to write a readable text that, nevertheless, is informative and hopefully more than many of the readers (which do not know about physics) would expect. Excurses could help in a future as a seed, even if they are not understood in their magnitude while reading for the first times (since they lie upon more complex mathematical structures and philosophies).
receiving particles that carry information and “lending” other atoms particles to get into an energetically lower level, so forming more complex particles like molecules. The main difference between the ancient atom and the modern one is that the modern one is no longer undividable, as its name should say. It is a unit but not a fundamental one. The atomistic theory is an empirical theory of a more fundamental one. An atom is formed basically by a nucleus (positively electrically charged) and electrons e\(^-\) (negatively electrically charged) in a (quantized) orbit around it, as given in Niels Bohr’s theory. The amount of possible orbits between two given ones is discrete and these orbits are of much greater size than the nucleus itself, so that most of the atom is full of vacuum\(^3\).

A stable atom is electrically neutral (Q=0). It possesses an equally positively electrically charged nucleus as the orbits of electrons. Originally, it was supposed that nucleons and electrons were bound through electromagnetical forces in the nucleus. However, the atomic nucleus is built “against” electromagnetism, since electrons are outside and the nucleus is made not only of one particle, but of one or more. There are, in the first place, the “elementary” electrically charged (Q=e) protons p, and, in addition, electrically neutral particles named neutrons n. Protons give the electrical neutrality when adding the electrons. They repulse each other electrically. Neutrons, however, don’t act electrically and are important for the stability, since they are coupled with an asymmetry term to assure the balance of forces, the electromagnetical and the new one that binds nucleons together.

Since equally charged particles avoid each other (electromagnetism), the protons of the nucleus are bound together through a stronger force that acts especially in nuclear ranges and is independent of electrical charge, so all nucleons are equal for it, differed only through their orientation in the abstract “isospin”-space, analog to the charge in the real space.

This is the so called strong nuclear force (stronger than electromagnetic force), which was first described by Yukawa 1947 as a consequence of particles sending an intermediate particle created from vacuum and that can therefore only live a very little interval of time, so conserving energy and momentum within Heisenberg’s Uncertainty Principle\(^4\). In this time, these particles, named Pions π (positively, neutrally or negatively charged), can move a little distance (about 1.3fm) equivalent to their mass. This distance is of the size of atomic nuclei, so that this force cannot be felt macroscopically. Nuclear stability is then given through a balance between the repulsive electric force and the attractive strong nuclear one. For neutrons, only the nuclear force counts, and so they help to saturate the nearest-neighbour strong interactions available, acting only strongly.

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\(^3\) The semi-classic interpretation is of electrons as particles moving in their orbits. Nevertheless, for QM electrons have wave a character, given through the quantum mechanical state, and what can be said is where they are more likely to be found. Following Bohr’s quantization, atoms only radiate when their components change from one discrete to another discrete energy level. The energetic difference between neighbour levels is the energy quantum. The radiated energy is coupled to the energy of the wave won. Orbits near the nucleus are less energetic as the ones far away. The reason why not all particles are in less energetical states is given through the Exclusion Principle of W. Pauli. This is, however, only valid for symmetric, i.e. fermionic, states (see later).

\(^4\) The Uncertainty Principle says that there are observable quantities that cannot all be measured at the same time (actually, one observable and its canonic conjugate momentum of analytical mechanics). One example is momentum p and distance r. If we know the exact place where an electron is, we cannot know both which momentum it possesses and its velocity, given through \(p=mv\). Another example is time and energy (as coordinate and canonical momentum of it). This leads to the possibility of breaking energy conservation for little amounts of time, where particles are produced out of the quantum mechanical vacuum and then return to it, after producing an interaction in the world.
Since only massive particles have short-ranged length scales, pions have to be massive (around \(m(\pi)=150\text{MeV}/c^2\), more exactly: \(m(\pi^0)=135.0\text{MeV}/c^2\), \(m(\pi^+)=m(\pi^-)=139.6\text{MeV}/c^2\). That is a characteristic Yukawa gave to short-ranged forces of nature. Generalizing this scheme, long-ranged forces like electromagnetism or gravitation should be quantum mechanically given through the interchange of massless (intermediate) particles, what brings us to a fundament of the Standard Model (SM) and generalizations of it:

Every interaction is given through an interchange of particles that carry the characteristics of this interaction and that change other particles through it.

The formation of these particles restore the symmetry of the system and their interaction is described through the gauge potential within the Yang-Mills theories -analog to the Christoffel symbol in General Relativity- after the so-called gauge of the group. The new term of the potential is identified with the new particles that mediate the interaction, since a force should not be mediated on the distance. This contributes to causality.

