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The World of Elementary Particles

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***If I could remember the names of all these particles, I'd be a botanist*.**

– Enrico Fermi

The Denizens of the Microcosm: *In the microcosm there is a whole world of elementary particles.*

In the mesocosm and macrocosm we encounter matter on the large scale: from dust bits and water droplets to animals and automobiles, to mountains and planets and stars. Each piece of matter is made up of unimaginably large numbers of atoms and molecules. The atoms and molecules of the microcosm are themselves composed of electrons and protons and neutrons. Extensive probes into these, with ingenious instruments, sophisticated concepts, and higher mathematics revealed that there arise and exist in the microcosm a host of other fundamental entities aside from electrons and protons. All these are collectively known as *elementary particles* (EPs)[1].

One of the major achievements of 20th century physics was the enormous amounts of detailed information it acquired on the nature, variety, and properties of various EPs which were discovered and created in high energy accelerators. From all of this we have gained much understanding of the physical laws and principles governing the world of EPs. The main points to bear in mind in this context are the following:

(a) A great many EPs are incessantly emerging and decaying in the microcosm. These processes are referred to as the *creation* and *annihilation* of EPs.

(b) One attributes measurable parameters (numbers) to EPs.

(c) Very few EPs are stable, i.e., last for considerable lengths of time: most of them decay into others soon after being formed in fundamental interactions.

(d) EPs may be classified into broad groups in different ways.

[1] The word 'particle' is misleading in that it creates images of tiny dust particles. EPs are microcosmic entities that have both momentum and wavelength. They may be more appropriately described as *corporundals*, a term used by Louis de Broglie, but never adopted.

Attributes of EPs: ***All EPs are characterized by certain intrinsic properties.***

As just noted, EPs have several attributes in terms of which they can be described and identified. The most important of these are the following:

(a) *Mass*: Except for the photon, all EPs have some mass associated with them. The mass of EPs is usually expressed in terms of their energy equivalent ($E = mc^2$). Thus, for example, we say that the mass of the electron is 0.51 MeV[2].

(b) *Charge*: An EP either carries an electric charge or is neutral. The charge of an EP may be positive or negative. The amount of charge of an EP is always equal to the electronic charge: 1.6×10^{-19} coulomb. To every charged particle there corresponds another particle with identical mass, but with a charge of opposite sign. Thus we have pairs of particles and antiparticles[3].

(c) *Spin*: We recall that the electron is endowed with the property of spin and that the magnitude of the spin is 1/2 in appropriate units. Most EPs are characterized by a spin of 1/2 or 1. Those without any spin are said to be spin zero particles. Spin 1/2 particles are subject to the Pauli Exclusion Principle. There are precise mathematical rules in terms of which the energy distributions of a group of EPs can be calculated. These rules are known as the statistics of the particles. Spin-half particles obey what is called the *Fermi–Dirac statistics*. They are referred to as *fermions*[4]. Particles with spin 0 or 1 are not subject to the exclusion principle. This means that an indefinite number of them can occupy the same quantum state. They are said to obey what is called the *Bose–Einstein statistics*. These particles are referred to as *bosons*[5]. One important consequence of these rules is that whenever a fermion arises in the universe, an antifermion must also arise at the same time. This is not the case with bosons.

Decay of EPs, the Weak Interaction: ***A particular type of force causes the decay of EPs.***

We recall that in the phenomenon of beta radioactivity, a proton is transformed into a neutron, an electron and an antineutrino. We may represent this as:

$$p = n + e^- + \nu_e.$$

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2 One electron-volt (1 eV) is 1.6×10^{-19} J. It is the energy equivalent of about 1.38×10^{-33} g. So when we say that the mass of an electron is 0.51 MeV, it means that its mass is 9.1×10^{-28} g.

3 The existence of particle–antiparticle pairs is an intrinsic aspect of quantum field theory. Neutral particles (like the neutron) also have their antiparticles. Here the members of a pair have opposite magnetic properties.

