# Generation Model of Particle Physics and the Parity of the Neutral Pion

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**Abstract** The chapter emphasizes that the Generation Model is obtained from the Standard Model of particle physics essentially by interchanging the roles of the mass eigenstate and weak eigenstate quarks. In the Generation Model the mass eigenstate quarks of the same generation form weak isospin doublets analogous to the mass eigenstate leptons of the same generation while the weak eigenstate quarks form the constituents of hadrons. This allows a simpler and unified classification scheme in terms of only three conserved additive quantum numbers for both leptons and quarks. This unified classification scheme of the Generation Model makes feasible a composite model of the leptons and quarks, which predicts that the weak eigenstate quarks are mixed-parity states. In the Standard Model pions have parity $P = -1$ and the chapter describes that this value of the parity of pions led to the overthrow of both parity conservation and CP conservation in weak interactions. In the Generation Model pions exist in mixed-parity states leading to an understanding of the apparent CP violation observed by Christenson et al. in the decay of the long-lived neutral kaon.

## 1 Introduction

This chapter introduces a new model of particle physics, which has been developed over the last decade, called the Generation Model (GM) [1–3]. Basically, the GM is obtained from the Standard Model (SM) [4] by making two postulates, which together maintain the same transition probabilities for both leptonic and hadronic processes as the SM so that agreement with experiment is preserved.

The differences between the GM and the SM lead to several new paradigms in particle physics: strange quarks in nucleons [3]; origin of mass [5, 6]; origin of gravity

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[5, 6] and mixed-parity quark states in hadrons [3, 7–9]. However, the discussion in this chapter is restricted to showing that the GM provides an understanding of charge-conjugation–parity (CP) symmetry in the decay of the long-lived neutral kaon, which is absent in the SM.

Section 2 demonstrates that the intrinsic parity of pions played a decisive role in the overthrow of both parity conservation in 1957 and CP conservation in 1964 within the framework of the SM. Section 3 presents the classification of the elementary matter particles of the SM in terms of additive quantum numbers and discusses the main problems arising from this classification. Section 4 introduces the GM and indicates how the simpler and unified GM classification scheme overcomes the problems inherent in the SM. Finally Sect. 5 states the conclusions.

## 2 Parity of Pions

In the SM the pions are assumed to have parity $P = -1$. This value was first obtained in 1954 by Chinowsky and Steinberger [10] using the capture of negatively charged pions by deuterium to form two neutrons: $\pi^- + D \to 2n$. This was prior to the quark model so that in the analysis of the experiment, the pion, the proton and the neutron were each assumed to be elementary particles with no substructure.

Following the adoption of the quark model [11, 12] as part of the SM, the parity of the pions remained accepted as $P = -1$. In the quark model, the pions were proposed to be combinations of up ($u$) and down ($d$) quarks and their antiparticles $\bar{u}$ and $\bar{d}$:

$$\pi^+ \equiv [u\bar{d}]\ ,\ \pi^0 \equiv ([u\bar{u}] - [d\bar{d}])/\sqrt{2}\ ,\ \pi^- \equiv [d\bar{u}]\ . \tag{1}$$

Assuming the quarks have intrinsic parity $P_q = +1$ while the corresponding antiquarks have intrinsic parity $P_{\bar{q}} = -1$, all the three pions have parity $P = -1$. This follows since parity is a multiplicative operator in quantum mechanics and consequently e.g. $P\pi^- \equiv P[d\bar{u}] = P_d P_{\bar{u}}[d\bar{u}] = -[d\bar{u}] \equiv -\pi^-$.

This value of the parity of pions led to the overthrow of both parity conservation and CP conservation in weak interactions. We shall now describe briefly how this came about.

### *2.1 Tau-Theta Puzzle*

In the period 1947–1953 several new particles were discovered. In particular one charged meson, named the tau meson [13], decayed to three charged pions, while another charged meson, named the theta meson [14], decayed to two pions:

$$\tau^+ \to \pi^+ + \pi^+ + \pi^-\ ,\ \theta^+ \to \pi^+ + \pi^0\ . \tag{2}$$

Analysis of the decays of both these particles indicated that they had closely similar lifetimes and masses. These properties suggested that the tau and theta mesons were simply two different decay modes of the *same* particle.

In 1953–1954 Dalitz [15] suggested that a study of the energy distribution of the three pions in tau meson decays would provide information about the spin and parity of the tau meson. Such analyses, assuming $P = -1$ for pions, led to the conclusion that the tau meson had $J^P = 0^-$ or $2^-$. On the other hand, the two-body decay of the theta meson gave the opposite parity for the two even spin values, i.e. $J^P = 0^+$ or $2^+$. This indicated that the tau and theta mesons were *different* particles.