The quanta of light of photons were first proposed by Einstein to explain electromagnetic effects, following Planck’s idea of the quanta of radiation, which he postulated to explain the problems of heat radiation. From it, he realized that energy is transferred only in multiples of a unit he called quantum. Photons, then, possess the energy unit of light, which then is postulated as a particle, contrary to classical electrodynamics, which work with light as a wave. The quanta of light possess no ruh-mass, so that they possess an infinite length scale, as should quanta of gravitation, since gravitation, as electromagnetism, act on the distance.

The fundamental matter is given through the elementary particles, found within SM-like theories. A problem within it is to be capable to realize which particles are fundamental and which are not and only do as if. For instance, pions are no such. They decay. Moreover, nucleons show an inner structure through scattering experiments. So, the strong nuclear force of Yukawa is not fundamental. It is a rest-interaction of a more fundamental one, named “strong” (which is long-ranged). This is the one that binds nuclear particles together, since neutrons and protons decay, too. Through the strong interaction the elementary particles called quarks are bound in nucleons (e.g. protons) and other composite nuclear particles (heavy hadrons), or, for instance, pions. Its rest-force is then short-ranged and binds protons and neutrons together in the nucleus. If the amount of nucleons is too high, then, the phenomenology of strong interaction, which is a quantum mechanical interaction, leads to the alpha (\(\alpha\))-decays in nuclei, where Helium nuclei are shot out of them, tunneling through a potential barrier higher than the energy they possess. This happens especially when the size of the nucleus is so large that the strong nuclear force cannot longer rule over the electromagnetic force, so it is energetically more favourable for the atom to split. It comes to nuclear fission. The exceeding energy is radiated out. Another decaying channel is when electron-like particles can come out of atomic nuclei, where no particles of such kind were before. The half-life of these particles lies at 18 minutes, which is too high for particles from strong decays. These are produced through another, non-classical interaction named the weak interaction, cause of beta (\(\beta\))-decays. Through it, electrons and positrons (positively charged electrons, or anti-electrons) are produced, along with new neutral particles that only act weakly, called neutrinos. In this
way, protons can for example transform in neutrons. The exceeding electrical charge, which has to be conserved, is found in a positron, and for reasons of energy and momentum conservation, the exceeding energy and momentum in neutrinos or anti-neutrinos, first postulated by W. Pauli 25 years before their experimental detection (at that time, he called them *neutrons*, since Chadwick hadn’t found the neutrons yet).

The intermediate particles that mediate the interaction should be elementary in a complete theory, so to comprehend dynamics from within. Nevertheless, not all interactions are by now explained through a unique theory. Microscopically the strong and weak interactions and forces, along with electromagnetism, are well explained by QM through special relativistic Quantum Field Theories (QFT) in SM, given especially through Yang-Mills Theories: generalizations of Electrodynamics of Maxwell for many dimensions, which are given through the amount of elementary particles that are equal for the described interaction and that are non-Abelian (non-commutative), so it comes to self-interactions of particles that act as a source of themselves. Macroscopically relevant interactions, namely the gravitation (or non-quantum electrodynamics), are well described by General Relativity (GR) or generalizations of it, with Field Theories based upon Poincaré’s work on geometry (thereafter, GR is a geometric theory to describe gravitation geometrically and not through interchange of particles\(^5\)).

The three known quantum mechanical interactions are
- (quantum) electromagnetism,
- weak interaction and
- strong interaction.

They give the specific behaviour of decays, forces and fields the experimentalist or at least some particles can feel. They are guilty of uniting elementary particles in complex systems. The elementary particles and those produced out of them can be characterized by many means, such as through their charge \(q\), mass \(m\) (as partially seen before) and spin \(s\), along with which interaction they couple with or if they conserve parity or other “natural symmetry laws”, for example.

In the next part, let us comment some of the characteristics of particles, so to be able to classify them before commenting more about their interactions:

- **Spin.** Bosons and Fermions:

  The principal way to differ particles from one another is the spin. This is a quantum mechanical characteristic without exact classical analogon, which can be projected for rational meanings as a momentum of rotation of particles around their own axis (within a space in which angle has another definition, since a revolution of \(720°=4\pi\) equals one complete rotation).

  The spin \(s\) is a (good) quantum number, since it does not change for particles (as a constant characteristic of them), and it is added to the other momenta for the total one to stay constant throughout all dynamical happenings (conservation of momentum, which

\(^5\) It is possible to unify GR (4-dimensional) and electrodynamics (ED) within a 5-dimensional theory, named Kaluza-Klein Theory (KKT). Unifications with all other elementary interactions are not yet possible (an example in that direction is given through the Superstring Theories, by now in over a 10-dimensional manifold). If the 5\(^th\) term of the 5-dimensional metric of the KKT is functional, one achieves then Jordan-Brans-Dicke (JBD) theories, which are scalar-tensor theories with a scalar field coupling to the curvature of the space-time and that might lead to a variable coupling parameter \(G\).
follows from the invariance of the Lagrangian\textsuperscript{6} to spatial rotations, since for every continuous symmetry of it, there is a quantity conserved by the dynamics (\textit{Noether theorem}).