4 Fermions are named after the Italian physicist Enrico Fermi (1901–1954).

5 Bosons are name after the Indian physicist Satyendra Nath Bose (1894–1974).

This is an example of the transformation of EPs from one kind into other kinds. In the case of free particles such transformations are usually from a less stable to a more stable kind. Most transformations of EPs are *decays*.

Thus far we have referred to three kinds of fundamental interactions in nature: gravitational, electromagnetic, and strong. Detailed studies of the decay of EPs have revealed that yet another fundamental interaction is at play in decay processes. This interaction, though it is considerably stronger than gravitation, is much less intense than the electromagnetic. It is known as the *weak interaction*[6].

We may grasp the concept of the weak interaction by means of an analogy. Imagine a fruit such as an apple. When it is cut in half, the pulp and the seeds separate out. Now if we see that such a fruit which was sitting on the table some time ago was transformed into the pulp and seeds, we will conclude that a knife or some other agent had been used to break it open. This agent corresponds to the interaction in the decay of an EP. Furthermore, if a sharp knife had been used, the fruit would have been broken open in one quick stroke. However, if it takes some time for the change to occur we will have to conclude that the agent was rather weak.

A somewhat similar situation arises in the context of the decay of EPs. A few of them do decay in incredibly short times, but with many others the decay is extremely slow (comparatively speaking). In these cases it is the weak interaction that is responsible for the decay.

To have an idea of the times involved, let us note that there are particles whose lifetimes are of the order of only 10^{-23} s. That is to say, they decay after this length of time has elapsed since being formed! This would be like cutting our fruit with a single stroke. On the other hand, many EPs particles live for as long as 10^{-8} s or even 10^{-6} s. This is somewhat like scraping off the skin little by little by stroking it with a silk cloth. These are very slow decays compared to the ones mentioned earlier. In these instances, it is the weak interaction that comes into play. On our scale, what this means is that if a non-weakly decaying particle lives for a whole year, a weakly decaying one will live for a thousand trillion years.

Every fundamental interaction plays an important role (indeed several important roles) in the sustenance and evolution of the universe. The decay of ephemeral particles, wherein the weak interaction intervenes, may seem a matter of little significance, but it is not. Beta decay processes are of utmost importance in nuclear reactions that are taking place in the core of the

[6] One very unique property of the weak interaction is that it does not give rise to any stable structure. Recall that gravitation leads to planetary and galactic systems, electromagnetism to atoms and molecules, and the strong interaction to atomic nuclei.

stars, and are thus responsible for solar and stellar energy. Astrophysicists have traced the relevance of weak interactions in stellar evolution. In some instances, the culmination of that evolution may be a supernova.

Cosmic Rays: ***We are inundated with EPs from extra-terrestrial space.***

Careful experimenters on radioactivity observed that sometimes their detecting devices (electroscopes and electrometers) reacted even when there was no radioactive substance around. Theodor Wulf (1868–1946), a Jesuit, decided to take his electrometer atop the Eiffel Tower in Paris, and found that the instrument reacted even more vigorously there[7]. He suggested that one should see what would happen if one went still higher. There was some skepticism about Wulf's results. But his suggestion was taken seriously by Victor Hess who made several ascents in balloons and established from his data that the radiations detected by Wulf were getting to be more and more intense as one went to higher levels of the atmosphere. These radiations came to be called *cosmic rays*[8].

In the 1930s and 40s further research detected a number of new particles in cosmic rays. Some of these, like the positron and the muon had been predicted by theories[9]. Others were totally new and unexpected.

Two most revealing discoveries from cosmic ray studies were that: (a) there are EPs that emerge and subsist for incredibly short time periods; (b) EPs arise when very high energy EPs collide with each other or with atomic nuclei. Indeed, many components of the so-called cosmic rays are not of cosmic origin at all, but very much from our atmosphere. They result from the collision of very fast protons from the sun and from outer space (the real cosmic rays) with the nuclei of atoms in our atmosphere.

Cosmic rays sometimes have noticeable effects on conditions on earth. It has been suggested that they often trigger lightning in the atmosphere and that they affect our computers in subtle ways. What is remarkable is that the primary protons in the cosmic rays that penetrate into the atmosphere may have come from the stupendous explosion of a supernova billions of years ago. The long-range impacts of even subtle processes light years away may be significant, showing

[7] Wulf's suspicion and early work on the Eiffel Tower led to uncovering this phenomenon which was unknown till then. But he is rarely even mentioned in the literature on the subject.