This tau-theta puzzle was resolved in 1956 by Lee and Yang [16], who suggested that parity may be violated in weak interactions. This suggestion was rapidly confirmed in 1957 in three independent experiments [17–19]. These experiments indicated that the tau and theta mesons were indeed the same meson (now called the $K^+$) and also showed that charge-conjugation (C) was violated in weak interactions.

## 2.2 Neutral Kaon Mixing

In 1955 Gell-Mann and Pais [20] considered the behavior of neutral particles under the charge-conjugation operator. In particular they considered the $K^0$ meson and realized that unlike the photon and the neutral pion, which transform into themselves under the C operator so that they are their own antiparticles, the antiparticle of the $K^0$ meson (strangeness $S = +1$), $\bar{K}^0$, was a distinct particle, since it had a different strangeness quantum number ($S = -1$). They concluded that the two neutral mesons, $K^0$ and $\bar{K}^0$, are degenerate particles that exhibit unusual properties, since they can transform into each other via weak interactions such as

$$K^0 \rightleftharpoons \pi^+\pi^- \rightleftharpoons \bar{K}^0. \tag{3}$$

In order to treat this novel situation, Gell-Mann and Pais suggested that it was more convenient to employ different particle states, rather than $K^0$ and $\bar{K}^0$, to describe neutral kaon decay. They suggested the following representative states:

$$K_1^0 = (K^0 + \bar{K}^0)/\sqrt{2}\,, \quad K_2^0 = (K^0 - \bar{K}^0)/\sqrt{2}\,, \tag{4}$$

and concluded that these particle states must have different decay modes and lifetimes. In particular they concluded that $K_1^0$ could decay to two charged pions, while $K_2^0$ would have a longer lifetime and more complex decay modes. This conclusion was based upon the conservation of C in the weak interaction processes: both $K_1^0$ and the $\pi^+\pi^-$ system are even (i.e. $C = +1$) under the C operation. On the other hand $CK_2^0 = -K_2^0$.

**Table 1** SM additive quantum numbers for leptons

| Particle | $Q$ | $L$ | $L_\mu$ | $L_\tau$ |
|---|---|---|---|---|
| $\nu_e$ | 0 | 1 | 0 | 0 |
| $e^-$ | $-1$ | 1 | 0 | 0 |
| $\nu_\mu$ | 0 | 1 | 1 | 0 |
| $\mu^-$ | $-1$ | 1 | 1 | 0 |
| $\nu_\tau$ | 0 | 1 | 0 | 1 |
| $\tau^-$ | $-1$ | 1 | 0 | 1 |

The particle-mixing theory of Gell-Mann and Pais was confirmed [21] in 1957 by experiment, in spite of the incorrect assumption of C-invariance in weak interaction processes.

This led to a suggestion by Landau [22] that the weak interactions may be invariant under the combined operation CP, although both C and P are individually maximally violated.

Landau's suggestion implied that the Gell-Mann–Pais model of neutral kaons would still apply if the states, $K_1^0$ and $K_2^0$, were eigenstates of CP with eigenvalues $+1$ and $-1$, respectively. Since the charged pions were considered to have intrinsic parity $P = -1$, it was clear that only the $K_1^0$ state could decay to two charged pions, if CP was conserved.

The suggestion of Landau was accepted for several years since it nicely restored some degree of symmetry in weak interaction processes. However, in 1964 the surprising discovery was made by Christenson et al. [23] that the long-lived neutral kaon could decay to two charged pions. The observed violation of CP conservation turned out to be very small ($\approx 0.2$ %) compared with the maximal violations ($\approx 100$ %) of both C and P conservation separately. Indeed the very smallness of the apparent CP violation led to a variety of suggestions explaining it in a CP-conserving way [24, 25]. However, these efforts were unsuccessful and CP violation in weak interactions was accepted.

## 3 Standard Model (SM)

Let us now discuss briefly the Standard Model (SM) [4] of particle physics. Tables 1 and 2 show the additive quantum numbers allotted to the six leptons (electron ($e^-$), muon ($\mu^-$), tau particle ($\tau^-$) and their three associated neutrinos, $\nu_e$, $\nu_\mu$, $\nu_\tau$) and the six quarks (up ($u$), down ($d$), charmed ($c$), strange ($s$), top ($t$) and bottom ($b$)), respectively, which constitute the elementary matter particles of the SM. For the leptons we have: charge $Q$, lepton number $L$, muon lepton number $L_\mu$ and tau lepton number $L_\tau$. For the quarks we have: charge $Q$, baryon number $A$, strangeness $S$, charm $C$, bottomness $B$ and topness $T$. For each particle additive quantum number $N$, the corresponding antiparticle has the additive quantum number - N.