The spin is either broken (1/2, 3/2…) or integer (1, 2…), i.e. particles can rotate a whole revolution or parts of it as elementary rotation. This spin gives the statistic with which particles are to be handled. This then gives their physical properties:

- \textbf{Bose-Einstein statistics} are used for broken spin-particles: \textit{BOSONS}. Bosons don’t follow the \textit{Exclusion Principle of Pauli}, so they can all be in one place, possessing all equal quantum numbers at the same time (in the case of light, it only augments its intensity). This is a given characteristic for such particles, which follows from the postulation of their quantum mechanical state being \textit{symmetric}.

- \textbf{Fermi-Dirac statistics} are used for integer spin-particles: \textit{FERMIONS}. Fermions follow the \textit{Exclusion Principle of Pauli}, so they cannot possess at the same time and place all quantum numbers equal. Fermions form clusters of finite and growing size. This given characteristic follows from the postulation of their quantum mechanical state being \textit{antisymmetric}.

\begin{itemize}
  \item \textbf{Fermions.} Leptons and Quarks:
  \begin{itemize}
    \item \textbf{Mass}:
      Fermions can be characterized in many ways. Nevertheless, most of these characteristics are found in bosons as well. One category could be the \textit{mass} \(m\), which in Special Relativity (SR) is important for them to move with the speed of light \(c\) (ruh-mass \(m_0=0\)) or below (non-vanishing ruh-mass), and in GR, mass \textit{shows the coupling to the gravitational interaction and curves spacetime} to resemble a gravitational force, changing the trajectories of particles\textsuperscript{7}.

      Also, massive particles tend to decay in less massive ones, so to use this extra energy (since energy and mass are proportional through \(E=mc^2\)) for other purposes (as radiating photons –light- or other particles). Sometimes, if one elementary particle decays in another one, it is spoken of resonances, as if both were ground and excited states of one truly elementary particle. Some non-standard theories even speak about so called “pre-quarks” or “preons”; more fundamental particles which form many of the now believed elementary particles. The amount of preons should be less than the one of the within SM believed to be fundamental ones and they should explain why
  \end{itemize}
\end{itemize}

\textsuperscript{6} In analytical mechanics, the main quantity is not the force \(F\) but the energies. In Hamiltonian physics, the main quantity is the energy or quasi-energy, given through the Hamilton function \(H\) or his density (the Hamiltonian), linked with the total energy of the (sub-) system. The Lagrangian or Lagrange density is a force density, following from the Lagrange function \(L=\mathcal{T}-V\) (with \(\mathcal{T}\) as kinetic energy \(E_{\text{kin}}\) and \(V\) for the potential). It is the main mathematical expression of Lagrangian analytical mechanics, describing the energy of a physical system and from which the dynamical expressions are derived.

\textsuperscript{7} In GR, there is no gravitational force. What we perceive as a force is only the curvature of spacetime. Nevertheless, in the Newtonian limit, one can couple the so-called metric (where the information about the spacetime lies) with the Newtonian gravitational potential and so get a gravitational force with the mass as its source. An analogy to SM is that, while interactions are given in SM through the gauge potentials (coupled with gauge bosons), the gravitational interaction is given (through gauging) through the Christoffel connection (which is, however, of other nature, connected with the geometrical parallel shift to generalize the vectors for curved manifolds).
a quark may decay in another one, although they are supposed to be fundamental. However, within SM, mass is no longer believed to be fundamental but a phenomenology, following from other more profound interactions between particle and fields (viz. “Higgs Mechanism and Mass generation”), as a consequence of symmetry-breaking effects. This is necessary to make the theory renormalizable (i.e. the probability amplitudes of the particles not to diverge) and in this way mathematically consistent.

- **Charge and leptons:**
  Another characteristic is the charge q. Charge is in most of the cases meant to be the electrical one of the electromagnetic (and electroweak) interaction (of Quantum Electrodynamics QED and Quantum Asthenodynamics QAD of the Glashow-Weinbeg-Salam model). Nevertheless, one can mean another, “strong” charge (colour charge), found within Quantum Chromodynamics QCD of strong interaction. Through the electric charge, another division of elementary particles is given (which gives their coupling to electromagnetic interaction). There are particles of integer (or vanishing) electric charge within fermions. These are called leptons. They are found in families. There are three electronic families characterized by “differently massive electrons”: electron e\(_1\) = e, muon e\(_2\) = \(\mu\) and tauon e\(_3\) = \(\tau\), with growing mass throughout the list. “Lepton” comes from the greek word λεπτόν: “small” or “thin” and tauons, with a mass many times the one of electrons (m(\(\tau\)) = 3477.5m(e)), are actually too heavy for that name (m(\(\mu\)) = 207 m(e)), which stays, however, for historical reasons. Why tau-particles possess such a high mass, however, stays at this time unanswered.