[8] The sublime name *cosmic rays* was coined by Robert Millikan (1868–1953) who thought that these were photons coming from the creation of new atoms in the universe.

[9] In 1936, Anderson observed the muon in cosmic rays, a particle that was initially mistaken for the one that Hideki Yukawa had postulated in 1935 in his theory of the strong interaction. The muon was eventually recognized as a decay product of the Yukawa-particle.

the intractable interconnectedness of our physical universe. Such links are no less astounding than quantum entanglement.

Production of EPs: ***EPs can be produced in High Energy Machines.***

Now we come to the question of how elementary particles arise and how they are studied. EPs are generally created in fundamental processes in the microcosm, for example, in radioactivity or when other EPs decay; and also when EPs, especially protons, electrons, or nuclei with great energy collide with atomic nuclei or with other EPs[10]. Once this was recognized in cosmic rays, and the mechanism of their production was known, in principle it was not a very difficult project for physicists to simulate cosmic ray effects in terrestrial laboratories. All one had to do was to accelerate protons and electrons to very high energies and make them hit one another or the nuclei of ordinary matter. When this was done and the resulting processes carefully analyzed, one began to create the EPs that had been observed in cosmic ray phenomena and more.

The experimental study of EPs in a systematic manner thus requires the construction of laboratories in which protons and electrons are accelerated to extremely high energies (measured in eV's). As a result, EP physics acquired another name: It is also known as *High Energy Physics* (HEP). More exactly, in HEP one is involved with experiments using high energy accelerators, with cosmic ray detection and interpretation, and also theoretical work on EP physics.

There are in the world today a number of centers where such high energy machines operate and where international teams of physicists work together. Their purpose is to produce collisions (interactions) exactly as in cosmic rays so as to generate the various EPs in order to study their properties. Sometimes they have detected particles whose existence was forseen by theories. Some of the more famous high energy laboratories of this kind include: the Fermi National Accelerator Laboratory (Fermilab) in Batavia, Illinois, USA; Centre Européen de Recherche Nucleaire (CERN) in Geneva, Switzerland; Illinois, USA. Deutches Elektronen Synchrotron (DESY) in Hamburg, W Germany. In India: BARC: Bhabha Atomic Research Centre, accelerators at IUAC: Inter University Accelerator Centre; SINP: Saha Institute of Nuclear Physics; VECC: Variable Energy Cyclotron Center.

Depending on the particular project, and sometimes on the method employed, the names of some of these machines are often abbreviated. The following are some examples:

PEP: Positron–Electron Project.
PETRA: Positron–Electron Tandem Ring Accelerator.

[10] In addition, there are the so-called field bosons which will be discussed in the next article.

LEP: Large Electron–Positron Ring.
ISR: Intersecting Storage Ring.
SPS: Super Proton Synchrotron.

High energy protons and electrons are produced in a number of ways: by accelerating them between positive and negative electrodes, by accelerating them in several stages through electric and/or magnetic fields, etc. In this manner energies of the order of several million and billion electron volts have been achieved[11].

Multiplets and Isospin: ***Particles may be looked upon as being in different charge states.***

Consider a coin on the floor. It may show head or tail. We may look upon these as two possible face-states in which the coin can be. Likewise, a particle like the electron which may be positive or negative, can be regarded as being in one of two charge states of the same particle[12]. Similarly, there are three kinds of pions (π^+, π^-, π^o), one carrying a positive charge, another carrying a negative charge, a third with no charge at all. These may be seen as a single particle which can be in one of three different charge states: +1, 0, –1. That is to say, the three pions may be seen as the same particle in three different charge states. Or again, the proton and the neutron have many things in common: they are both fermions, they have almost the same mass, they both play an important role in atomic nuclei, etc. Their principal difference lies in the fact that one carries a positive charge and the other is neutral. Thus we may regard these two to be the same particle in two different charge states, positive and neutral. The same may be said about a number of other particles which were discovered later.