**Table 2** SM additive quantum numbers for quarks

| Particle | $Q$ | $A$ | $S$ | $C$ | $B$ | $T$ |
|---|---|---|---|---|---|---|
| $u$ | $+\frac{2}{3}$ | $\frac{1}{3}$ | 0 | 0 | 0 | 0 |
| $d$ | $-\frac{1}{3}$ | $\frac{1}{3}$ | 0 | 0 | 0 | 0 |
| $c$ | $+\frac{2}{3}$ | $\frac{1}{3}$ | 0 | 1 | 0 | 0 |
| $s$ | $-\frac{1}{3}$ | $\frac{1}{3}$ | $-1$ | 0 | 0 | 0 |
| $t$ | $+\frac{2}{3}$ | $\frac{1}{3}$ | 0 | 0 | 0 | 1 |
| $b$ | $-\frac{1}{3}$ | $\frac{1}{3}$ | 0 | 0 | $-1$ | 0 |

It should be noted that, except for charge, leptons and quarks are allotted different kinds of additive quantum numbers so that this classification is *non-unified*. Each of the additive quantum numbers is conserved in any interaction, except for $S$, $C$, $B$ and $T$, which can undergo a change of one unit in weak interactions.

The six leptons and six quarks are all spin-$\frac{1}{2}$ particles and fall naturally into three families or generations: (i) $\nu_e$, $e^-$, $u$, $d$ ; (ii) $\nu_\mu$, $\mu^-$, $c$, $s$ ; (iii) $\nu_\tau$, $\tau^-$, $t$, $b$ . Each generation consists of particles which have similar properties apart from mass: two leptons with charges $Q = 0$ and $Q = -1$ and two quarks with charges $Q = +\frac{2}{3}$ and $Q = -\frac{1}{3}$. The masses of the particles increase significantly with each generation with the possible exception of the neutrinos, whose very small masses have yet to be determined.

### *3.1 Basic Problem Inherent in SM*

The basic problem with the SM is the classification of its elementary particles employing a diverse complicated scheme of additive quantum numbers (Tables 1 and 2), some of which are not conserved in weak interaction processes; and at the same time failing to provide any physical basis for this scheme.

A good analogy of the SM situation is the Ptolemaic model of the universe, based upon a stationary Earth at the center surrounded by a rotating system of crystal spheres refined by the addition of epicycles (small circular orbits) to describe the peculiar movements of the planets around the Earth. Although the Ptolemaic model yielded an excellent description of the observed movements of the constituents of the universe, it is a complicated diverse scheme for predicting the movements of the Sun, Moon, planets and the stars around a stationary Earth and unfortunately provides no understanding of these complicated movements.

### 3.2 Universality of Charge-Changing (CC) Weak Interactions

Another problem with the SM concerns the method it employs to accommodate the *universality* of the CC weak interactions [26, 27]. The CC weak interactions are mediated by the $W^+$ and $W^-$ vector bosons, which have zero additive quantum numbers apart from charge.

In the SM, the observed universality of the CC weak interactions in the lepton sector is described by assuming that each mass eigenstate charged lepton forms a weak isospin doublet ($i = \frac{1}{2}$) with its respective neutrino, i.e. $(\nu_e, e^-)$, $(\nu_\mu, \mu^-)$, $(\nu_\tau, \tau^-)$, with each doublet having the third component of weak isospin $i_3 = (+\frac{1}{2}, -\frac{1}{2})$. In addition each doublet is associated with a different lepton number so that there are no CC weak interaction transitions between generations.

Restricting the discussion to only the first two generations for simplicity, this means that $\nu_e$ and $\nu_\mu$ interact with $e^-$ and $\mu^-$, respectively, with the *full* strength of the CC weak interaction but $\nu_e$ and $\nu_\mu$ do *not* interact at all with $\mu^-$ and $e^-$, respectively. This is guaranteed by the conservation of lepton numbers.