  These electronic families are accompanied (as is the case of all matter) of antimatter, in this case of three “antifamilies” for the antiparticles ě\(_1\) = ě\(^+\), ě\(_2\) = \(\mu^+\) and ě\(_3\) = \(\tau^+\) (not being too careful with the formalism). Each of these families and antifamilies consists of a pair (iso-pair) of the characterizing electric particle and his related neutrino \(\nu\) and antineutrino (actually, only for left-handed states \(\nu\)\(_L\)), since electroweak interaction does not follow (CP) parity conservation (Conjugation-Parity). See “CP conservation and interaction coupling”). Right-handed neutrinos \(\nu\)\(_R\) are believed not to exist.

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8. The by now most known physical theory that proposes a pre-quark nature is the Superstring Theory, to unify all fundamental interactions. The String Theory proposes the existence of “superstrings”, i.e. in many dimensions rotating and translating one-dimensional strings (instead of point-like particles as quanta). The frequency and vibration characteristics of the strings should manifest as the particles we have as elementary, including gauge bosons of all interactions. Most of the high amount of dimensions should “compactify”, i.e. be closed in themselves.

9. Muons were first believed to be the Yukawa particles because of their mass. Nevertheless, they can orbit within atomic nuclei without being absorbed. Moreover, other than said in many old sources, they are NOT mesons, which are quark-composites.

10. Antimatter particles possess the same mass as the particle analogues (gravitation couples in the same way). Nevertheless, they possess contrary spin and charge (as well electrical as colour one). Antimatter was first proposed by Dirac in his theory, which explains the problems within the relativistic Schrödinger theory (Klein-Gordon), with negative energy states. The most usual antiparticle is maybe the positron, which comes out of weak decays. Antineutrons and antiprotons are not rare. Nevertheless, there seems to be more matter than antimatter in the universe (what has not been understood, yet, since it means that there is an asymmetry in nature). Matter, in contact with its antimatter analogue, becomes energy (photons), so this asymmetry is good for us to exist.
as well as left-handed antineutrinos (the right-handed iso-vector of the
electronic family is an iso-scalar, with only e_R and not the accompanying
ν_R).
Massive electrical family particles (such as a tauon) decay in less massive
ones (as a muon, which can decay in an electron). Leptons decay only
electro-weakly and especially free electrons give the electronic character of
matter. Neutrinos, as almost not detectable particles (because of their
(almost) vanishing mass, neutral charge and only weak coupling) are almost
only important for momentum conservation after weak decays.

- Charge and Quarks. Hadrons:
If the electric charge is broken, elementary fermions are called quarks.
There are thought to exist three families of quarks (named flavours), every
component of which consists of a doublet: (u,d), (c,s), (t,b), for “up”,
“down”, “charm”, “strange”, “top” and “bottom” quarks (plus antiquarks).
These parity conserving families form more complex systems through the
fundamental interactions, the most important of which is (in the given scale
of nucleons) the strong one, which does not let quarks be found in nature as
separate systems (confinement) and, especially, forces them to stay in form
of so-called hadrons (as neutrons and protons, formed out of three quarks)
with total integer electric charge. Neutrons are formed out of a triple of (udd)
superposition. Protons are made out of (udu).

Hadrons are non-elementary particles with quarks as constituents and can be
either fermions or bosons. They are divided in baryons (fermions) and
mesons (bosons), depending especially on the amount of quarks and
antiquarks needed for them:
- Mesons are quark-systems which have at least one antiquark (generalizing,
matter particles that possess partially antimatter particles as constituents).
The most usual form of them are the so-called quarkonia, made out of the
same amount of quarks and antiquarks and as a special case of the so-called
onia (where one can find leptonic onia, too, e.g. the pseudo-atom
positronium (e⁺e⁻)).

Quarkonia and generally mesons possess a vanishing spin (scalar mesons) or
a non-vanishing integer spin (vector mesons), as well as different electric
charges. One example of a vector meson are the pions π⁺ = (u,−d) and π⁻ =
(−u,d) and of a scalar meson the pion π⁰ = (u,û; d,~d) (actually, always
superpositions, as normal in QM and necessary, according to colour charge
in QCD). More complex mesons are called tetraquarks, made out of four
quarks, one of which is an antiquark (so, a conjunction between quarkonia
and baryons).

- Baryons are triplet systems of quarks. The less massive type of baryons is
called nucleonic, possessing only quarks of the first (less massive) flavour
and spin ½. More massive baryons are hyperons, of half-spin or higher
broken one (one example is Σ⁻ = (d,d,s), for which the “strangeness S=−1 is
defined (one s-quark is found). Analogously, numbers as the “charmness”
and so on are defined for the amount of quarks of higher flavour).