Groups of EPs are thus looked upon as forming different *charge multiplets*. A charge multiplet consists of one, two, or three different particles. When we explore the mathematical aspects of this idea, it turns out that this is very similar to the spin idea associated with the electron. Recall that a spin 1/2 particle can exist in two different spin-states (+1/2 and –1/2). With this analogy, we attribute to EPs another type of spin quantum number whose multiplicity would correspond to the different charge states of the particle. This charge-associated quantum number is called *isospin* (or isotopic spin), and is represented by **I**. Thus, for example, the isotopic spin of the nucleon is 1/2. Its two isotopic spin states (values that I_3 can take) correspond to the two charge states of the nucleons, namely, the proton and the neutron. We indicate this by writing:

I for nucleon: 1/2. $I_3 = +1/2$: proton; $I_3 = -1/2$: neutron.

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11 For a full listing of these, see http://www-elsa.physik.uni-bonn.de/accelerator_list.html, *Particle Accelerators Around the World*.

12 The concept of isospin was introduced by Werner Heisenberg in 1932.

Other Quantum Numbers: ***Elementary particles may be reckoned in terms of a variety of quantifiable parameters.***

Isospin is only one example of other similar quantum numbers that were introduced in EP physics for a complete and coherent description of their properties and processes in which they are involved. Like mass, energy, and charge of classical physics, these quantum numbers are preserved or transformed in well-defined ways in elementary particle interactions. Recall that EPs are involved in a variety of interactions. Primarily, in all of these interactions, some particles decay and others are produced. In their effort to see some order in these processes, to discover what rules are obeyed in various interactions, physicists have introduced different *quantum numbers*. First we classify particles into heavy ones and lighter ones: *baryons* and *leptons*[13]. Let us now consider some of these quantum numbers.

(a) *Baryon Number*: All heavy fermions (nucleons and hyperons) are assigned a baryon number B = +1. Their antiparticles have a baryon number of –1. All other particles, i.e., mesons and leptons have B = 0.

(b) *Lepton Number*: Every lepton is assigned a lepton number L which takes on a value +1 for the particle and –1 for the antiparticle. Thus the lepton number for the positron is –1, and that for the electron is +1. Non-leptons have L = 0.

(c) *Strangeness*: In the decade following the end of the Second World War a number of new particles were discovered in cosmic rays as well as in laboratories. These particles behaved in rather strange ways. They are often produced in pairs (*associated production*). They live for relatively long periods of time 10^{-10} to 10^{-8} seconds. Their behavior was understood by introducing a new idea: that there is another intrinsic property of these particles of which physicists were then unaware. This property is expressed in terms of a quantum number, called *strangeness* quantum number[14]. This number is associated with all particles that can engage in strong interactions. The strangeness quantum number is conserved in strong and EM interactions, but not in weak interactions. This recognition explained the properties of the then newly discovered *K* mesons.

The first particles of this kind that were discovered are the so-called *K*-mesons or kaons which

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[13] The name *lepton* is from the Greek $\lambda\varepsilon\pi\tau\acute{o}\zeta$ (leptos), meaning small. The name was given before leptons heavier than some baryons were discovered.

[14] The idea of this special quantum number is due to Murray Gell-Mann and Kazuhiko Nishijima; the name was suggested by Gell-Mann and Abraham Pais.

occur in two pairs[15]: K^+ and K^- as well as K^0 and K^{0*}. The strangeness quantum numbers S assigned to them are:

S = +1 for K^+ and K^0; S = –1 for K^- and K^{0*}. (*stands for the antiparticle here).

Soon a number of other strange particles were discovered, such as Λ^0 for which S = –1, and Ω^{-1} for which S = –3.

The strangeness quantum number for the proton and the neutron is zero. Strangeness quantum numbers are associated only with particles that are involved in strong interactions.

(d) *Hypercharge*: Every charge multiplet has a certain average charge Q associated with the group. Twice this average charge is called the *hypercharge* Y. Thus, by definition,

$$Y = 2Q \; . \qquad (1)$$

An equivalent formula for the hypercharge is given by

$$Y = 2(q - I_3) \; , \qquad (2)$$

where q is the charge on the particle, and I_3 is its isospin.