On the other hand the universality of the CC weak interactions in the quark sector is treated differently in the SM. Again for simplicity, restricting the discussion to only the first two generations, it is assumed that the $u$ and $c$ quarks form weak isospin doublets with so-called weak eigenstate quarks $d'$ and $s'$, respectively. These weak eigenstate quarks are linear superpositions of the mass eigenstate quarks ($d$ and $s$):

$$d' = d\cos\theta_c + s\sin\theta_c\ ,\ \ s' = -d\sin\theta_c + s\cos\theta_c\ , \tag{5}$$

where $\theta_c$ is a mixing angle introduced by Cabibbo [28] in 1963 into the transition amplitudes prior to the development of the quark model in 1964.

The SM assumes that $u$ and $c$ interact with $d'$ and $s'$, respectively, with the *full* strength of the CC weak interaction and that $u$ and $c$ do *not* interact at all with $s'$ and $d'$, respectively. However, this latter assumption is dubious since, unlike the lepton sector, there are no conserved quantum numbers to guarantee this.

It should be noted that the extension of the above discussion to all three generations is straightforward [29]. In this case, the quark-mixing parameters correspond to the Cabibbo-Kobayashi-Maskawa (CKM) matrix elements [30], which indicate that inclusion of the third generation would have minimal effect on the above discussion.

## 4 Generation Model (GM)

The Generation Model (GM) of particle physics has been developed over the last decade. In the initial chapter [1] a new classification of the elementary particles, the six leptons and the six quarks, of the SM was proposed. This classification was based upon the use of only three additive quantum numbers: charge ($Q$), particle number ($p$) and generation quantum number ($g$), rather than the nine additive quantum numbers

**Table 3** GM additive quantum numbers for leptons and quarks

| Particle | $Q$ | $p$ | $g$ | Particle | $Q$ | $p$ | $g$ |
|---|---|---|---|---|---|---|---|
| $\nu_e$ | 0 | $-1$ | 0 | $u$ | $+\frac{2}{3}$ | $\frac{1}{3}$ | 0 |
| $e^-$ | $-1$ | $-1$ | 0 | $d$ | $-\frac{1}{3}$ | $\frac{1}{3}$ | 0 |
| $\nu_\mu$ | 0 | $-1$ | $\pm1$ | $c$ | $+\frac{2}{3}$ | $\frac{1}{3}$ | $\pm1$ |
| $\mu^-$ | $-1$ | $-1$ | $\pm1$ | $s$ | $-\frac{1}{3}$ | $\frac{1}{3}$ | $\pm1$ |
| $\nu_\tau$ | 0 | $-1$ | $0, \pm2$ | $t$ | $+\frac{2}{3}$ | $\frac{1}{3}$ | $0, \pm2$ |
| $\tau^-$ | $-1$ | $-1$ | $0, \pm2$ | $b$ | $-\frac{1}{3}$ | $\frac{1}{3}$ | $0, \pm2$ |

(see Tables 1 and 2) of the SM. Thus the new classification is both simpler and *unified* in that leptons and quarks are assigned the same kind of additive quantum numbers unlike those of the SM.

Another feature of the new classification scheme is that all three additive quantum numbers, $Q$, $p$ and $g$, are required to be conserved in all leptonic and hadronic processes. In particular the generation quantum number $g$ is strictly conserved in weak interactions unlike some of the quantum numbers, e.g. strangeness $S$, of the SM. This latter requirement led to a new treatment of quark mixing in hadronic processes [1, 3], which will be discussed in Sect. 4.1.

The development of the GM unified classification scheme indicated that leptons and quarks are intimately related and led to the development of composite versions of the GM [6, 31].

Table 3 displays a set of three additive quantum numbers for the unified classification of the leptons and quarks corresponding to the current composite GM [6]. As for Tables 1 and 2, the corresponding antiparticles have the opposite sign for each particle additive quantum number. Each generation of leptons and quarks has the same set of values for the additive quantum numbers $Q$ and $p$. The generations are differentiated by the generation quantum number $g$, which in general can have multiple values. The latter possibilities arise from the composite nature of the leptons and quarks in the composite GM.

## *4.1 Conservation of Generation Quantum Number*

The conservation of the generation quantum number in weak interactions was only achieved by making two postulates, which requires the GM to differ fundamentally from the SM in two ways. Again, for simplicity, the discussion is restricted to the first two generations.

Firstly, the GM postulates that it is the *mass* eigenstate quarks of the same generation, which form weak isospin doublets: $(u, d)$ and $(c, s)$. Thus the GM assumes that the $u$ and $c$ quarks interact with the $d$ and $s$ quarks, respectively, with the *full* strength of the CC weak interaction and do *not* interact at all with the $s$ and $d$ quarks, respectively. These properties are guaranteed by the conservation of generation quantum number.

Secondly, the GM postulates that hadrons are composed of *weak* eigenstate quarks such as $d'$ and $s'$ rather than the corresponding *mass* eigenstate quarks, $d$ and $s$, as in the SM. Essentially, in the GM the roles of the mass eigenstate quarks and the weak eigenstate quarks are *interchanged* from that in the SM.

### 4.2 Composite Generation Model

The unified classification scheme of the GM makes feasible a composite version of the GM [6, 31]. This is not possible in terms of the non-unified classification scheme of the SM, involving different additive quantum numbers for leptons than for quarks and the non-conservation of some additive quantum numbers, such as strangeness, in the case of quarks.

In the composite GM, the leptons and quarks are not elementary particles as in the SM but are composed of rishons and/or antirishons [6]. For the present purposes, it should be noted that this composite model predicts that the down and strange quarks have *opposite intrinsic parities*: the $d$ quark consists of two rishons and one antirishon while the $s$ quark consists of three rishons and two antirishons and it is assumed that rishons and antirishons have opposite intrinsic parities. This is important because it implies that the weak eigenstate quarks, $d'$ and $s'$, are *mixed-parity* states so that pions exist in mixed-parity states.

### 4.3 Pions in GM

In the GM the pions consist of weak eigenstate quarks:

$$\pi^+ \equiv [u\bar{d}'] \, , \; \pi^0 \equiv ([u\bar{u}] - [d'\bar{d}'])/\sqrt{2} \, , \; \pi^- \equiv [d'\bar{u}] \, . \tag{6}$$

rather than mass eigenstate quarks as in the SM (Eq. (1)).

Recently it has been demonstrated [8] that the early experiment of Chinowsky and Steinberger [10] is *indeterminate* with respect to the determination of the intrinsic parity of the negatively charged pion, if the pion, neutron and proton have a complex substructure as in the composite GM: the experiment is also compatible with the mixed-parity nature of the charged pions.

Similarly, it has been shown [9] that the recent determination [32] of the parity of the neutral pion, using the double Dalitz decay $\pi^0 \to e^+e^-e^+e^-$, is also compatible with the mixed-parity nature of the neutral pion predicted by the composite GM.

Analysis of this experiment placed a limit on scalar contributions to the decay amplitude of the $\pi^0$ of less than 3.3 %. The GM predicts a scalar contribution to the decay amplitude of about 2.5 %, which is of the same order of magnitude as the experimental result, suggesting that further experimentation may determine a non-zero scalar contribution to the decay amplitude.

Thus the mixed-parity natures of both charged and neutral pions are compatible with experiment.

### *4.4 Conservation of CP in Neutral Kaon System*

Recently, Morrison and Robson [7] have demonstrated that the indirect CP violation observed by Christenson et al. [23] for the $K^0 - \bar{K}^0$ system can be described in terms of mixed-quark states in hadrons. In the GM, within the two generation approximation, the long-lived neutral kaon exists in a $CP = -1$ eigenstate and the mixed-parity of the charged pions provides the two-charged pion system $(\pi^+\pi^-)$ with a small component of a $CP = -1$ eigenstate so that the long-lived neutral kaon can decay to two charged pions without CP violation. Thus the GM predicts that essentially the decay of the long-lived neutral kaon into two charged pions arises from the mixed-parity of the charged pions and *not* from CP violation.

## 5 Conclusion

The GM has been developed from the SM essentially by *interchanging the roles* of the mass eigenstate and weak eigenstate quarks from that in the SM. In the GM the mass eigenstate quarks of the same generation form weak isospin doublets analogous to the mass eigenstate leptons of the same generation while the weak eigenstate quarks form the constituents of hadrons. This allows a simpler and unified classification scheme in terms of only three conserved additive quantum numbers for both leptons and quarks.

This unified classification scheme of the GM makes feasible a composite model of the leptons and quarks, which predicts that the weak eigenstate quarks of the GM are mixed-parity states. Consequently, in the GM, pions exist in mixed-parity states, which to date are compatible with experiment. The mixed-parity nature of the neutral pion predicted by the GM suggests the existence of a scalar contribution of about 2.5 % to the double Dalitz decay amplitude for $\pi^0 \rightarrow e^+e^-e^+e^-$, which further experimentation may be able to detect. Finally, the mixed-parity nature of the charged pions allows the observed decay of the long-lived neutral kaon to be described with the *conservation* of CP symmetry, indicating that the observed decay of the long-lived neutral kaon into two charged pions by Christenson et al. [23] in 1964 does not correspond to indirect CP violation.

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