Antihydrogen atoms (with antiprotons and positrons) have been produced for some years now.
For nuclear physics, only nucleons are of relevance, since atoms are built upon nucleons (protons and neutrons) and electrons.

A problem arises for vector mesons and hyperons, since it is possible to construct high-spin particles for which the Pauli principle would seem to fail (i.e. with both or the three particles possessing the same spin, c.f. the $\pi^0$). For this, it is postulated the quantum number of the colour (charge), namely red, blue and green (and "anticolours"). This is in QCD the analog of the electric charge for the strong interaction and plays a role within quark dynamics to constitute hadrons. Macroscopic systems are postulated to possess no total colour (to be white/black), so hadrons have to possess quarks of different colours with total none. Mesons are then quark-antiquark pairs that possess colour and anticolour. In this way, e.g. neutrons are a superposition of $u_d d_g$, $u_b d_g$ and $u_g d_b$.

"Coloured" particles are the ones that couple strongly. In them, the colour can change all the time (interchange of the intermediate particles called gluons that, in contrast to photons as intermediate particles of QED, possess a charge and self-interact). Important is here only that the total colour of the total system vanishes (is neutral, black or white), so for quarks to stay confined and the Pauli Principle to be valid. The changes of colour within a system follow internal dynamics given through the (gauge) bosons of the strong interaction.

- **Hadronic number and Quarkness:**
  
  In the case of baryons, the baryon number $B$ is defined as a quantum number ($B=1/3$ for quarks). For leptons, the lepton number $L$ (e.g. $L=1$ for the electron). For nucleons and hyperons, there is $B=1$. Mesons are characterized through the number $B=0$.

  In a reaction (decay process) $B$ and $L$ of a subsystem can change. What seems to be conserved within SM is their sum $L+B$. Also the "quarkness" (as S and C) is conserved within electro-weak interactions and many times in the strong one, too. Non-conservation of it would need energy differences (with different flavours as a type of resonances of quarks as in the experiment of Franck-Hertz for quantization of the atomic orbits in energy levels).

  $L+B$ non-conservation signifies fluxes between leptons and bosons, which are forbidden within SM, so free protons to stay stable. Such fluxes are predicted for example within GUT (Great Unifying Theory), which unifies all qm interactions of SM in a more fundamental theory, for which quarks decaying into leptons would be necessary and so free protons to decay (what has not been seen yet), as a consequence of new GUT-interaction forces of new intermediate (gauge) bosons (called leptoquarks).\(^\text{11}\)

\[\text{11} \text{ Fluxes within these families signify for example that nucleonic particles could end as an electron after decay, given the right energy scales. Especially, it would mean that free protons are not stable. The amount of gauge bosons is given through the dimension of the mathematical group used for the theory. This dimension signifies, physically, the amount of particles equal for the given interaction. The dimension of QED is 1, with the photon as gauge boson (generators of the group). QAD has } N=2 \text{ (electron and neutron), with } N^2 -1=3 \text{ new gauge bosons. QCD has } N=3 \text{ (three quarks of different colour), with } 8 \text{ new gauge bosons. Standard GUT has } N=5, \text{ with } 24 \text{ new gauge bosons. These would cause instability in free protons because of new interactions.}\]
Bosons. Mass and Charge:

Bosons can as well been characterized by their mass and charge (and parity conservation, too). Nevertheless, the significance of it is not the same as for fermions. While for fermions, mass only gives a decaying way, the coupling to Gravitation and the limit-velocity, for bosons, it gives another profound characteristic, since it can show the type of interaction the bosons are coupled with. Following the Yukawa-theory, long-scaled interactions are given through interchanging massless (intermediate) bosons (which carry the basic characteristics of the interaction), while short-ranged ones are given through interchanging massive bosons (by means of Heisenberg’s principle of uncertainty and Energy conservation).

The main characterization of boson-types can be given as quasi- and real bosons. Quasi-bosons are phenomenological particles as phonons (as interacting bosons of sound) or plasmons or surface plasmons of plasma. “Real” bosons are composites or virtual (gauge or intermediate). Virtual bosons are the fundamental bosons that carry out interactions (namely photons, weakons, gluons, and non-SM bosons like gravitons, leptoquarks …). Composite-bosons are non-fundamental ones like mesonic hadrons or glueballs (a bounded, massive state of gluons – a case of “onia”). Less fundamental are atomic and molecular bosons like Na\textsubscript{23} and He\textsubscript{3} (the most common stable isotope of Helium, achieved through the radioactive decay of Lithium in Tritium, while the rare isotope He\textsubscript{3} is gotten through the following decay of Tritium), the particles of which give a total integer spin, characterizing of bosons. The characteristics of such atoms are special, since bosonic nature is very different of fermionic one.\textsuperscript{12}