Consider, for example, the nucleon. The average charge of this multiplet, consisting of the proton (q = +1) and the neutron (q = 0), is +1/2. Therefore, by (1) the hypercharge of the nucleon (proton or neutron) is simply +1.

On the other hand, remembering that I_3 is 1/2 for the proton and –1/2 for the neutron, we can also get the same result from (2). It is easy to establish that

$$Y = S + B \; . \qquad (3)$$

We may use this relation to determine the strangeness of the sigma and the xi particles, for example[16].

Conservation of the New Quantum Numbers: *When EPs transform or interact, some quantum numbers are preserved.*

We know that in classical physics, electric charge is always conserved; so is matter-energy. In particle physics too these are always conserved. However, of the new quantum numbers we

[15] Kaons were first observed, in 1946 by George Rochester and Clifford Butler. Initially puzzling in their decay modes they gave rise to the notion of strangeness, and played an important role in the formalization of EP physics.

[16] The notion of the hypercharge was very valuable fifty years ago, but with the advent of the quark model (to be discussed later) it is no longer as useful.

have seen in the last two sections, only B and L are conserved in all fundamental processes. What this means is that if we write down any fundamental process as an equation the total value of B or L will be the same on both sides. Consider, for example, the process of beta decay in which a neutron becomes a proton, an electron and an antineutrino:

$$\begin{aligned} & n \rightarrow p + e^- + \nu. \\ \text{B:}\quad & 1 = 1 + 0 + 0; \\ \text{L:}\quad & 0 = 0 + 1 - 1. \end{aligned}$$

The conservation of baryon number gives extraordinary stability to nucleons: they simply cannot decay into lighter particles. But for this our universe of solid substantial matter would have dissipated into subtle nothingness eons ago. As for the other quantum numbers isospin, hypercharge and strangeness, they are all conserved only in strong interactions.

Let us consider, for example, the production of the Λ^0 particle along with the kaons when highly energetic protons collide with each other as indicated below:

$$\begin{aligned} & p^+ + p^- \rightarrow K^0 + \Lambda^0. \\ \text{S:}\quad & 0 + 0 = -1 + 1; \\ \text{Y:}\quad & 1 - 1 = +1 - 1. \end{aligned}$$

This is a strong interaction. In weak interactions, they may not be conserved. Thus, in the decay of the sigma plus or the omega minus particle, indicated by

$$\Sigma^+ \rightarrow p^+ + \pi^0$$

Strangeness: – 1 not equal to 0 + 0,

$$\Omega^- \rightarrow \Xi^0 + \pi^-$$

Strangeness: –3 is not equal to –2 + 0.

Variety and Classification of EPs: ***EPs may be classified on different criteria.***

As noted before, the investigations of physicists have revealed the existence of a variety of EPs. So many of them have been discovered that one sometimes speaks of an *EP-zoo*[17]. It is useful to put all the known EPs under two or more broad categories[18]. This could be done on the basis

[17] Living organisms may be looked upon as species with different DNAs. Likewise, according to String theorists, the various EPs are strings in different modes of vibration.

[18] Taxonomy is the first step in observational science. One of the features of classical Hindu thought was the ingenious ways in which the thinkers categorized the experienced world.

of different properties. Thus, for example, we may classify particles in terms of their masses: heavy particles and light particles. Or, we may choose the spin property to be the criterion for classification, and divide EPs broadly into fermions and bosons. Or again, choosing electric charge, we may have three classes of EPs: positively charged particles, negatively charged particles, and neutral particles. All these are valid categorizations.

A classification scheme on the basis of the types of interaction in which EPs can be involved gives a good deal of insight into their nature. So one classifies EPs first into the following two broad groups:

1. *Hadrons*: EPs which can take part in strong interactions[19].

2. *Leptons*: EPs which cannot take part in strong interactions[20]. Leptons are involved primarily in weak interactions.