The characteristic of charge in bosons gives the type of changes suffered by a particles or system of them after an interaction. Bosons can possess an electric charge of 1, 0 or -1 and have a vanishing one in case of the gauge boson of electromagnetism, namely the photon (or quantum of light)\textsuperscript{13}. Within electromagnetism and electrodynamics, the dynamics do not alter the charge of a system (an electric or magnetic field cannot change the charge of a system and electrons stay as such for all times, so the photon as intermediate boson does not possess electric charge). Different is the case within bosons of (electro-) weak interaction, since weakons (W\textsuperscript{+}, W\textsuperscript{-} and Z\textsuperscript{0}) couple electromagnetically, changing the electric charge of a system after

\textsuperscript{12} These bosons possess warmth and transport characteristics of an ideal gas, as do their fermionic isotopes. However, for low temperatures it comes to superfluidity and the so-called Bose-Einstein condensation, with a vanishing resistance value (discovered 1911), so that a macroscopic part of the bosons fall in the same quantum mechanical state. Following the BCS theory of Bardeen, Cooper and Schriefer, this follows from a coupling of electrons through interchange of virtual phonons (BCS-pairs as bosons) that can even happen to fermions as He\textsubscript{3} if two atoms couple. The BCS- pairs move all in the same direction and higher energies break their state, and resistance appears for the electric transport. This is a phase transition, as is the case of the one from liquid to gas.

\textsuperscript{13} Another important difference between photons and the hypothetic gravitons lies in their spin. Both are bosons but while photons possess a spin 1, gravitons would have to possess spin 2, so it to couple only attractively (photons mediate between two electrons a repulsive force). In some models, though, there might exist more graviton-like particles, such as “graviscalar” and “gravivector” particles with spin 0 and 1, respectively (for example in supergravitation), or even Higgs or Higgs-like particles, since they would change the 1/r-potential of gravitation, depending on their length scale (as for example in HSTT or in a fundamental theory for the Finite Length-Scale Anti-Gravity of Sanders to explain Dark Matter).
weak reactions of decay (such as beta-decay). In this way, electrons and the
other interacting particles can be altered in their fundaments, converting
neutrons in protons (and electrons and anti-neutrinos –so conserving L+B
and momentum-) and protons in neutrons (and anti-electrons and neutrinos).
Electrons can “disappear” and be “eaten” by another system. Nevertheless,
total charge is always conserved (as a consequence of “gauge invariance” of
the Lagrangian or Lagrange density).

In the case of strong (colour) charges, the situation is as follows. Strong
charge is found in bosons and changes through strong interaction,
interchanging gauge bosons of this interactions named gluons (from “glue”,
since they glue quarks together in hadrons through confinement, given
through interchange of these gauge bosons in only very short ranges).
Quarks possess a colour, which changes through interaction of gluons with other quarks. Gluons are electrically uncharged but possess colour and
anticolour (and total not necessarily vanishing colour charge), as well as a
vanishing mass, so that strong interaction is long-ranged, and at all distances
outside nuclear length, gluons can find quarks to confine them and not to let
them be found free.

A fourth kind of bosons is the one of “symmetry mode”-bosons. This kind of
bosons can be fundamental or composite and is linked with symmetry-modes
of physical systems. They are supposed to be linked to phase transitions and
symmetry transformations, such as (CP)-breakdown by axions or Goldstone
and Higgs bosons of the Goldstone and Higgs Mechanism, through which
mass “created” as a consequence of particles interacting with Higgs
field(s) (which is a scalar field as the temperature, which is in all the universe and
possesses a non trivial ground state for its potential). Such interactions are
often said to be a fifth interaction of symmetry breakdown, the
(intermediate) boson of which would be especially the Higgs boson, whose
coupling to particles that get mass through it is of gravitational nature (and
short-ranged). Modern standard physics need them to explain the appearance
of mass, since because of parity violation and the divergence of Feynman
diagrams with massive propagators, the field equations have to be given as
massless, for their symmetry to be broken later, when mass appears
phenomenologically.
The generation of mass is given in SM through the field of Higgs bosons.
Nevertheless, not all particles are supposed to get mass through it (they
should stay massless), so that, following Dirac’s equation, not all particles
exist (e.g. the right-handed neutrino since right-handed-ones don’t possess
mass –and vice-versa). Consequently, mass generation shall not be parity
conserving and not all particles have to couple to Higgs field (photons and
gluons, according to their long-scale nature and neutrinos because of their
weak-interaction (not CP-conserving)-nature). However, a possible non-
vanishing neutrino mass coupled with the so-called neutrino-oscillations
(neutrinos changing the family to explain the experimental situation that not
all solar neutrinos are measured) would need them to get massive; problem
that has not yet a solution within SM that postulates them as massless.
CP conservation and Interaction coupling:
The characteristic of parity conservation of particles is coupled with which interaction plays a role in the dynamics.
Parity conservation means for particles that right- and left-handed ones are equal for the dynamics (i.e. nature makes no difference between them). For photons, handedness is not important and electrons exist left- and right-handed. The same happens with weakons and so on. Neutrinos, though, exist only left-handed and antineutrinos only right-handed. This happens for particles that only couple weakly. So, a basic characteristic of weak interaction is non-CP-conservation (“C” because the changing-invariance of charge –conjugation- is broken, too). As such, weakons, although existing both-handed (for they couple electrically and gravitationally, too), couple differently for right-handed and left-handed states.
Parity conservation is also connected with mass of particles through Dirac’s equation. Through it, left- (right-) handed states are coupled with the mass of right- (left-) handed ones. Since right-handed neutrinos do not exist, left-handed ones cannot possess a mass within SM (and backwards). So, if neutrinos shall possess a non-vanishing mass, it should come out of another mass generation mechanism or right-handed neutrinos do exist but interact differently, so that they were not detected yet. Since neutrinos only hardly interact with anything, it is nothing easy to say, although there seems to exist an interaction between neutrino-families, so that they can change from one to the other (neutrino oscillations). This can be explained through non-vanishing mass (coupled with parity violation) or maybe, if gravitation should couple differently for different neutrino-families (which has not yet been analyzed).