All charged particles, whether hadrons or leptons, are involved in the EM interaction; and all particles are subject to the gravitational interaction, however feeble this may be. Protons, neutrons, and pions are examples of hadrons, whereas electrons and neutrinos are examples of leptons. Hadrons may sometimes be involved in weak interactions also, but leptons will never take part in a strong interaction. Some hadrons are fermions and some are bosons. The former are called *baryons*[21], and the latter are known as *mesons*[22]. The proton and the neutron are examples of baryons, while the pion is a meson. The proton and the neutron are together referred to as *nucleons*. Non-nucleonic baryons are called *hyperons*. They include: the lambda particle (Λ^0), the sigma particles (Σ^0, Σ^+, Σ^-), the xi particles (Ξ^0, Ξ^-), and the omega (Ω^-) particle[23]. Other than the pions, there is also a whole variety of mesons, which have been given names such as kaons, phi-particles, psi-particles, etc. Unraveling their precise roles in the physical world was once quite a challenge to physicists.

All leptons are fermions. Leptons always occur in pairs. In each pair there is a charged particle and a corresponding neutrino. The positron and the neutrino, encountered in the phenomenon of beta decay, constitute such a pair; the electron and the anti-neutrino are a pair of antiparticles corresponding to these. Two other such pairs and their antiparticles are also known to exist.

[19] The name *hadron* was introduced in 1962, i.e., fifty years ago.

[20] The name *lepton* was introduced in 1946 at the Shelter Island Conference.

[21] The name *baryon* is due to Abraham Pais (1954).

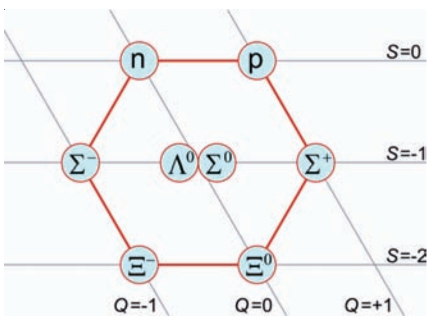
[22] The name *nucleon* was given by Christian Moeller in 1942.

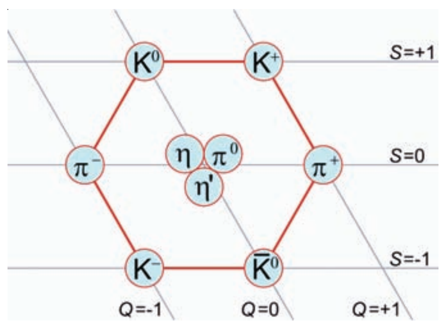
[23] Many particles, like *hyperons* were named at the *Bagnères-de-Bigorre* Conference of 1953. For more details, see Abraham Pais, *Inward Bound: Of matter and forces in the physical world*, Oxford University Press, p.514, 1986.

These have been named the *muon* (μ) and the μ-neutrino, and the *tauon* (τ) and the τ-neutrino[24].

The Eightfold Way: *There is an order in the variety of hadrons and leptons*.

When one considers the strongly interacting particles from the mathematical aspects of symmetry one recognizes that they may be looked upon in terms of what are called the representations of a special kind of group[25]. This led to the arrangement of the particles in terms of their charge and strangeness quantum numbers as below, where S is the strangeness quantum number which can take on values 0, –1, –2; and q is the charge which can take on values –1, 0, +1. In terms of charges (isotopic spin) we have one singlet (Λ^0); two doublets (p and n, and Ξ^0 and Ξ^-); and one triplet (Σ^-, Σ^0, Σ^+). These may be arranged as an octet (eight fundamental particles); likewise, one can form an octet of the known mesons also:





These modes of classifying elementary particles changed drastically after the emergence of the quark model[26].

Uses of EP Physics: *Our knowledge of EPs has found practical applications.*

The primary goal of physics is to understand and explain the physical world, more exactly, the world of perceived reality. The excitement a devotee of Nature experiences at every new discovery of science should be enough for any effort or money expended to acquire it. However, this is reserved only for those who are fully engaged in the pursuit and experience of scientific knowledge and worldviews. Those outside the ivory tower may also appreciate and marvel at

[24] The *tauon* stands for the *tau* (letter *t*) particle to denote that it is the third (*triton* in Greek) of the leptons; electron and muon being the first two. It is an extremely short-lived (lifetime of 2.9×10^{-13} s) but also very massive (1,777 MeV) lepton. It was experimentally discovered in the mid 1970s.