As seen, there are 4 fundamental interactions, namely gravitation (long-ranged with hypothetical massless gauge bosons of spin 2 named gravitons – at least-), electromagnetism (long-ranged with massless gauge bosons of spin 1 named photons A or \(\gamma\)), weak (short-ranged with massive gauge bosons named weakons \(W^+, W^-\) and \(Z^0\), mass 80.4GeV/c\(^2\) and 91.2GeV/c\(^2\), respectively) and strong (long-ranged with massless gauge bosons named quarks G, bounded through self-interactions in massive glueballs, so to shorten the range of the effective interaction). If Higgs Mechanism is to be seen as a fundamental interaction, then one might have to be added (namely a Higgs-5\(^{th}\)-force). The characterizing particle of it is the spin 0 particle called Higgs particle, as the excited state of the scalar Higgs field.
At “normal” energies, fundamental interactions act as different ones but at higher energies they seem to unite. So, it is spoken of the electro-weak one at energies of about \(10^{16}\)GeV. This united force is analyzed in the Glashow-Weinberg-Salam model. At higher energies, all quantum mechanical interactions are believed to unite (at GUT-scale), so to unite with the strong one, too. At even higher energies, all interactions, incl. gravitation should unite in a TOE (Theory of Everything)-scale. It is spoken of a symmetrization of nature and it is believed that the primogeneous universe was symmetric. For that, more (GUT and TOE -?) bosons seem to be necessary (see “Hadronic number and Quarkness”). For that to be sure, higher energy scales have to be analyzed experimentally and with them, unifying models be examined. A complete unified interaction with
gravitation, however, is far away, since a complete quantum mechanical gravitation does not exist yet and the meaning and interpretations out of GR and SM equations are very different, although formal analogies of both theories can be given. That is the reason why gravitation is often let out of the discussions, since it is a very weak interaction that only appears practically on astrophysical (macroscopical) scales (since all other interactions are cancelled at those scales). Electromagnetism, for example, stays, as it is long-scaled but, however, does not play a role in long scales, since negative and positive charges sum to zero.

Particles (states) are supposed to be created massless after the Big Bang (which can be singular or not, depending of whether some energy conditions –known as “Penrose-Hawking-conditions”– are valid for the primogeneous universe or not). Nevertheless, mass has to be generated, as is believed, through Symmetry Breakdown through a 5th force interaction of particles with a scalar field (Higgs). This is essential for SM to be mathematically consistent. Else, propagators of the system would diverge, leading to a nonsensical theory of non-measurable quantities. The theory is then said not to be renormalizable (not quantum mechanical) with divergent vacuum energies.

Also, only through Higgs Mechanism would SM stay non-CP-conserving in the easiest way. Mass cannot be only added to the Lagrangian term from which all basic formulae are given under the postulation of the Hamiltonian Principle of Stationary (or Least) Action. Else, all masses would couple equally to all particles and mass would stay unexplained as in GR, although Higgs particles have not been detected yet and its coupling and nature might not yet be completely understood.

- Epilogue:

Matter in modern physics is no longer something tangible, as it can be particle- or wave-like, according to Quantum Mechanics, an given that energy and mass are only two forms of the same, according to Special Relativity. It doesn’t even need mass, as it is a phenomenological consequence of elementary interactions, and as mass changes in dependence on velocity, according to Einstein’s theory. Matter is now categorized by other characteristics, most of them quantum mechanical, as are their quantum numbers as the spin, momentum, strangeness and so on, as well as the different charges and coupling to the mass generation mechanism. Another categorization is of which type of particles composites are made. This lets characterizations parting from the supra-atomic structure into the fundamental one, as well as a categorization according to the elementary interactions possible, since they can act in different ways for different types of particles.