[25] This is the so-called Special Unitary Group 3 or SU(3).

[26] The theory of the quark model, to be discussed in the next article, is due to Murray Gell-Mann and George Zweig, working independently, although the name quark is due to Gell-Mann alone (1964). See in this context, Gell-Mann's popular book, *The Quark and the Jaguar: Adventures in the Simple and the Complex*, St. Martin's Griffin, 1995.

Leptons					
Particle			**Associated Neutrino**		
Name	**Charge (e)**	**Mass (MeV)**	**Name**	**Charge(e)**	**Mass(MeV)**
Electron (e^-)	–1	0.511	Electron neutrino (ν_e)	0	< 0.000003
Muon (μ^-)	–1	105.6	Muon neutrino (ν_μ)	0	< 0.19
Tau (τ^-)	–1	1777	Tau neutrino (ν_τ)	0	< 18.2

Baryons

Particle	Symbol	Mass (MeV/c^2)	Mean lifetime (s)
Proton	P	938.3	Stable
Neutron	N	939.6	885.7 ± 0.8
Delta	Δ^{++}	1232	6×10^{-24}
Delta	Δ^{+}	1232	6×10^{-24}
Delta	Δ^{0}	1232	6×10^{-24}
Delta	Δ^{-}	1232	6×10^{-24}
Lambda	Λ^{0}	1115.7	2.60×10^{-10}
Sigma	Σ^{+}	1189.4	0.8×10^{-10}
Sigma	Σ^{0}	1192.5	6×10^{-20}
Sigma	Σ^{-}	1197.4	1.5×10^{-10}
Xi	Ξ^{0}	1315	2.9×10^{-10}
Xi	Ξ^{-}	1321	1.6×10^{-10}
Omega	Ω^{-}	1672	0.82×10^{-10}

Some Mesons

Particle	Symbol	Antiparticle	Mass (MeV/c^2)	Mean lifetime (s)
Charged Pion	π^+	π^-	139.6	2.60×10^{-8}
Neutral Pion	π^0	Self	135.0	0.84×10^{-16}
Charged Kaon	K^+	K^-	493.7	1.24×10^{-8}
Neutral Kaon	K^0	K^0	497.7	
Eta	H	Self	547.8	5×10^{-19}
Eta Prime	η'	Self	957.6	3×10^{-21}

the stupendous achievements of science in a variety of fields, and even applaud the dedication of those in the pursuit of scientific understandings and their contributions to human knowledge. However, not infrequently, instigated as much by ignorance of what science is all about as by an inability to grasp its essence or methodology, non-scientist thinkers rattle about the limitations of science, its inability to account for pre-origins or create a mosquito in a test tube, its presumptuousness in talking about a God-particle, etc., or even that all this knowledge is not really new in that it is all embedded in ancient aphorisms enshrined in sacred writings.

Be that as it may, every revelation of science has turned out to be of some useful or dangerous application sooner or later. A scientific discovery, as someone wisely stated, is like a new-born infant. One can never predict what it can or will do when it grows up. So it has been with EPs also. Alpha, beta, and gamma emanations from radioactive nuclei have been used to combat cancer cells. Through the phenomenon of nuclear magnetic resonance (NMR) the magnetic properties of nuclei have found application in medicine, geology, chemistry, archaeology, and such. Positrons and even muons have been used for diagnostic purposes. The annihilation of positrons in metals has enabled us to detect metal fatigue. Neutrons have been used for uncovering art forgeries[27].

Thus, the physics of elementary particles, though esoteric in concepts, abstruse in mathematics, and costly in detection techniques, have turned out to be very valuable in a variety of contexts. It bodes well for India's standing in the international arena that there are also a great many physicists of Indic origin in this fascinating quest of physics.

[27] For more on this, see Frank Close *et al*., *The Particle Explosion*, Oxford University Press, 1987, Chapter 11.

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