In this relation, the spin is of special importance, since it gives the symmetry property of the quantum mechanical state and thus the statistic that has to be used for the particles, what is important for Pauli’s Principle to be valid or not. Elementary bosons and fermions are thought to be the fundamental categories of particles, although there are ideas of possible, more fundamental particles. Some of the fundamental bosons and fermions can decay in one another; in which account this happens is dependent of the model used. Quarks decay in quarks, fermionic fundaments of nucleonic particles,
united through strong quantum mechanical forces, and which compound in atoms, which can be bosonic or fermionic, and for which electromagnetic forces are of special relevance. Leptons decay in leptons, which give most of the electromagnetical nature of matter. Even neutrinos, a type of leptons that only couple weakly, through a quantum mechanical non-parity conserving interaction, can decay in one another, following maybe a non-vanishing mass for them that is not explained within the Standard Model.

This decay processes are believed, though, in SM, to let the sum of so-called baryons and leptons unchanged. Nevertheless, quarks decay in leptons, if grand unified models should be valid, so breaking the upper conservation law.

The symmetry is another important point for a discussion of elementary particles, since symmetries are connected with conservation laws, some of which are valid for some fundamental interactions and not for others.

The universe is assumed to have been symmetric in the primogeneous era, from which time symmetry-breaking effects led mass appear and interactions dissociate, as well as parity break in weak mechanisms. Interactions should come together again at high temperatures, at which more massive particles are possible. Especially Higgs particles should appear; particles that are thought to be coupled with the appearance of mass in the universe and the interaction of which is of gravitational nature. But other particles should appear, too, if the interactions are to unite in a more symmetric one. They need intermediate particles (bosons) that carry information, massive or not depending on the length scale of these forces, and interactions of higher symmetry as in grand unification would need the appearance of more intermediate fields of a higher mass.

The same with gravitation, since a quantum mechanical approach of this geometrical theory should predict graviton particles to mediate the interaction.

Although fundamental questions stay open in modern elementary particle physics and astrophysics, much is known about nature and structure of matter. Much about the dynamics can be said, using especially analytical mechanics. Fundamental pictures have been made parting from Quantum Mechanics and General Relativity and many predictions have been demonstrated experimentally, giving much strength to standard models of physics. Where future research may lead is unknown, but it won’t change the fact of great knowledge achieved by now, even if an equal amount or more should come.

Literature:

Elementary particles and Symmetry Breakdown:

Nils M. Bezares Roder: 2005; „Kann die Higgs Skalar-Tensortheorie zur Lösung der modernen Probleme der Kosmologie beitragen?“, Diplomarbeit an der Universität Konstanz. Scalar-tensor theory with coupling of the Higgs field with the curvature scalar and Higgs Mechanism, especially used for explaining flat rotation curves and inflation.

Nils M. Bezares Roder and Hemwati Nandan: 2006; “Spontaneous Symmetry Breakdown and Perspective of Higgs Mechanism” and sources therein, to be published. Review on Higgs Mechanism within and outside the Standard Model.


Higgs Gravitation:


A. Fäßler and C. Jönsson: 2005; „Die Top Ten der Schönsten Physikalischen Experimente“: H. Dehnen; „Cavendish’s Torsionswaage und die Bedeutung der Gravitationskonstanten“, Rororo Science, Hamburg. The problem of measuring the gravitational coupling constant and the possible reason of this and possible meaning or variability of this constant,


Inflation and primogogeneous universe:


L.M. Libby and F.J. Thomas: 1969; Phys. Lett. 30B: 88. Hadronic forces can lead to negative pressures,

pressures at early universe stages, postulating a maximal Hagedorn-
temperature (R. Hagedorn: 1968; “Hadronic Matter Near the Boiling Point”;

A. Guth: 1981; “Inflationary Universe: A Possible Solution to the
on Inflation for the primogeneous universe. Exponential inflation of the
universe,

with a scalar field falling from its false vacuum.

D.A.D. Linde: 1983; Phys. Lett. 128B: 177. Chaotic inflation after a
non-singular Big Bang, for high initial values of the scalar inflaton field.

General Literature:

Nuclear Physics in general (experiments): Bodenstedt; „Experimente der
Kernphysik und ihre Bedeutung“.


Discovery of the positron: Anderson: 1933; Science 77: 432.
   Anderson and Neddermeyer: 1933; Phys Rev. 42: 1034.

Discovery of the antiproton: Chamberlain, Segre, Wiegand and Ypsilantis: 1955;

   6: 293.

   Robson: 1951; Phys. Rev. 83: 349.


Interaction between muons and atoms: Conversi, Pancini and Piccioni: 1945;

Discovery of the pi-meson: Lattes, Murihead, Occialini and Powell: 1947; Nature
   159: 694.


Wu experiment on parity violation: Wu, Amber, Hayward, Hoppes and Hudson: