A11102 490219

NAT'L INST OF STANDARDS & TECH R.I.C.
A11102490219
Marx, Egon/The composite proton
QC100 .U56 NO.86-3370 1986 V19 C.1 NBS-P

The Composite Proton

NBS
PUBLICATIONS

Egon Marx

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
National Engineering Laboratory
Center for Manufacturing Engineering
Gaithersburg, MD 20899

April 1986

U.S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

QC
100
.U56
86-3370
1986
C. 2

NBS
RESEARCH INFORMATION
CENTER
QC NBSC
100
.U56
86-3370
1986
C.2

NBSIR 86-3370

THE COMPOSITE PROTON

Egon Marx

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
National Engineering Laboratory
Center for Manufacturing Engineering
Gaithersburg, MD 20899

April 1986

U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, ***Secretary***
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, ***Director***

ABSTRACT

A model is proposed in which the proton and other baryons are particles composed of only two basic particles: an archaeobaryon (archyon) and one or more pions. Mesons are composed of pions alone. A third basic particle is the neutrino, which is a component of all leptons. The interactions between the three corresponding fields and the electromagnetic field are derived from a Lagrangian density that has only two masses and three coupling constants. The interactions are expressed in terms of conserved currents, one for each particle. All particle reactions are reduced to four processes: particle scattering, antiparticle scattering, pair creation, and pair annihilation. The last two correspond to the reflection of the wave function in the time direction. There is no longer a need for a separate theory of unstable particles. The pion is the only electrically charged particle, which accounts for the equality of the magnitude of all charges of elementary particles. Strong and weak interactions of hadrons are different manifestations of a single interaction; the distinction is related to pair creation or annihilation, energy barriers, and the flux of particles and antiparticles. Charmed and beauty particles are not different from other particles in any significant way. Strangeness, which is not a basic concept in this model, is related to the reluctance of particles to decay. Charm and beauty may be included in strangeness as defined here. The strangeness of stable baryons is the number of positive pion components minus 3, and that of stable mesons is the number of different pion components minus 1. Composite particles are bound states with a large binding energy, larger than twice the mass of the lighter component. This allows for spontaneous pair creation which makes the heavy component decay into the composite particle. Resonances can be long-lived in spite of large negative binding energies. Particle reactions are rearrangements of the basic components, much like those of chemistry, with the added possibility of pair creation and annihilation. Future calculations are to provide the masses and lifetimes of all particles and resonances, plus other information such as branching ratios, in terms of the five parameters in the Lagrangian density.

Key words: beauty; bound states; charm; composite particles; electromagnetic interactions; elementary particles; hadrons; leptons; relativistic quantum mechanics; resonances; strangeness; strong interactions; weak interactions.

CONTENTS

1. INTRODUCTION

This model of elementary particles parallels Dalton's model of atoms and molecules in chemistry. The "atoms" are three basic particles: the pion, the neutrino, and a basic baryon. The "molecules" are all other so-called elementary particles and resonances. A particle interaction or decay involves the rearrangement of components. A basic particle cannot be created or annihilated, but it can be reflected in time to effect pair creation or annihilation.

The present standard theoretical formulation of particle physics explains remarkably well a large body of experimental facts. Nevertheless, there are puzzles of long standing, such as the mass difference between the muon and the electron, that remain unsolved. We propose a theory that is simpler than the standard one and that shows promise of solving such puzzles. The equations of motion of the fields would allow us to compute many constants that are now free parameters. The physics community has a large investment in the present theory of elementary particles and is understandably reluctant to start a comparable effort on an alternative approach. We submit that a theory based on an elegant Lagrangian density with only five parameters deserves a closer examination.

Dirac [1][1] has aptly compared the present formulation of quantum field theory (QFT) to the Bohr theory before quantum mechanics. We believe that this model is the correct generalization of nonrelativistic quantum mechanics.

The neutrino and the pion are familiar particles, but the basic baryon is a neutral (strangeness -3) baryon that may or may not have been detected and which

---

[1] Numbers in square brackets indicate the literature references at the end of this monograph. Further references can be found therein.

we call archaeobaryon, archyon, or Ω^0. The most promising candidate for archyon in the experimentally established particle conglomerate is the beauty baryon Λ_b^0. The neutrino is massless and only two masses, those of the pion and of the archyon, have to be specified in our model.

The pion is the only charged basic particle and it interacts with the electromagnetic field in the usual manner. This explains why the electric charge has the same magnitude for different particles such as the electron and the proton. The charge is a coupling constant that constitutes the third required parameter. The electromagnetic field is a real field which may have to be quantized depending on the formulation chosen for the particles.

The pion also interacts with the neutrino and the archyon, which introduces two (possibly equal or related) further coupling constants. Strong and weak interactions are different manifestations of this interaction, which also provides the large binding energies required to form composite particles with masses smaller than those of the heavier component. The masses correspond to the energy levels of bound states. The difference between strong and weak interactions must be dynamical, related to pair creation, pair annihilation, and the penetration of energy barriers by virtual pions.

We introduce a single neutrino in this model, but this is not a fundamental restriction. The other leptons, including the τ-lepton and its neutrino, are particles composed of a neutrino and one or two pions.

Stable[2] baryons are composed of an archyon and one, two, or three pions. We predict the existence of a positively charged baryon of strangeness -2, the Ξ^+, and a second neutral baryon of strangeness -2, the Ξ'^0, which decays electromagnetically into a Ξ^0. The Ξ^+ and the Ξ'^0 may be the charmed baryons

[2]We use the term "stable" in the sense of "stable under strong interactions," which describes a relatively long-lived particle.

Λ_c^+ and Σ_c^0, respectively.

Pions form resonances of two kinds. Some are fairly broad resonances such as the ρ and the ω, while others give rise to stable mesons such as the kaons, the charmed mesons, and the beauty mesons.

The dynamical framework that underlies this theory is that of relativistic quantum mechanics (RQM), modelled after the theory of charged scalar particles in an external electromagnetic field. The wave function contains the probability amplitudes for a particle and for an antiparticle, and the latter propagates backward in time [2]. Although a classical particle cannot turn around in time to become an antiparticle, the scattering of a relativistic wave function reflects a part of it back in time; the resulting process is pair annihilation. We allow for particle scattering, antiparticle scattering, pair creation, and pair annihilation [3]. There can be no creation or annihilation of a single basic particle in any reaction. We may also use a form of QFT that corresponds to a many-particle version of RQM. Either of these formalisms has advantages over the standard QFT. The perturbation expansion of the wave function is free of divergent diagrams [4], there are no complications associated with the vacuum, there are properly normalized probability amplitudes, and there is no need for a separate theory of unstable particles.

The number of particles minus the number of antiparticles is conserved for each basic particle. Consequently, there is a conserved charge and current density for each one. The exchange of pions and the creation and annihilation of pairs of pions or neutrinos give rise to almost all of the listed decays of stable particles [5]; only a few rare or uncertain decay modes are not allowed in this model.

The symmetry between past and future in particle interactions appears to conflict with our perception of the arrow of time. Our particular perspective is caused by the circumstance that we are composed of particles, all of which propagate forward in time. Particle reactions are laid out in space-time, and we figuratively sample them as we propagate in the positive-time direction.

We often use the generally accepted names for particles and their interactions [6], although at times this is not the most logical or consistent choice. We refer to strangeness, charm, beauty, quarks, and the multiplet structure of SU(3) because these terms are familiar to the reader, who might be distracted by a completely new nomenclature. Greek indices range from 0 to 3 unless defined otherwise, and we use the modified summation convention for these indices if they are repeated. We use capital letters such as A for spinor indices that range from 1 to 2; some of these indices are dotted to reflect the transformation properties of the spinor. We use natural units and the time-favoring metric in space-time.

We recall the dynamical formalism that provides the framework for this model in section 2. We extend the model of composite leptons in section 3. We discuss pions and their decay modes in section 4. Section 5 is dedicated to the baryon octet and section 6 is about kaons. We discuss the baryon and pion resonances and the related stable hadrons in section 7. In section 8 we examine the strong interactions, the associated production of strange particles, and the concept of strangeness. In section 9 we present possible additional strange baryons and their decay modes. In section 10 we show the decay modes of the τ-lepton and its neutrino. We extend the model to include particles that have charm or beauty in section 11 and to psions and upsilons in section 12. We present the Lagrangian density and equations of motion in section 13.

Most figures represent particle interactions and decays, and show how the pions are involved in the rearrangements of the "atoms." A typical diagram is a kind of Feynman graph or ray diagram in which the straight lines represent particles propagating freely between interactions at the vertices. Actually, wave functions are fields that can extend over all of space and interactions occur over extended regions of space-time. Particle lines are displaced for visibility; a composite particle appears as a set of parallel lines. Arrows on the lines show direction of propagation, and horizontal lines represent the propagation of virtual particles or simply an interaction. Thin solid lines represent neutrinos, heavy ones represent archyons, and wavy lines represent photons. Dashed lines represent pions and they have an arrow to show the direction of propagation or charge of a charged pion. The neutral pion is a superposition of two charged pions and we represent it by a dashed line heavier than that of a charged pion; this line carries no arrow. We have developed a system of drawing diagrams that allows us to trace the pion lines, although the result is not unique. A vertex which is not a kink in a pion line is the confluence of two charged pions of opposite charges and a neutral pion. When following a pion line through a diagram, if one arrives at the vertex via a charged pion line, one must continue on the neutral pion line, and if one arrives via the neutral pion line, one must continue on the charge pion line with the appropriate directional arrow. A neutral pion line is traversed once in each direction, and if this line ends in one or more photons, one must go back on the same line. We have not scaled the length of the lines to the actual time elapsed between interactions or decays.

2. BASIC CONCEPTS

Our model is a development that has its root in the relativistic quantum mechanics of a scalar particle in an external electromagnetic field. The physical interpretation of a relativistic wave function implies that an antiparticle is a particle propagating backward in time. When a "particle"[3] turns around in time, the result is pair creation or annihilation. RQM is a dynamical theory where the given time-boundary conditions are the particle probability amplitudes at the initial time and the antiparticle probability amplitudes at the final time. This formalism follows from the properties of the causal Green function or Feynman propagator when used in the solution of the Klein-Gordon equation. Charge conservation is the basis for the interpretation of the wave function in terms of probability amplitudes [3, 7].

Bound states can have a binding energy that exceeds twice the mass of the lighter particle, which allows for spontaneous pair creation. This process is interpreted as a particle decay.

We review the foundations of RQM in subsection 2.1 and relate the many-particle formalism of RQM to QFT in subsection 2.2. We show how these ideas apply to the electromagnetic interactions of charged scalar particles in subsection 2.3, and we discuss bound states and resonances in subsection 2.4.

2.1 Relativistic quantum mechanics

The Klein-Gordon equation was introduced as a relativistic generalization of the nonrelativistic Schrödinger equation. This change doubles the number of degrees of freedom because the Klein-Gordon equation is of second order in the time variable. The retarded Green function of the nonrelativistic theory is replaced by the causal Green function [7], which affects the specification of the time-boundary conditions.

---

[3] We use "particle" or a similar term in quotes, such as "lepton," to indicate that we are referring to either a particle or an antiparticle. If the distinction between "particle" and particle is not important or if it is clear from the context, we do not use the quotes.

The relativistic wave function ϕ of a free particle is decomposed into a positive-frequency part, $\phi^{(+)}$, and a negative-frequency part, $\phi^{(-)}$, defined by

$$\phi^{(\pm)}(x) = \frac{1}{2}(1 \pm i\tilde{E}^{-1}\partial_0)\phi(x), \tag{1}$$

where x is a four-vector with $x_0 = t$ and $\tilde{E}$ is the integral operator

$$\tilde{E} = (-\nabla^2 + m^2)^{1/2}. \tag{2}$$

Initial values for a field that obeys the Klein-Gordon equation and for its time derivative are associated with the retarded Green function. Similarly, the causal Green function leads to the specification of the positive-frequency part of the wave function at the initial time and of the negative-frequency part at the final time. These time-boundary conditions and conservation of charge allow us to define

$$g^{(\pm)}(x) = (2\tilde{E})^{1/2}\phi^{(\pm)}(x) \tag{3}$$

as probability amplitudes. If $g^{(+)}$ or $g^{(-)}$ is given at a time t for all $\vec{x}$, we can find $\phi^{(+)}$ or $\phi^{(-)}$ at that time, and vice versa. The fields $\phi^{(+)}$ and $\phi^{(-)}$ obey partial differential equations that are of first order in time, similar to the Schrödinger equation.

To normalize the probability amplitudes, either we specify the probability amplitude for the particle at the initial time normalized to 1 and set the antiparticle amplitude equal to 0 at the final time, or we specify the antiparticle amplitude at the final time normalized to 1 and we set the particle amplitude equal to 0 at the initial time. In either case we compute the particle amplitude at the final time and the antiparticle amplitude at the initial time. Conservation of charge then implies that the sum of the norms of these two amplitudes has to be 1, which allows us to interpret these quantities as probabilities.

If a particle is given at the initial time, there is a probability of finding a particle at the final time (particle scattering) and the complementary probability of finding an antiparticle at the initial time (pair annihilation). This process is represented in figure 1a. If an antiparticle is given at the final time, the time-reflected process shown in figure 1b is interpreted as antiparticle scattering and pair creation.

The wave function is also determined at intermediate times, but there is no

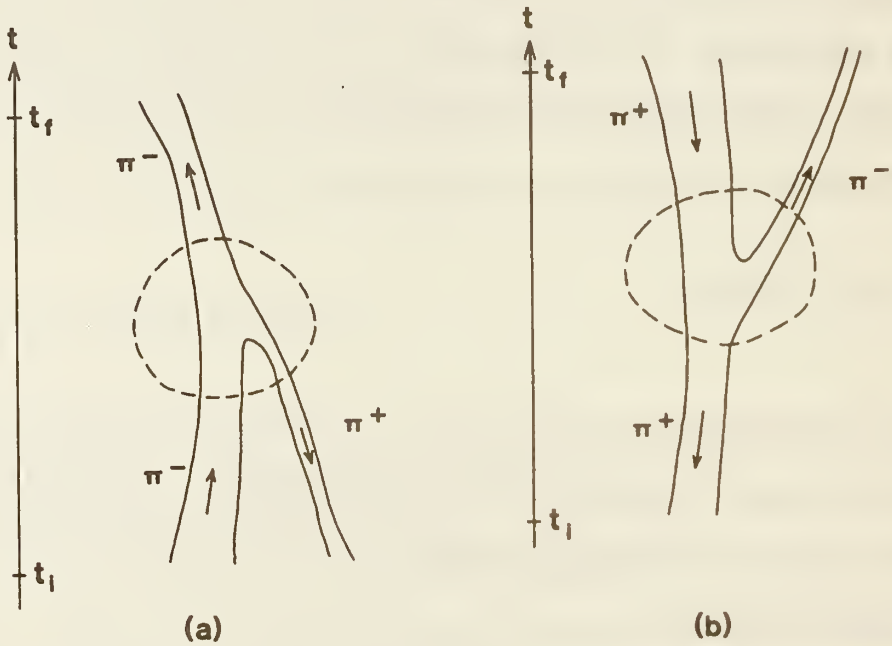

Figure 1. Diagrams showing the interaction between a charged field and an external electromagnetic field. In (a), the probability amplitude for a negative pion is given at the initial time with total probability 1, and the interaction causes part of this amplitude to be scattered to the final time and the remainder to be reflected back to the initial time, processes which are interpreted as particle scattering and pair annihilation. The time-reversed processes in (b) show antiparticle scattering and pair creation. The horizontal dimension represents space.

obvious interpretation for the corresponding values of the probability amplitudes. A measurement at an intermediate time would disrupt or change an experiment constrained by initial and final conditions.

A different view [8] of the same processes is shown in figure 2, in which a potential barrier in the time direction either reflects or transmits a particle coming from the past or from the future. The limitation to one or the other initial direction of propagation is a physical, as opposed to a mathematical, constraint; in principle we can combine both cases in a single wave funtion.

We have extended this formalism to several identical particles. They are represented by a single wave function with the appropriate symmetry. For n particles we need a function of n time variables [9], $\phi(\vec{x}_1,t_1;\vec{x}_2,t_2;\ldots;\vec{x}_n,t_n)$, which can be decomposed into n+1 independent probability amplitudes with the different combinations of particles and antiparticles, $\phi^{(\pm\pm\ldots\pm)}(x_1,x_2,\ldots,x_n)$. Only one of these amplitudes is given with the particles at the initial time and the antiparticles at the final time, and all other amplitudes vanish at the

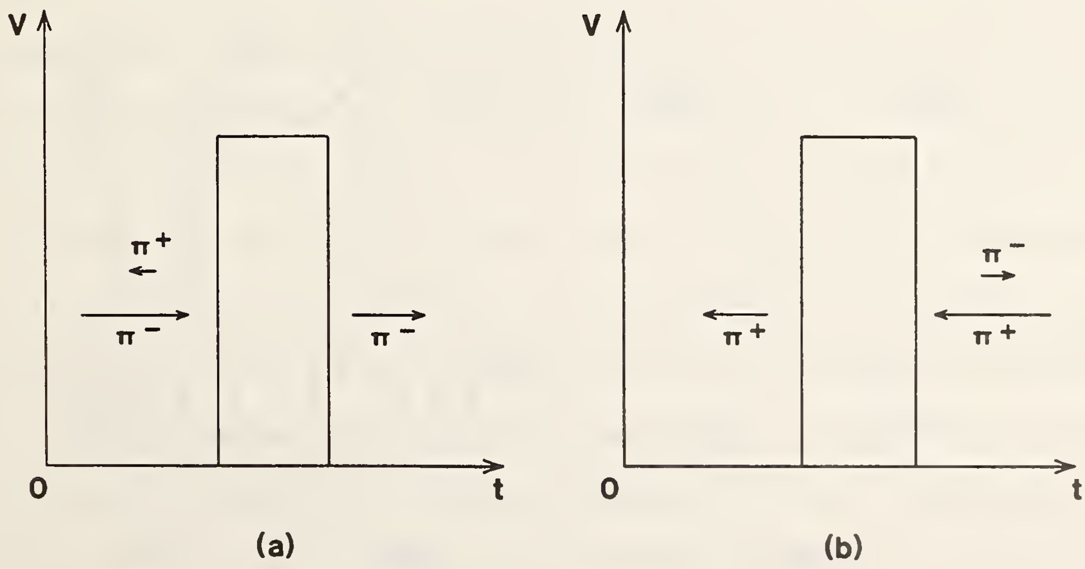

Figure 2. A different perspective of the processes shown in figure 1, illustrating the analogy with transmission and reflection of a nonrelativistic particle by a potential barrier. Here the barrier exists in the time direction.

corresponding time-boundaries. For instance, for a two-"particle" state we may give $g^{(++)}(\vec{x}_1,\vec{x}_2)$ for the boundary condition at the initial time, which determines

$$\phi^{(++)}(\vec{x}_1,t_i;\vec{x}_2,t_i) = (4\tilde{E}_1\tilde{E}_2)^{-1/2} g^{(++)}(\vec{x}_1,t_i;\vec{x}_2,t_i). \qquad (4)$$

We also have to set $\phi^{(+-)}(\vec{x}_1,t_i;\vec{x}_2,t_f)$ and $\phi^{(--)}(\vec{x}_1,t_f;\vec{x}_2,t_f)$ equal to 0. Or one of these other amplitudes may be given to represent further processes. In figure 3 we show the possible diagrams for a two-"particle" wave function when the two-particle probability amplitude is given at the initial time.

The extension of this theory to a charged spinor field is complicated by the fact that the corresponding charge density is positive or negative definite. The same difficulty exists in the standard single-particle theory, where reference is often made to an infinite sea of negative-energy particles.

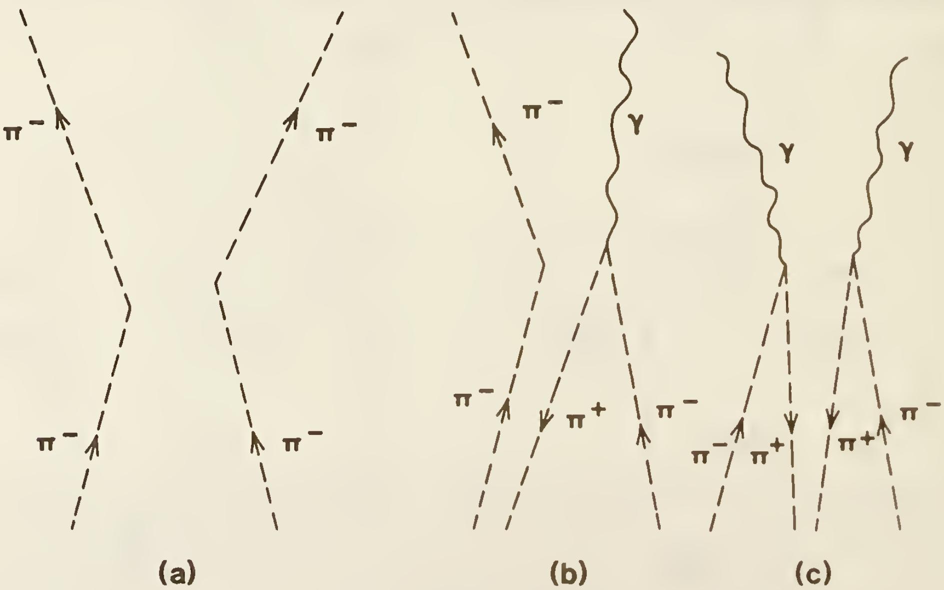

Figure 3. Two-"particle" interactions, with the two particles given at the initial time. The outcome can be (a) particle-particle scattering, (b) one pair annihilation in the field of the other particle with emission of a photon, or (c) two pair annihilations with emission of two photons. The time axis is vertical and the space axes are horizontal whenever no axes are drawn.

2.2 Quantum field theory

The so-called second quantization of the Schrödinger field is a compact way of stating the many-particle theory. Both approaches are equivalent.

We have similarly reformulated [10] the RQM of many particles in the form of a QFT. The state vectors are part of a generalized Fock space and only the subspace that corresponds to a given number of "particles" has nonzero components. A state vector is a function of as many time variables as there are "particles" in the subspace.

This theory differs from the standard QFT in that the field operator is decomposed into annihilation operators for both particles and antiparticles. For instance, the decomposition of the fermion operator ψ becomes

$$\psi(\vec{x}) = (2\pi)^{-3/2}\int d^3p(m/E)^{1/2}\sum_\lambda[b_\lambda(\vec{p})u_\lambda(\vec{p})e^{i\vec{p}\cdot\vec{x}} + d_\lambda(\vec{p})v_\lambda(\vec{p})e^{-i\vec{p}\cdot\vec{x}}], \qquad (5)$$

where λ ranges over the two helicity states, b_λ and d_λ are annihilation operators for a particle and an antiparticle, respectively, u_λ and v_λ are four-component spinors, and $E = p_0 = (\vec{p}^2 + m^2)^{1/2}$ is the energy for a particle of mass m. We thus obtain the null vector when ψ operates on the vacuum state. Creation and annihilation operators have to be associated with a particle number in this generalized Fock space, and the difficulty with the definite charge of states is resolved by assuming that the Hamiltonian operator propagates particles forward in time and antiparticles backward in time. Consequently, the vacuum is trivial and there is no vacuum polarization. As in RQM, there are no closed particle loops or other divergent diagrams. A Hermitian Hamiltonian and the operator (5) lead to conservation of the number of "particles."

It is possible to define a scattering matrix that relates states that have particles in the remote past and antiparticles in the remote future with those that have particles in the remote future and antiparticles in the remote past, which is not the usual definition.

The multiplicity of time variables makes this theory more complicated than the standard QFT. The two formulations are not equivalent.

2.3 Electromagnetic interactions

A charged pion in an electromagnetic field A_μ is represented by a complex (pseudo)scalar field ϕ that satisfies a second-order differential equation,

$$(D^2 + m^2)\phi(x) = 0, \tag{7}$$

where m is the pion mass and

$$D_\mu = \partial_\mu - ieA_\mu(x). \tag{8}$$

The scattering of scalar charged particles by an external electromagnetic field is a well defined problem that can be solved, for instance, by finding the perturbation expansion of the wave function ϕ. We have shown the convergence of this perturbation expansion for a single particle in an electromagnetic field represented by well-behaved potentials A_μ [7].

We have also found a perturbative solution for the wave function and the electromagnetic field in the case of a single charged particle [4] in the context of RQM. The electromagnetic field remains unquantized, and its time-boundary values are given at the initial time if the probability amplitude for a particle is given at the initial time or at the final time if the amplitude for an antiparticle is given at the final time. The perturbation expansion is similar to that of the standard theory, but there are no divergent diagrams.

The extension of the nonrelativistic theory of interacting particles to RQM requires a relativistic generalization of the Coulomb interaction, which is not presently available in a form we can use. There also is no well-defined current density four-vector in terms of the many-particle wave function [11] to serve as a source of the electromagnetic field. We may avoid these problems by going to QFT or by generalizing the electromagnetic potentials A_μ to a tensor $A_{\mu\nu\ldots\lambda}(x_1,x_2,\ldots,x_n)$, which is a function the n arguments in the wave function.

What we abstract from the theory of the electromagnetic interactions of scalar particles are guidelines which we generalize to serve as the basis of this model. We use the language of Feynman diagrams and perturbation expansions, without implying that this is the only or the best way to solve the equations of motion.

Particle lines start either at the initial or at the final time and may end at either one of these times. Closed loops do not occur. The counting of the number of "particles" involved in a process is different from that of the standard theory; for instance, the graphs shown in figure 3 all correspond to two-"particle" processes.

Charge, energy, momentum, and angular momentum are all conserved, and no reaction that violates any of these conservation laws is possible.

Complex wave functions can be decomposed into positive- and negative-frequency parts that represent particles and antiparticles, respectively. This decomposition does not apply to the electromagnetic field, which is real. The (complex) causal Green function is not compatible with a real field, which requires either the retarded or the advanced Green fuction.

Pair creation or annihilation is the observer's interpretation of a "particle" that turns around or is reflected in the time direction. Laboratory experiments are constrained by the fact that observers are composed of particles and propagate only forward in time. Final antiparticle states cannot be prepared, but are selected by the observer; this distiction disappears when we are using scattering amplitudes. Particle reactions occur in space-time in a time-symmetric manner, and the arrow of time is introduced by the observer. The separation of the wave function into positive- and negative-frequency parts and the specification of time-boundary conditions are also influenced by the observer, who determines the time axis in his frame of reference [12].

2.4 Bound states

The bound-state solutions of the Schrödinger equation are stationary states that have a special time dependence. These states can be generalized to RQM, where the time axis is associated with the observer.

A relativistic bound state is a quasi-stationary state of the system [13], in which a particle remains in a steady state of the truncated theory obtained by neglecting the antiparticle amplitudes. The full interaction causes the antiparticle amplitudes to build up slowly, which corresponds to a small probability for annihilation of a particle in an otherwise stable system.

In the hydrogen atom, a 511-kev electron is bound to a 938-Mev proton by a mere 13.6 ev, which makes the atom easy to dissociate and shows that it is a composite system. If the binding energy were to increase, it would be more difficult to separate the hydrogen atom into its components. If it were to increase to more than twice the electron mass, an electron-positron pair could be created spontaneously (in other words, a positron propagating from the future could be reflected in time by the proton). The proton would decay into hydrogen and a positron; an observer would conclude that the proton is unstable and that hydrogen is an elementary particle. The effect of the existence of bound states with very large binding energies is illustrated in figure 4, where we show how the dissociation of hydrogen (a) or the formation of hydrogen (b) is related to the hypothetical process in which a proton decays into hydrogen and a positron (c). The photon in figure 4a or figure 4b is required to conserve energy and momentum.

This decay of the proton is the precise analogue of the pion decay in our model, where an electron or a muon is produced (an electron and a muon are bound states of a pion and a neutrino [14]). When the binding energy is large and comparable to the masses of the components of the system, the mass of the composite particle can be significantly smaller than the mass of the heavier component. A composite particle may have more than two component particles.

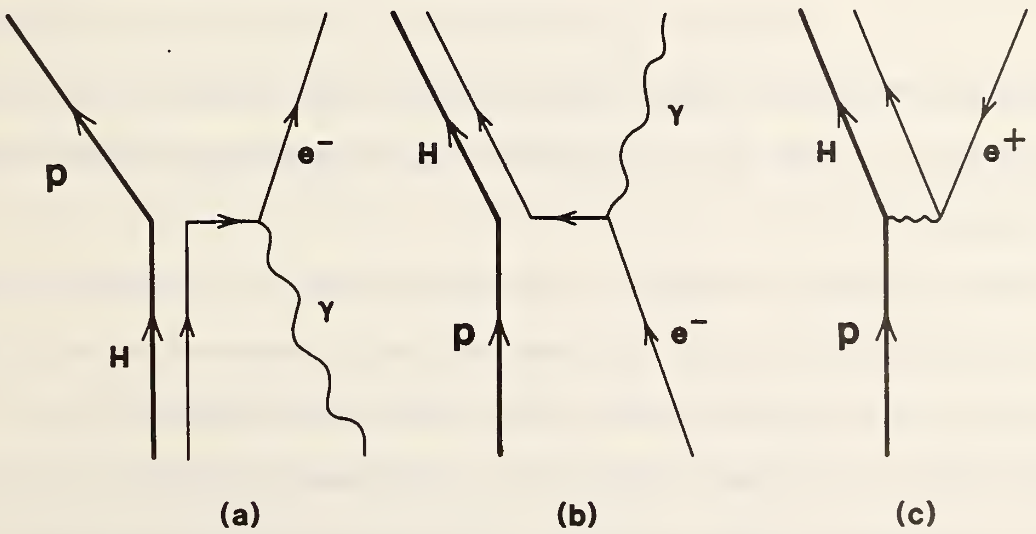

Figure 4. Relationship between bound states and unstable particles. The three diagrams represent closely related reactions: (a) the dissociation of hydrogen into a proton and an electron, (b) the time reversed process of formation of hydrogen, and (c) the decay of a proton into hydrogen and a positron, which is possible only if the binding energy is greater than twice the mass of the electron. The heavy line represents the proton and the light line represents the electron (in this figure only).

The concept of relativistic bound states has to be extended to a bound state of a particle and an antiparticle, and to that of several "particles," by choosing the appropriate parts of the wave functions. We expect that the bound state of a particle and an antiparticle will have a significantly different binding energy than that of two particles.

There also are systems in which the binding energy of a possible bound state turns out to be negative. This state is then a resonance located in the continuum part of the spectrum. Resonances are well understood and are observed in the laboratory. They retain some of the properties of the bound state, such as charge and spin. Just as we have bound states with large binding energies, we may have resonances with large negative binding energies, that is, the resonance may be far into the continuum spectrum.

3. LEPTONS

Leptons are relatively light particles that may or may not be charged. They participate in the weak interactions, but they do not interact strongly. They all have spin 1/2.

The total number of "leptons" is conserved, that is, "leptons" are always created or annihilated in pairs. We associate such a conservation law with the existence of a basic particle, which in this case is the neutrino [14].

Until recently, the known leptons were the electron, the muon, one or two neutrinos, and their antiparticles. We review their composition [14] in subsection 3.1. We generalize this model to include the newer τ-lepton or tauon and its neutrino in subsection 3.2. We also predict the existence of another heavy lepton, which is related to the tauon as the muon is related to the electron. We do not have to introduce a new basic neutrino.

3.1 The neutrino, the electron, and the muon

The law of conservation of lepton number and the conservation of angular momentum indicate that lepton lines in Feynman diagrams are unbroken.

The generally accepted existence of two lepton numbers that are separately conserved suggests that the electron and the electron-neutrino are in some sense the same particle, as are the muon and the muon-neutrino [15]. In muon decay, the charge is transported from the muon to the electron by an intermediary. The traditional intermediary is the vector boson W, a spin-1 particle that is difficult to fit into our model. The theory of the Yang-Mills field, which plays the role of the electromagnetic field in quantum chromodynamics, is complicated and hard to quantize due to its nonlinearity. Our attempt to incorporate the Yang-Mills field into RQM [16] had only limited success. The pion is a more natural candidate for the role of intermediary, although the intermediate vector boson is not necessarily excluded.

The relatively small mass difference between the muon and the pion also suggests that they may be closely related. If the muon is a bound state of a pion and a neutrino and the electron is a bound state of a the same pion and a different neutrino, it is difficult to see where the large mass difference can come from. We restrict ourselves to only one massless neutral spin-1/2 particle. We identify the electron-neutrino with this neutrino and the muon-neutrino with the antineutrino. This would provide an explanation for the different masses of the muon and the electron. This choice is not fundamental to our model, which can accommodate two or more different neutrinos. We associate the long life of the muon with the creation of a neutrino pair and the energy barrier the pion has to cross when it propagates from the antineutrino to the neutrino.

This sector of the model is illustrated by the diagram of muon decay shown in figure 5, where the π^- is a virtual particle. The assignment of particle status to the π^- and the ν is to some extent arbitrary and reversible.

The interpretation of the reaction in figure 5 leads to the definition of the neutrino, the electron and the muon as shown in figure 6a, b, and c.

The Lagrangian density proposed for the pion-neutrino system can serve as a basis for the calculation of binding energies and scattering cross sections. We have little or no experience with the physical and mathematical properties of bound states with a large binding energy.

The strong interaction of a pion with other particles must be saturated in a bound state with a neutrino, since a lepton shows no strong interactions.

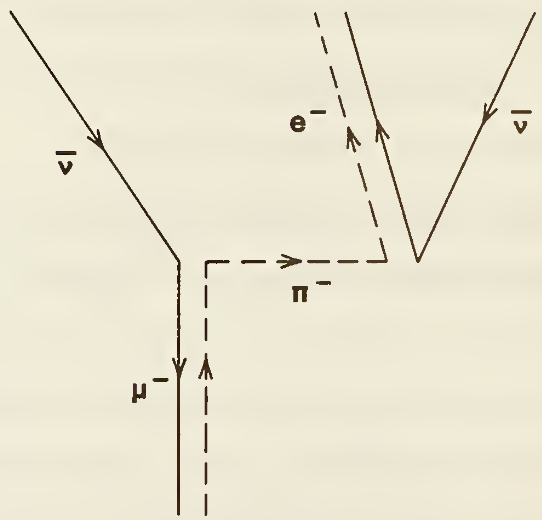

Figure 5. Muon decay by the transfer of the component pion from the antineutrino to the neutrino of the created pair. There is an energy barrier because the state with a free pion has an energy larger than the muon mass. Parallel lines are used to indicate the components of a composite particle, while horizontal lines represent virtual propagation of particles and serve to improve the clarity of the diagrams. A light dashed line with an arrow represents a π^- if the arrow points up and a π^+ if it points down. A light solid line represents a neutrino.

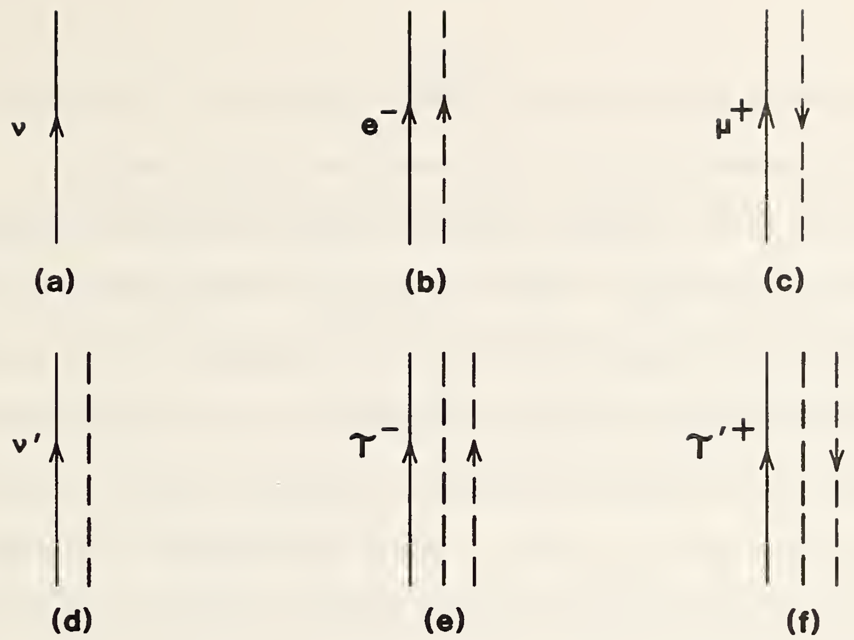

Figure 6. Components of the leptons. Only particles are shown; the antiparticles are obtained by charge conjugation. A dashed line heavier than that of a charged pion with no arrow represents a π^0 (it really corresponds to two superimposed light dashed lines).

3.2 The tau lepton and its neutrino

Recently a much heavier charged lepton has been discovered together with a decay product that is assumed to be its own neutrino [17].

We could add another neutrino to the theory, especially if it turns out to be massive, but this is not necessary at this time. We propose that the tauon be composed of a neutrino, a pion, and an additiona neutral pion, as shown in figure 6e. The lower limit for the mass of the tauon-neutrino is comparable to the mass of the muon, and we propose that, to the extent that this neutrino is different from the basic one, it be composed of a neutrino and a π^0, as shown in figure 6d. We designate this particle by the symbol ν', although it might be more logically called a μ^0 instead.

The large mass and relatively short lifetime of the tauon reflect its definition as a resonance with a large negative binding energy.

There is at least one more probable lepton configuration, shown in figure 6f, heavier than the tauon. Such a particle, designated τ', is sometimes included in theoretical models, and it is being searched for in the laboratory.

Tauon pairs are found in the products of e^+e^- annihilation rections. The usual interpretation of such a process is shown in figure 7a, but there can be intermediaries other than the photon, such as those shown in figures 7b, c, and d. We postpone the discussion of the decay reactions of the tauons until subsection 10.3, because they may involve kaons.

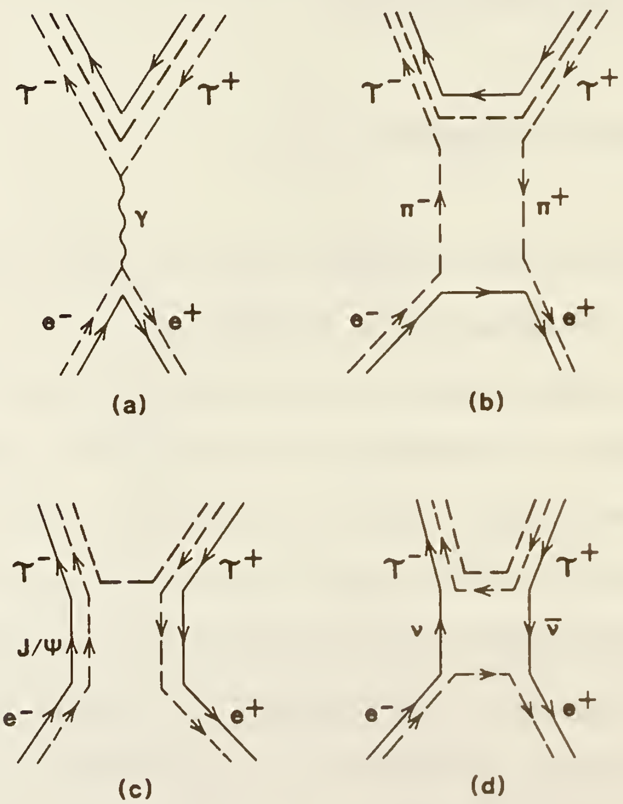

Figure 7. Diagrams for e^+e^- annihilation into a $\tau^+\tau^-$ pair. The particles in the intermediate state do not have to be on the mass shell.

4. PIONS

In our model, the pion is one of the basic particles. It is coupled to the electromagnetic potentials and also to the neutrino and archyon currents.

The pion is the only electrically charged particle, which explains why the magnitude of the charge in an elementary particles is always the same. We exclude the quarks from this argument because they are not composed of pions, although pions may be composed of quarks.

To decide which of the two charged pions is the particle, we notice that the negative pion is a component of the electron and the electron is part of the matter around us. We therefore choose the π^- as the particle propagating forward in time, represented by the positive-frequency part of the wave function. There is no compelling reason to exclude the opposite choice, since not much changes if the π^+ is the particle; this choice may be more convenient in the context of baryon decay. Calculations of bound-state energies have to be taken into account to decide which overall choices are consistent with the masses of the composite particles.

In addition to the charged pions there exists a neutral pion, which we have identified with an interference state of a π^- and a π^+, a state analogous to that of positronium.

We discuss the decay modes of the charged pions in subsection 4.1, and we describe the neutral pion and its decay modes in subsection 4.2.

4.1 Charged-pion decay modes

Charged pions decay mainly into muons or electrons. The reactions

$$\pi^- \rightarrow \mu^- + \nu \qquad (9)$$

$$\pi^- \rightarrow e^- + \bar{\nu} \qquad (10)$$

are shown in figures 8a and b; they were described in the model of composite electrons and muons [14]. Other decay modes are those represented in figures 8c and d,

$$\pi^- \rightarrow \pi^0 + e^- + \bar{\nu}, \qquad (11)$$

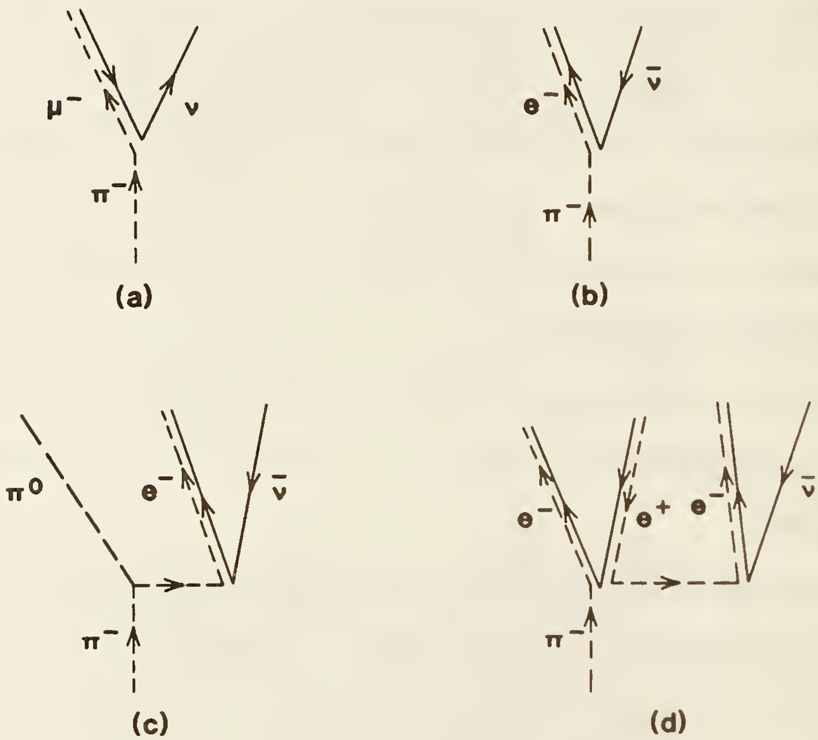

Figure 8. Decay reactions of the π^-. The reactions all require the creation of at least one pair of neutrinos.

$$\pi^- \to e^- + e^- + e^+ + \bar{\nu}; \quad (12)$$

the last one requires the creation of two neutrino pairs. There are also radiative decays, which are characterized by the emission of an additional photon; we do not display these decays separately. The decay

$$\pi^- \to \mu^- + \bar{\nu} \quad (13)$$

is not allowed in our model. The electromagnetic decay of the muon is forbidden because the neutrino in the e^- cannot become the antineutrino in the μ^-.

The decay modes of the π^+ are obtained from those of the π^- by charge conjugation.

4.2 The neutral pion and its decay modes

We represent the π^0 by an interference state [14] of a π^+ and a π^-, both of which are part of the same "pion." The positive- and negative-frequency parts of a single-"particle" wave function can interact to form bound states of a particle and an antiparticle that later decay.

For instance, an electron-positron pair can interact to form positronium before annihilating [16]. Positronium and the π^0 both decay predominantly into two photons, and these decays are shown in figures 9a and 9b. The π^0 is represented by a single dashed line, instead of two pion lines with arrows in opposite directions, to emphasize the tight binding (the neutrino in the electron probably keeps the pair apart in positronium). If the π^0 is isolated, it is represented by a "pion" wave function or state of total charge 0 that decays in time. On the other hand, the π^0 in figure 8c exists at the same time

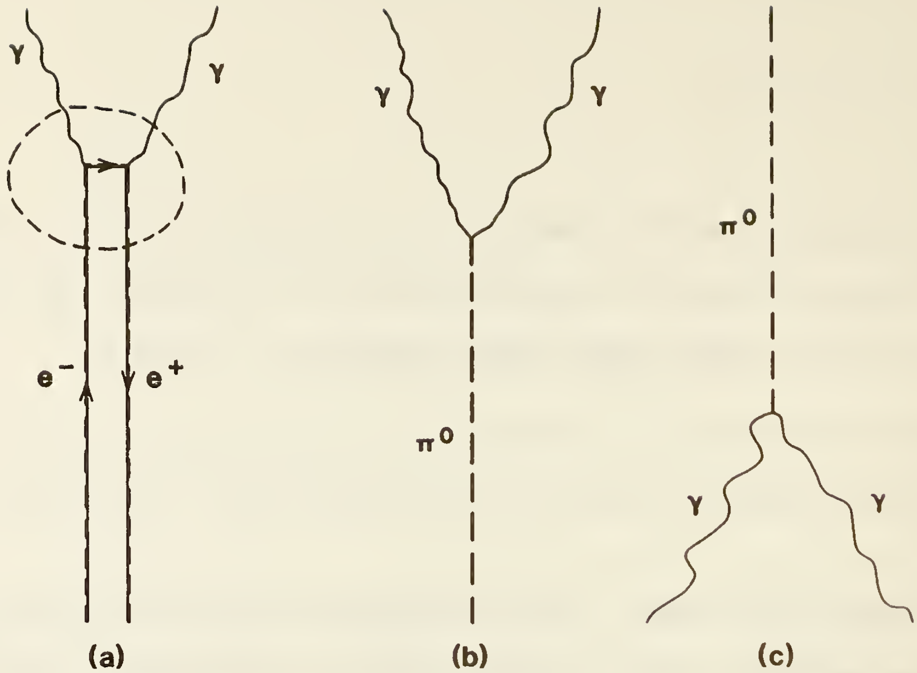

Figure 9. (a) Positronium annihilation into two photons. (b) Decay of a π^0 into two photons. (c) Time-reversed process of (b). The composite line in (a) represents an "electron." The diagram in (b) is a collapsed form of (a) with one (double) line for the π^0, to represent the tight binding.

as the π^- in the e^- and is part of the same single-"particle" wave function. The time-reversed process of the pion decay in figure 9b, shown in figure 9c, can be interpreted as pion creation by a collision of two photons. Each dashed line with an arrow represents either the positive- or the negative-frequency part of the pion wave function. If the π^0 does not decay into photons, it may not be necessary for the two components to correspond to the same "particle."

The remaining decays of the π^0 are shown in figure 10. The reaction

$$\pi^0 \rightarrow \mu^+ + e^- \tag{14}$$

is forbidden in our model, but

$$\pi^0 \rightarrow \mu^+ + e^- + \overline{\nu} + \overline{\nu}, \tag{15}$$

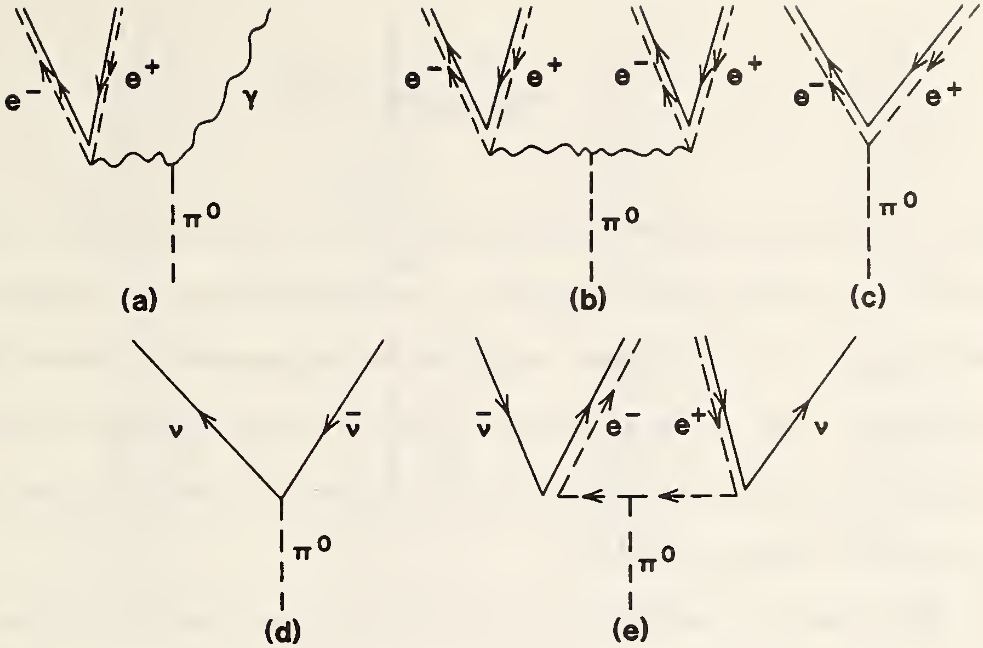

Figure 10. Decay modes of the π^0 other than into two photons. They involve the creation of at least one neutrino pair, whence they are weak and not electromagnetic in strength.

depicted in figure 10e, as well as

$$\pi^0 \to \mu^- + e^+ + \nu + \nu, \tag{16}$$

are allowed.

A π^0 that decays does not appear in the final state, and it represents a round-trip time-excursion of a charged pion. The π^0 does not decay when it is bound to an archyon in a baryon, just as the neutron does not decay in a stable nucleus, because the final state would be higher in energy.

There is some ambiguity in the counting of neutral pions. For some purposes, such as the composition of a particle, we count it once. For others, such as following pion lines, we count it twice.

5. THE BARYON OCTET

The well-established conservation of baryon number leads to the introduction of a third basic particle, the archaeobaryon or archyon.

The members of the baryon octet can be represented as bound states of the archyon and one, two, or three pions. If the binding energies are large and if unstable particles decay by means of pair production, the basic baryon has to be heavier than the decay products.

In the model of the composite electron, we chose the pion as a basic particle. Pions are also frequently present as decay products in weak decays of baryons and mesons, and we select the pion as a basic component in composite hadrons. Since we would like to retain the pion as the only carrier of the electric charge, the other component has to be a heavy neutral fermion, preferably of spin 1/2.

We do not have a prescription to determine a unique composition for the baryons. Extensive analysis of the decay reactions and the consideration of the spin-3/2 resonances and the Ω^- have led us to select the structure shown in figure 11, which results in a somewhat unusual grouping of the baryons. Four of them, the proton, the neutron, the Σ^0, and the Σ^-, are composed of one archyon and three pions; three more, the Σ^+, the Λ, and the Ξ^-, are composed of one archyon and two pions; and the Ξ^0 is composed of one archyon and one pion. Other possible configurations correspond to the Ω^-, baryon resonances and other baryons that may not have been found yet. We tried selecting the Ξ^0 as the basic baryon (the other baryons are obtained from those shown in figure 11 by eliminating one π^0 from each), but we could not find a satisfactory representation for the Ω^- and its decay reactions. We rejected another set of

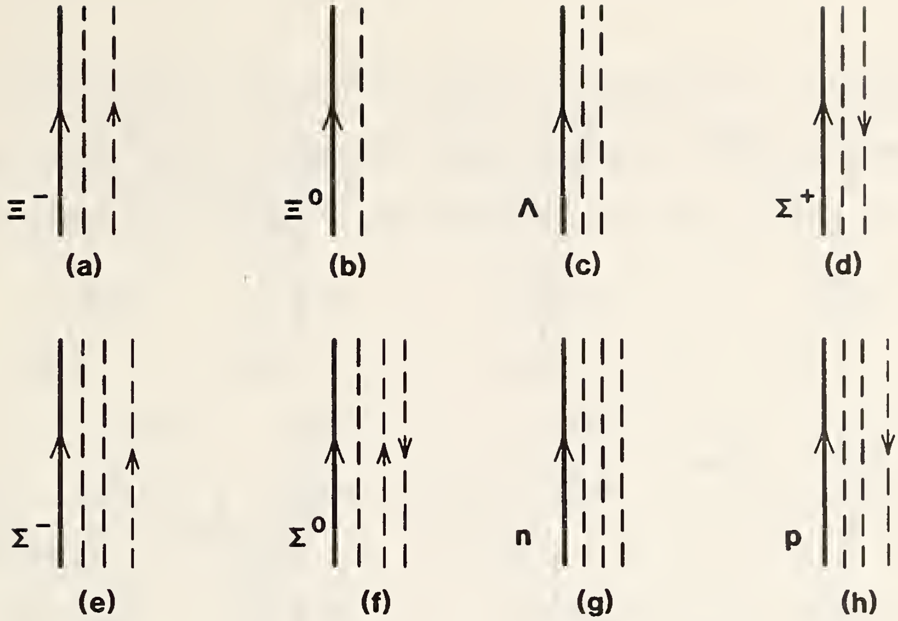

Figure 11. Configurations of the baryons in the octet. The heavy solid line represents an archyon.

configurations that keeps the subdivision of the octet intact because it was hard to explain the absence of particles such as a negative partner to the proton and neutron. The confirmation of any model must come from the calculation of the energies of the bound states of an archyon with one or more pions.

The principal modes of decay of the unstable strange baryons are shown in figure 12. All of the decays, with the exception of the electromagnetic decay of the Σ^0 in figure 12h, involve the creation of a pion pair. The creation of a pair slows down the decay and makes the interaction appear weak.

In figure 13 we show the β^- decay of the neutron together with the related processes of β^+ decay of a proton within a nucleus and μ^- capture. We attribute the unusually long lifetime of the free neutron to the large energy barrier that the virtual pion has to cross.

The other decay reactions [5] of the baryons are much less frequent. Some

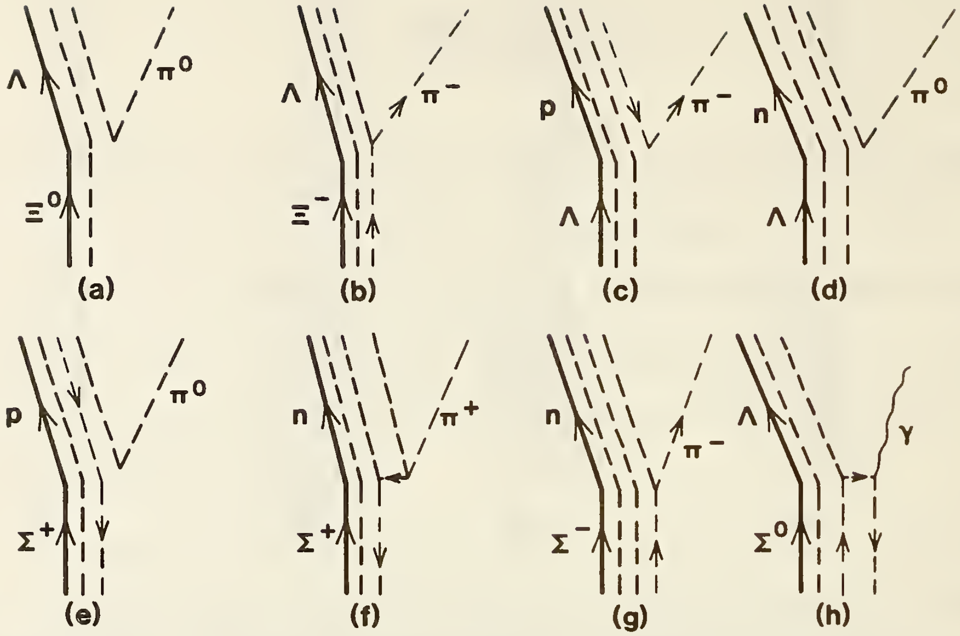

Figure 12. Common decays of hyperons. Weak decays involve the creation of a pion pair, and the electromagnetic decay in (h) results in the emission of a photon.

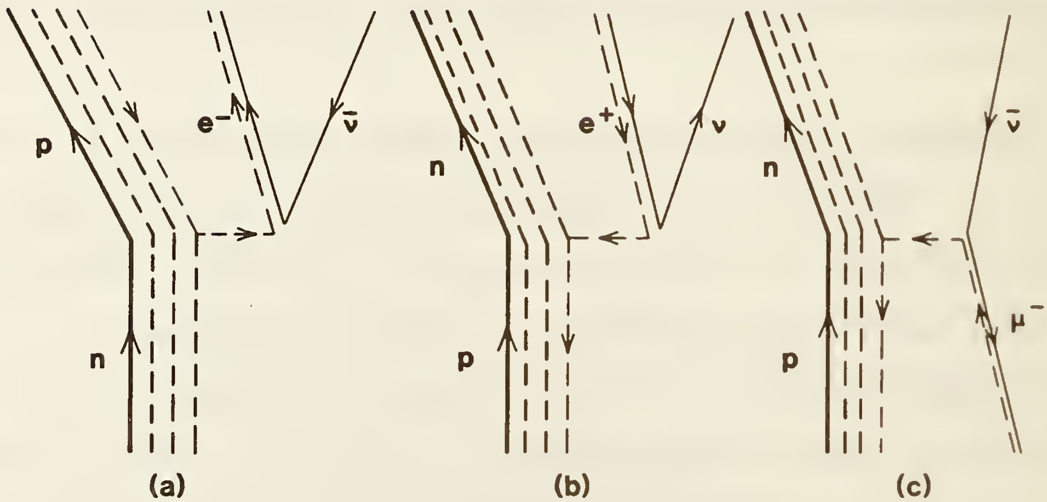

Figure 13. (a) Beta decay of a free or bound neutron. (b) Beta decay of a proton in a nucleus. (c) Muon capture. The small mass difference between the neutron and the proton cause a large energy barrier for the free-neutron decay.

are radiative decays that involve the additional emission of a photon. Others are leptonic decays that can be obtained from those in figure 12 by showing the decay of a virtual pion instead of the emission of a real one. For instance, the decay

$$\Lambda \rightarrow p + e^- + \bar{\nu} \tag{17}$$

is a combination of the decay

$$\Lambda \rightarrow p + \pi^-, \tag{18}$$

which is shown in figure 12c, and the decay (10) of the virtual pion. Some involve the decay of a virtual π^0 into a single photon, which is possible because there is another particle to participate in the energy and momentum balance. For instance,

$$\Sigma^+ \rightarrow p + \gamma \tag{19}$$

corresponds to

$$\Sigma^+ \rightarrow p + \pi^0 \tag{20}$$

in figure 12e, and if the photon is replaced by an electron-positron pair we obtain

$$\Sigma^+ \rightarrow p + e^- + e^+. \tag{21}$$

Additional leptonic decays are possible where the energy is not sufficient to permit a free pion as a decay product, and these are shown in figure 14. The few remaining decays that do not fit into any of the previous categories are shown in figure 15.

Possible reasons for the suppression of the leptonic decays relative to the nonleptonic ones are the creation of a neutrino-antineutrino pair and phase space considerations. The nonleptonic decays in figure 15 are also less frequent than the main types of decay, and they all are the result of more complicated interactions. Detailed calculations should provide the corresponding lifetimes and branching ratios.

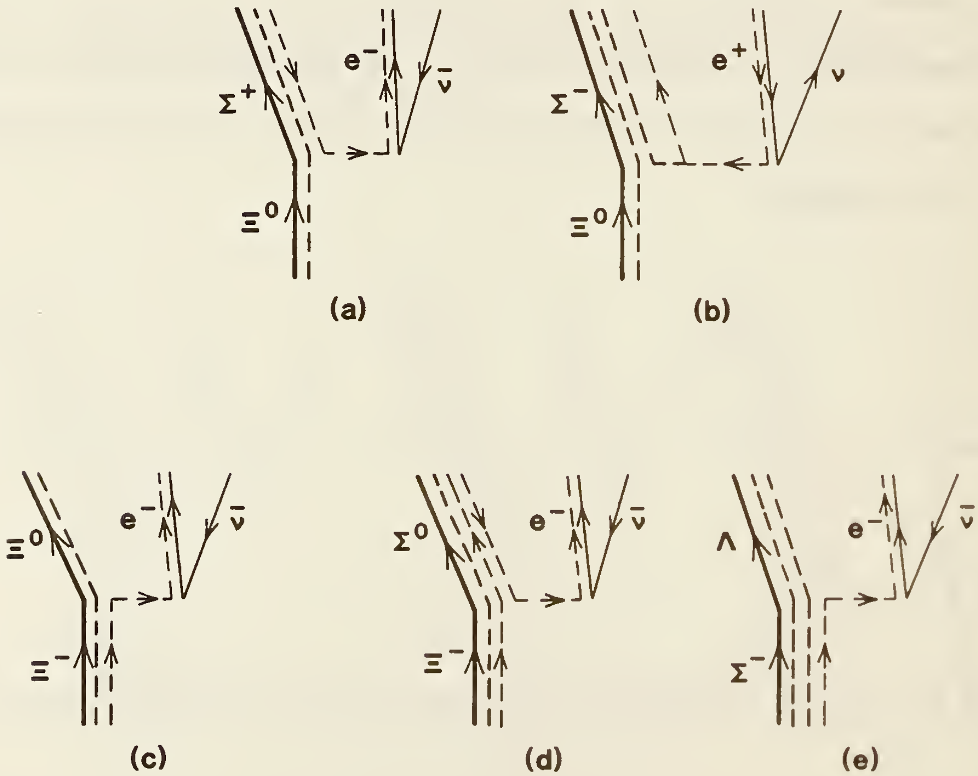

Figure 14. Leptonic decays of hyperons.

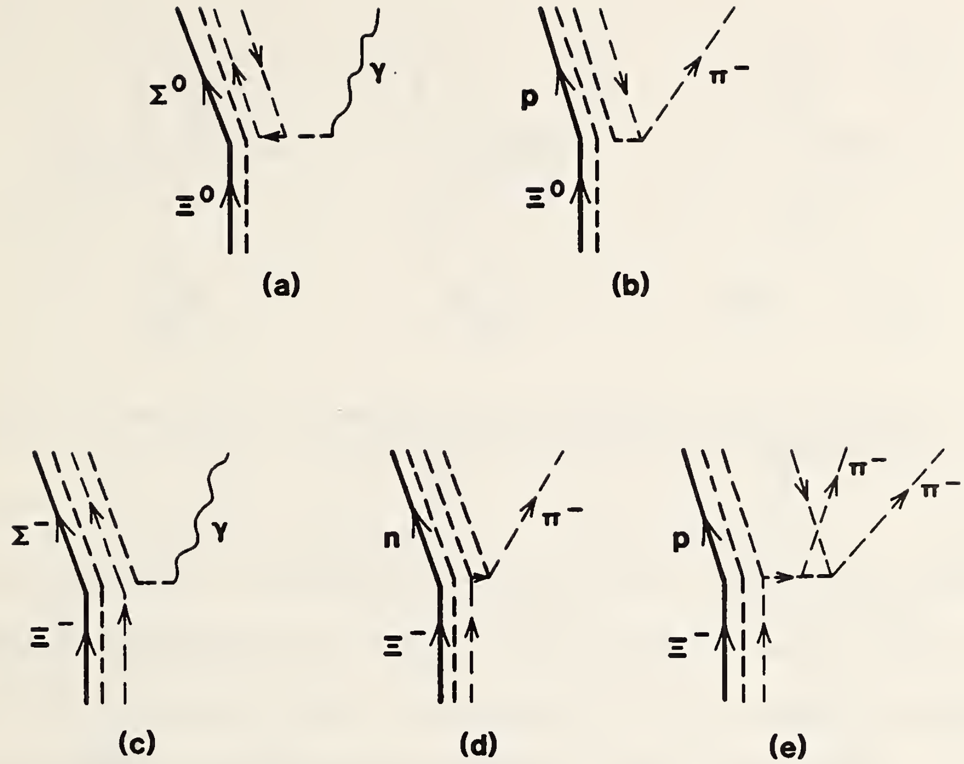

Figure 15. Rare decays of hyperons. In (a) and (c), the bound π^0 decays into a single photon. In (b), (d), and (e), which show transitions with $\Delta S = 2$, the creation of two pion pairs is required.

6. KAONS

Kaons decay mostly into pions or into leptons that are the decay products of a virtual pion. There is no stable kaon to play a role comparable to that of the electron or the proton, and no absolute conservation law is associated with these particles. We thus conclude that the kaons are resonant states of pions with no other components involved. The reason for the long lifetime of the kaon compared to that of other pion resonances such as the ρ and the ω mesons is the annihilation or creation of pairs in the decay of the kaon.

We find that the simplest composition of a kaon that agrees with the rest

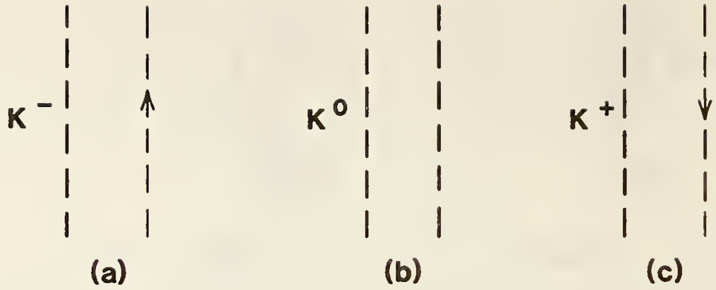

Figure 16. Configuration of kaons. The components of the neutral pions do not have to be bound separately from the other pion.

of the model is that of two pions, as shown in figure 16. The mass of a kaon is more than three times the mass of the pion, thus the magnitude of the negative binding energy is large. We also considered a model of the kaon as a three-pion resonance or bound state (the binding energy between the components of the π^0 could be smaller in a kaon than for a free π^0), but not much is gained by adopting this more complicated model.

The best way to explore further the composition of a kaon is to follow pion lines in a process that involves the production as well as the decay of kaons, which we do in section 8. By this procedure we learn the following.

The K^+ can be interpreted as a composite of two individual pions, a π^+ that comes from the future and a π^0 that can be annihilated when the kaon decays or that can continue as a free pion to decay at a later time. The leptonic decay in figure 17a shows a direct transition of the π^+ into leptons at the time of decay. In figure 17b we see a real π^+ (it decays at a later time), which is made possible by the presence of the π^0 to balance energy and momentum; this π^0 is really just an excursion into the future and back of a single pion. The π^+ and π^- on the right side of figure 17c form a pair that is created at the time of the decay. Other common decay modes are shown in figures 17d, e, and f, and

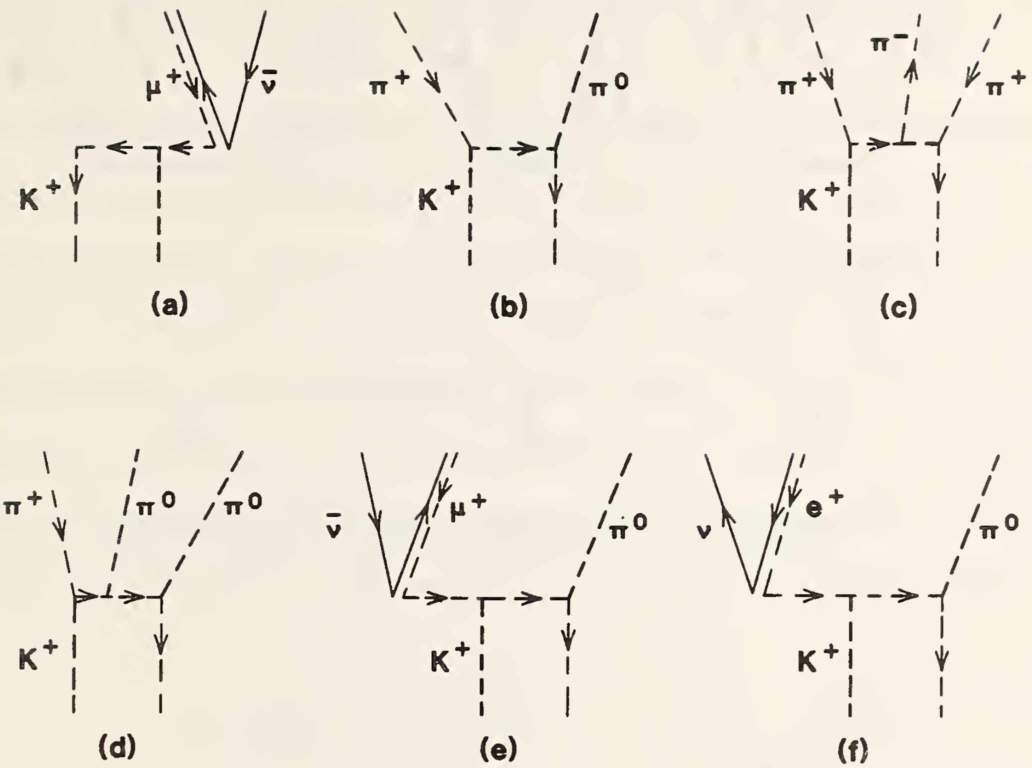

Figure 17. Common decay modes of the K^+ into leptons and pions. The identity of the pions in the processes are best understood if they are traced in conjunction with the creation of the kaons. The decays of the K^- can be obtained from those of the K^+ by charge conjugation.

some rare decays are shown in figure 18. The remaining listed decay modes [5] are variations of those in figure 17 where a virtual pion decays into leptons, where a π^0 is replaced by a photon, where one or more photons are added to the reaction, or where one of these photons is replaced by an e^+e^--pair or a $\mu^+\mu^-$-pair. Some of the listed decays are not allowed in this model. For instance, the reactions

$$K^+ \rightarrow \pi^- + e^+ + e^+, \qquad (22)$$

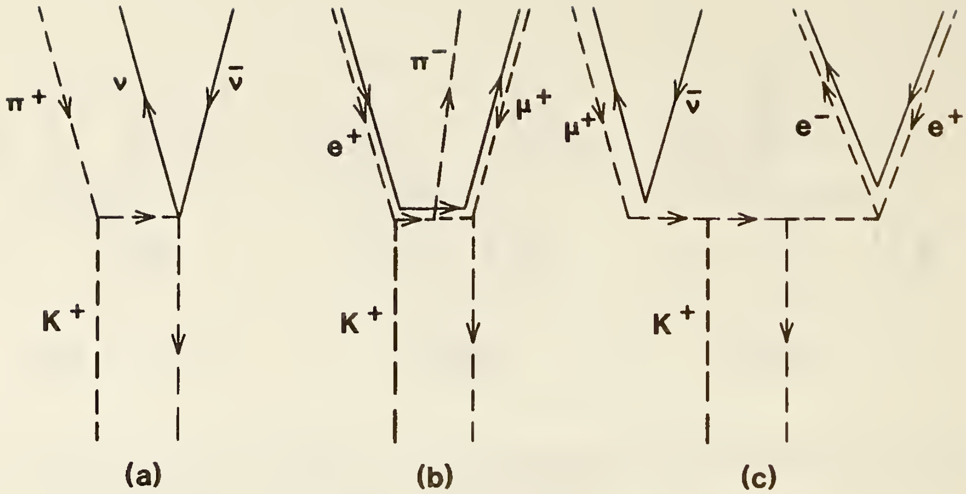

Figure 18. Less common decays of the K^+.

$$K^+ \rightarrow \pi^+ + e^+ + \mu^-, \tag{23}$$

$$K^+ \rightarrow \pi^+ + e^- + \mu^+, \tag{24}$$

$$K^+ \rightarrow \mu^- + \nu + e^+ + e^+, \tag{25}$$

violate the lepton-conservation law.[4] The last three decays on the list [5] specify the type of neutrino (ν_e instead of ν_μ), but we distinguish only between neutrinos ($\nu_e = \bar{\nu}_\mu$) and antineutrinos ($\bar{\nu}_e = \nu_\mu$). All of these absolutely forbidden decays represent a very small fraction of the total of K^+ decays, and probably do not occur at all. If they do occur in the laboratory, the model could be changed, for instance, by adding neutrinos to the components of a kaon.

[4] We recall that the e^-, the μ^+, and the ν are leptons, while the e^+, the μ^-, and the $\bar{\nu}$ are antileptons. This classification has been proposed in the past [18].

The decays of the K^- are obtained from those of the K^+ by charge conjugation.

The neutral kaon decays into two or more particles; the two-particle decay modes in figure 19 correspond to the short-lived kaon, K^0_S, and the three-particle decay modes in figure 20 correspond to the long-lived kaon, K^0_L. The reason for this double-lifetime decay is dynamical [6f, 6g]. There are different processes of production and decay of the K^0 that can interfere, and we return to this problem in section 8. Other decay modes are the usual variation on these two groups. In our model, the only difference between the K^0 and its antiparticle, designated by $\bar{K}^0$, is the origin of the component pions in the past

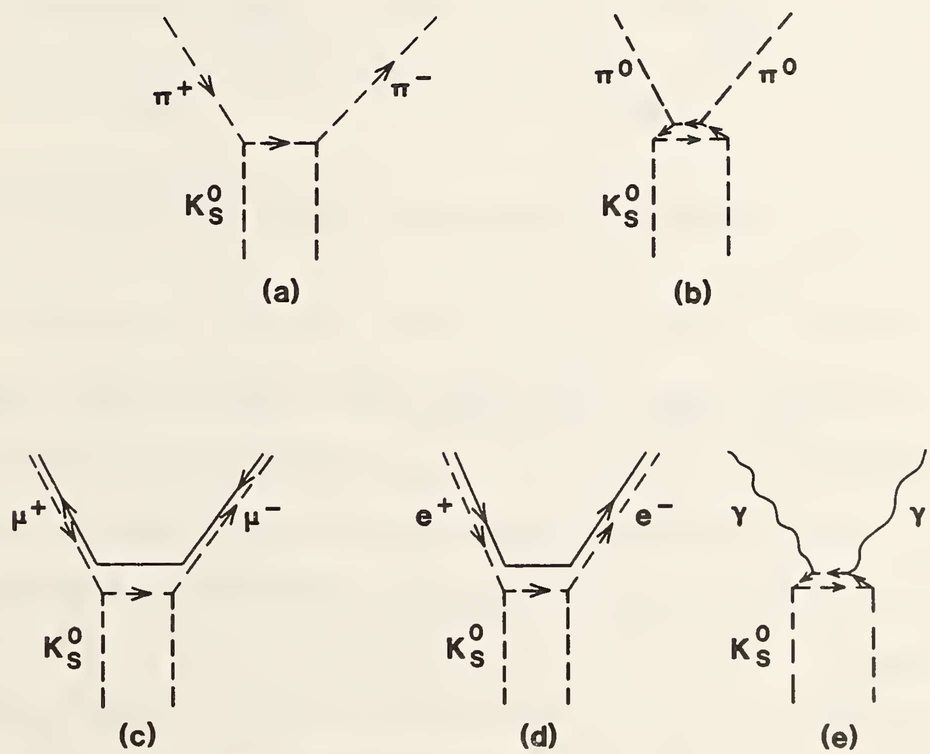

Figure 19. Decay modes of the short-lived K^0. In (a), the π^- component of the π^0 on the left crosses over and turns around to become the π^+ in the other π^0. In (b), there are two charged pions that turn around in time if the neutral pions decay into photons. The processes in (c) and (d) are derived from the one in (a), and the process in (e) is similar to the one in (b).

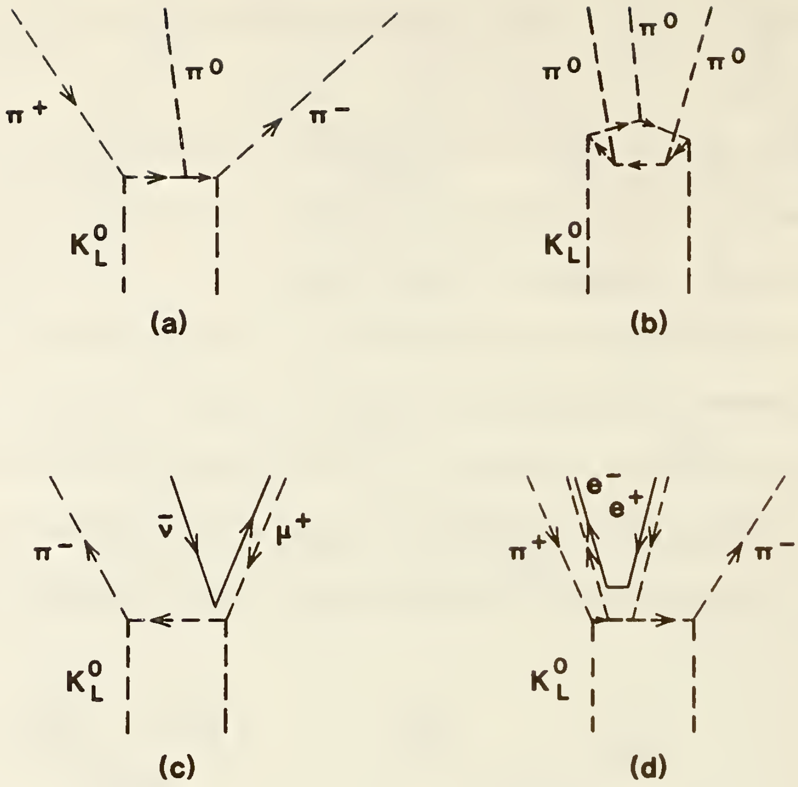

Figure 20. Decay modes of the long-lived K^0.

or in the future; there are interference effects that contribute to a transformation between the two. These effects may also explain the decays of the K_S^0 or the K_L^0 via modes favored by the other, usually interpreted as a violation of CP invariance. We only keep the $\bar{K}^0$, K_S^0, and K_L^0 notation to follow common usage.

The decays

$$K_L^0 \to e^+ + \mu^-, \quad K_L^0 \to e^- + \mu^+, \tag{26}$$

are not permitted in our model.

7. RESONANCES

If we vary a parameter in the binding energy of a bound state and this binding energy becomes negative, we obtain a resonance. This state retains many of the properties of a bound state, such as charge, spin, and mass. There are both short-lived and long-lived resonances; the difference should be dynamical, related to pair creation or annihilation.

There are resonances of one archyon and several pions, and we discuss these in subsection 7.1. We include the Ω^-, which is a stable particle that is associated with pion-baryon resonances in a decuplet. We may also have resonances of pions alone, and we discuss these in subsection 7.2. We include there the η-meson, which is also considered a stable particle.

7.1 Baryon resonances and the Ω^-

The spin-3/2 decuplet of the SU(3) theory consists of nine resonant baryon states and the Ω^-, which is stable with respect to strong interactions.

The four pion-nucleon resonances (Δ^-, Δ^0, Δ^+, and Δ^{++}) are resonant states of a system of one archyon and four pions, as shown in figures 21a, b, c, and d. The three Σ^* resonances are composites of a Λ and an additional pion, as shown in figures 21e, f, and g. The Ξ^* can be constructed from a Ξ^0 and a pion, as shown in figures 21h and i. Finally, there is the Ω^-, with the configuration in figure 21j. This configuration is compatible with the rest of the particles and resonances, and with the decay modes shown in figure 22.

The Δ-resonances decay by emitting a real pion, or a virtual π^0 that decays into a photon. The reactions

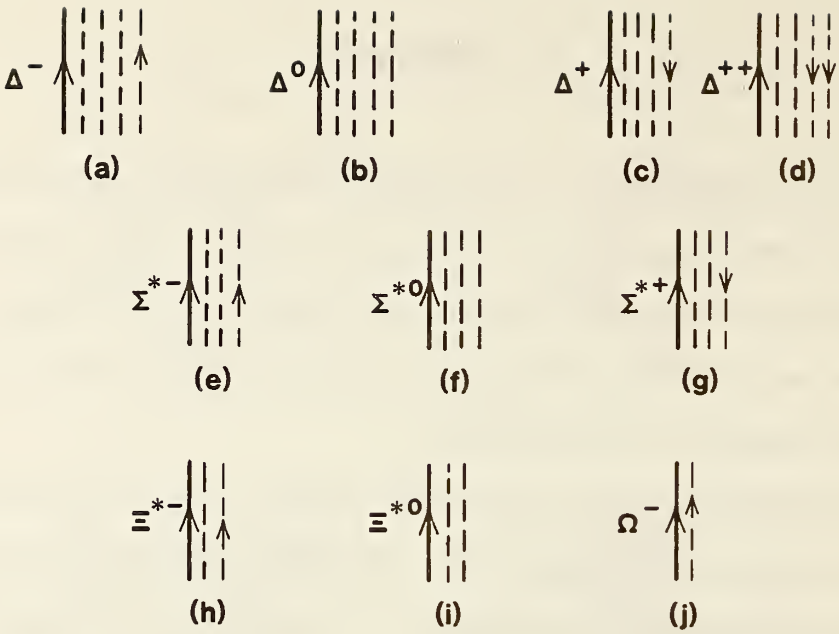

Figure 21. Configuration of the baryon resonances and the Ω^- in the baryon decuplet.

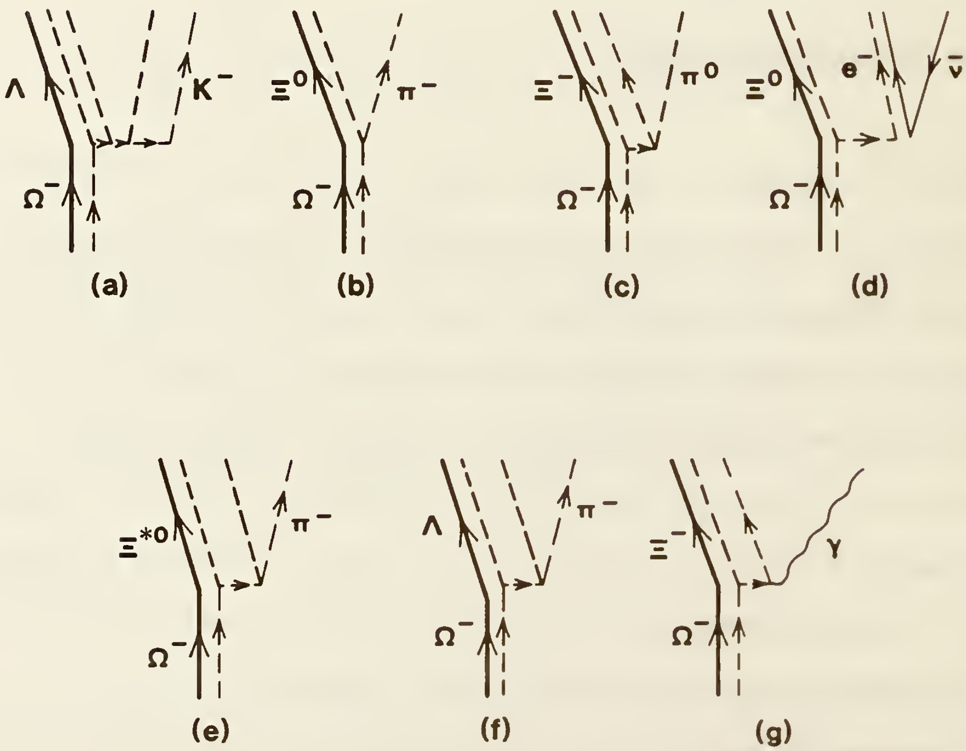

Figure 22. Decay modes of the Ω^-. They all involve pair creation and hence are weak interactions.

$$\Delta^0 \rightarrow n + \pi^0, \tag{27}$$

$$\Delta^0 \rightarrow p + \pi^-, \tag{28}$$

are shown in figures 23a and b. The Σ^*-resonance decays into a Λ-particle and a pion or into a Σ-particle and a pion, and in figures 23c and d we show the reactions

$$\Sigma^{*-} \rightarrow \Lambda + \pi^-, \tag{29}$$

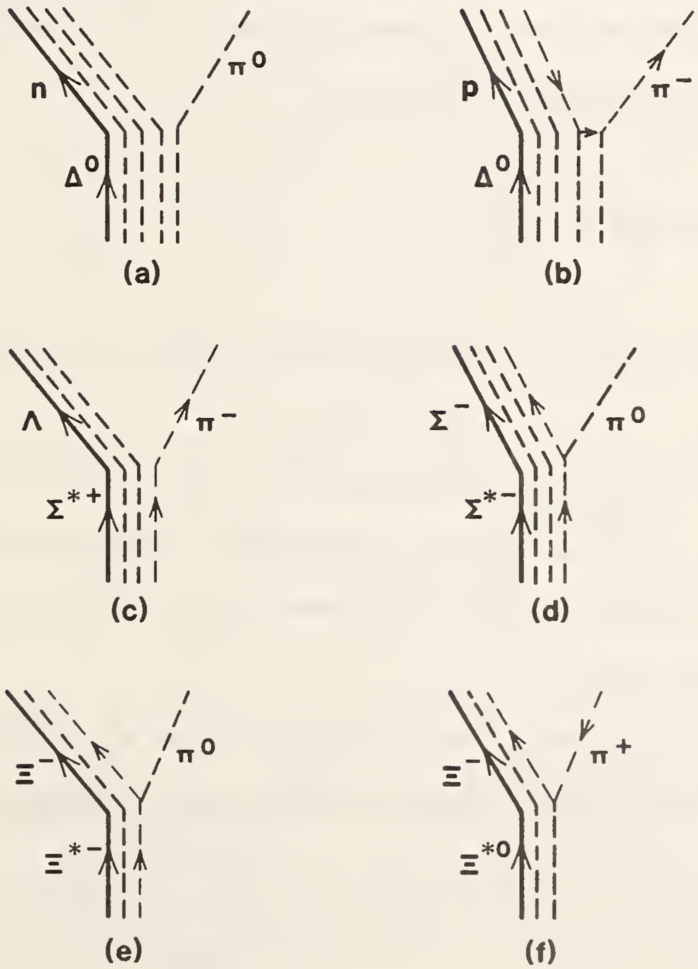

Figure 23. Decay modes of the resonances in the decuplet. Some of the processes involve pair annihilation and creation.

$$\Sigma^{*-} \rightarrow \Sigma^{-} + \pi^{0}. \qquad (30)$$

The Ξ^* decays into a Ξ and a pion, and in figures 23e and f we show

$$\Xi^{*-} \rightarrow \Xi^{-} + \pi^{0}, \qquad (31)$$

$$\Xi^{*0} \rightarrow \Xi^{-} + \pi^{+}. \qquad (32)$$

The resonances that have the same configuration as baryons of the octet correspond to excited states of these systems. The Ω^- may have a spin-1/2 counterpart, which has not been identified.

7.2 Pion resonances and the η

There are large numbers of meson resonances that are resonant states of two or more pions.

In figure 24 we show the composition of some of the more familiar resonances. The η, which is usually considered a stable particle, is shown in figure 24a, three forms of the ρ in figures 24b, c, and d, the ω in figure 24e, and the ϕ in figure 24f.

The η behaves much like an excited state of the π^0, and it is also composed of two pions that correspond to the same "particle." The decay modes are shown in figure 25.

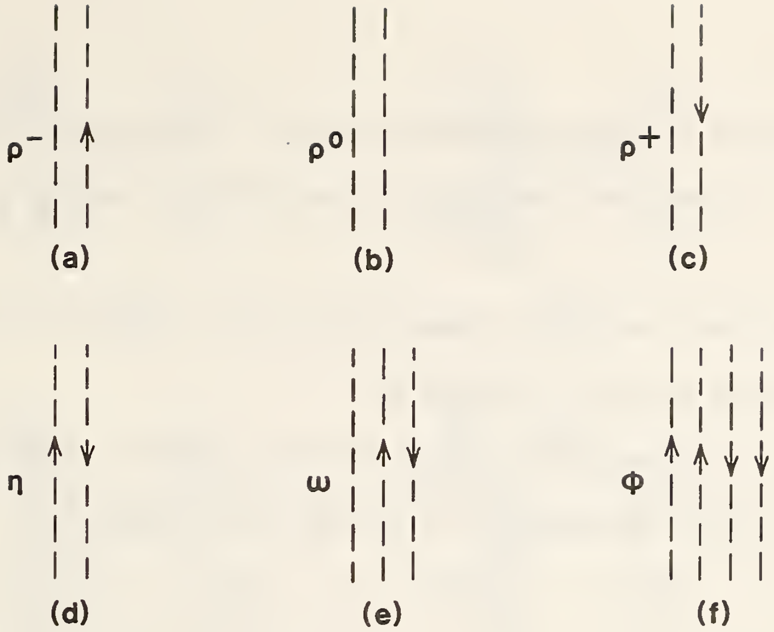

Figure 24. Components of some of the pion resonances. These resonances decay via strong interactions.

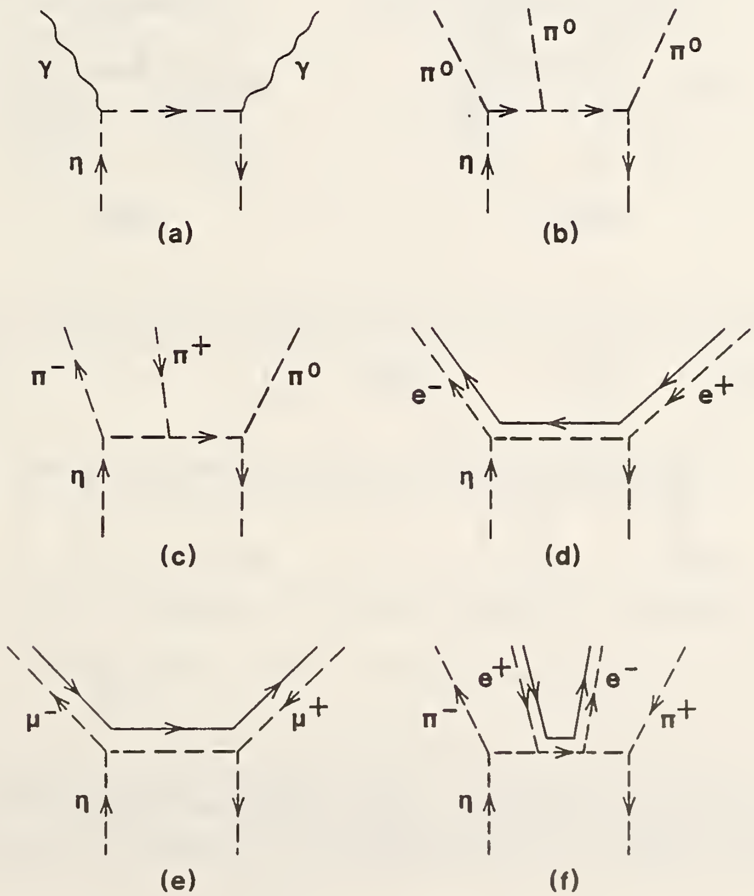

Figure 25. Decay modes of the η.

The ρ and ω are resonances of two and three pions, respectively, one of which is a π^0. They decay essentially just by separating into the component pions.

We assume that the φ is a bound state of four pions, and the diagrams for the decay modes are shown in figure 26.

In figure 27 we show how some of the more common resonances are obtained in pion-nucleon scattering, as well as one $p\bar{p}$ annihilation [6d].

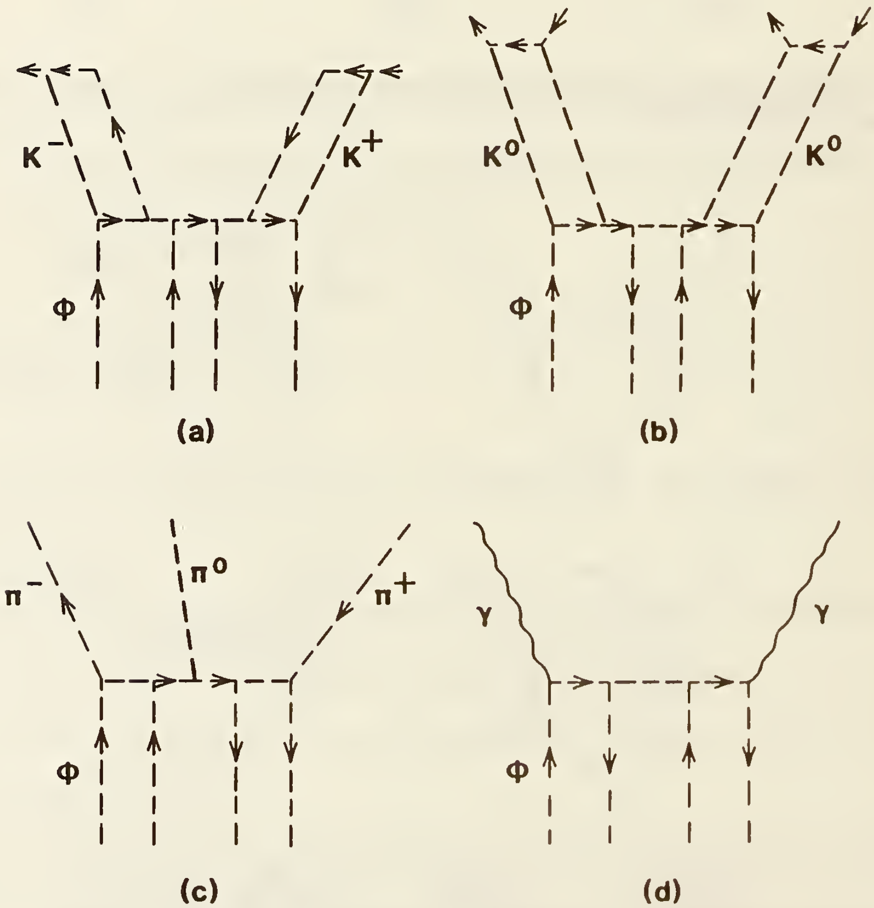

Figure 26. Decay modes of the φ. The charged kaons are shown decaying into a virtual pion and the neutral kaons are shown decaying into two real charged pions. These decays are representative of most of the decay modes of the kaons.

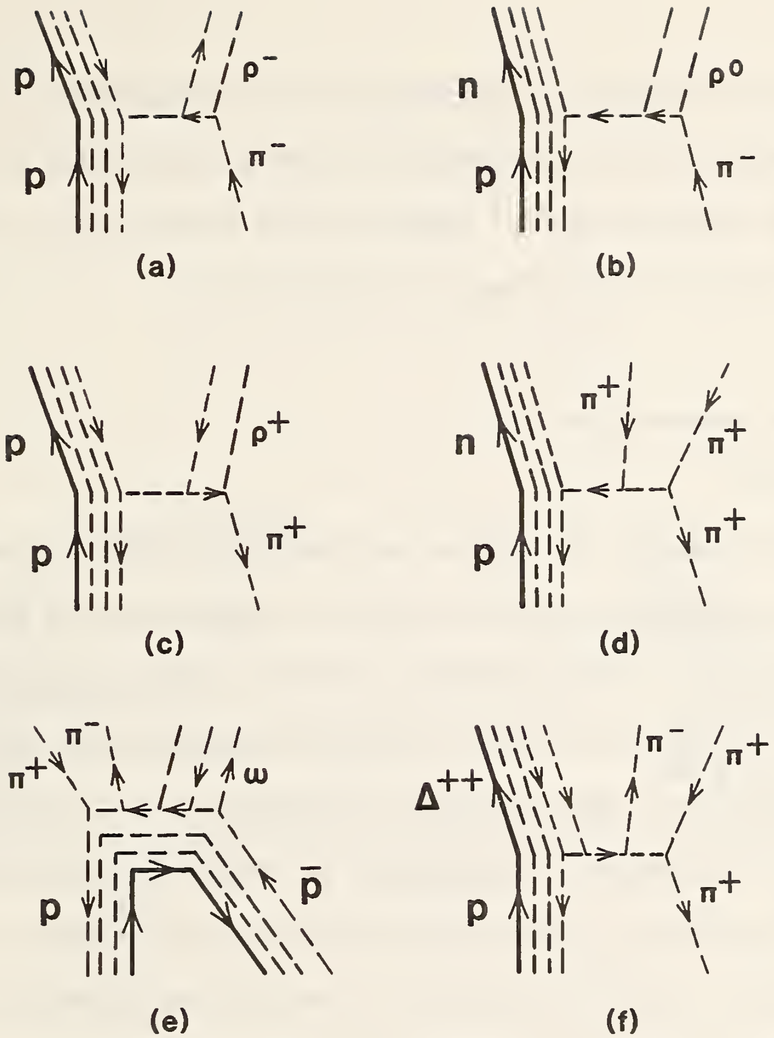

Figure 27. Creation of nucleon and pion resonances. Some of the processes involve pair annihilation and creation.

8. ASSOCIATED PRODUCTION OF STRANGE PARTICLES

Weak decays of strange baryons all involve pion-pair creation, which is why they occur slowly. On the other hand, the associated production of strange particles does not have to involve pair creation or annihilation, and is much more copious than production via the inverse reaction of a weak decay. The standard explanation for this behavior is the law of conservation of strangeness in strong interactions.

We relate the concept of strangeness to the composition of baryons and we discuss the conservation of strangeness in strong interaction in subsection 8.1. We continue the study of kaons, especially the neutral one, in subsection 8.2, and we show how the Ω^- is produced in subsection 8.3.

8.1 Strangeness conservation

To define strangeness we examine the baryons in figure 11 and see that the strangeness of a stable baryon is obtained by subtracting 3 from the number of positive pions in the configuration, including in the count those that are components of the neutral pions. This definition extends to the Ω^- in figure 11j. At least one of these pions is reflected in time when strangeness decreases in a weak decay. Strangeness is conserved in an interaction if all positive pions go from the final state to the initial state and all negative pions go from the initial state to the final state, allowing for intermediate excursions in the opposite direction. Conservation of strangeness can be restated as the essential unidirectionality of pion lines in reactions involving strange particles. If a strange baryon is produced in a strong interaction, the pion that is no longer in the baryon continues in a kaon that later may decay weakly.

We consider the following reactions,

$$\pi^- + p \to \Sigma^- + K^+, \qquad (33)$$

$$\pi^- + p \to \Sigma^0 + K^0, \qquad (34)$$

$$\pi^- + p \rightarrow \Sigma^+ + K^-, \tag{35}$$

$$\pi^- + p \rightarrow \Sigma^- + \pi^+, \tag{36}$$

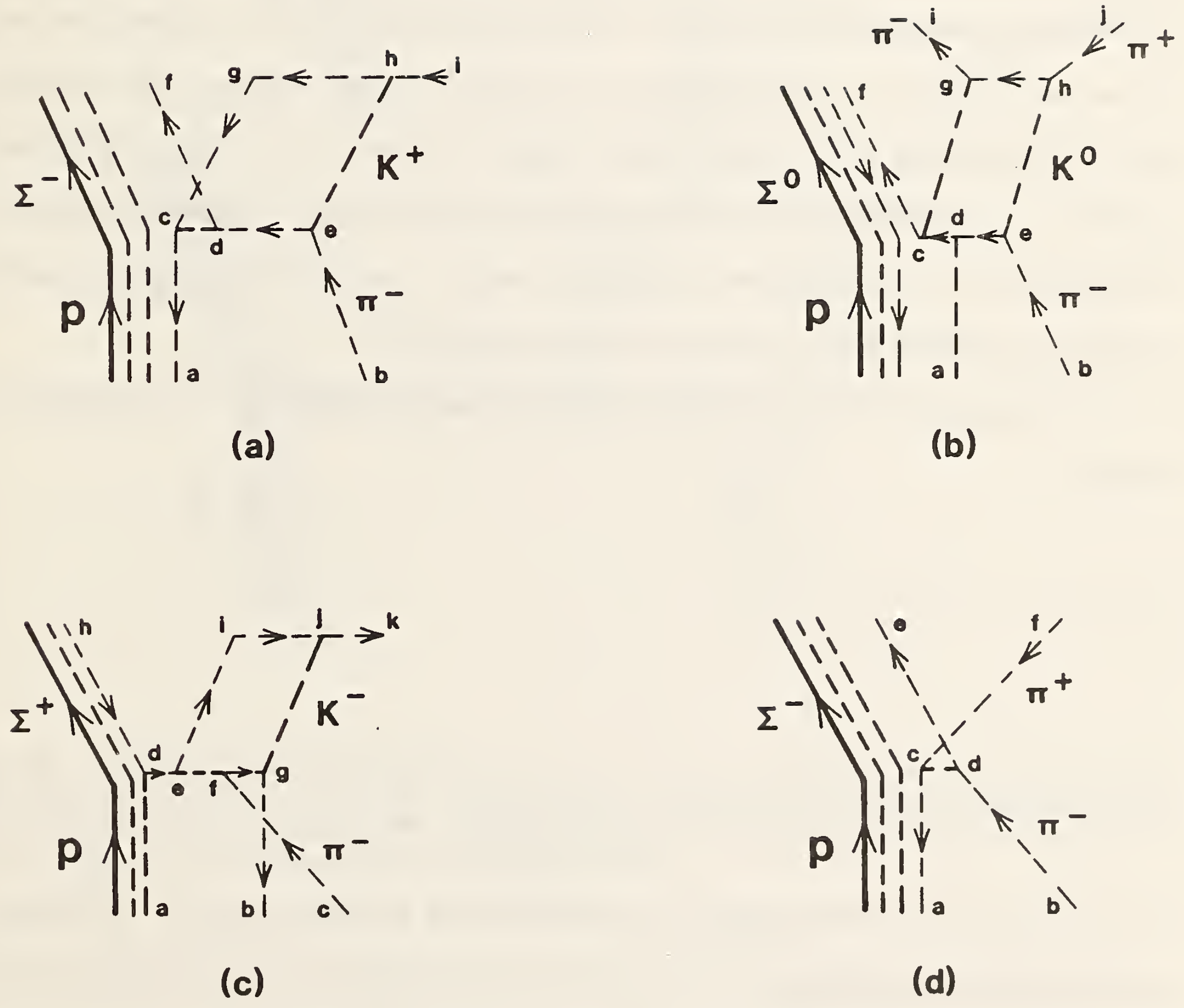

Figure 28. Associated production of strange particles (Σ and K). It is of interest to follow the pions around the diagram to find out which pion lines are essentially unidirectional in spite of possible temporary turns, and which end up at the same time they started. There is no pair creation or annihilation in (a) and (b), there is one in (c) and there are two in (d). The paths are (a) behgcdf, ihedca, (b) adcgi, behgcf, jheda, (c) adefgjk, cfeijgb, hda, (d) bdca, fcde.

which proceed as shown in figure 28. The first two reactions are strong interactions and the requirement of pion unidirectionality is satisfied. The incident π^- becomes a component of the Σ after an excursion in time as a component of the kaon, while one of the π^+ in the proton becomes another component of the kaon. The reaction (35) involves pair annihilation and does not proceed via strong interactions; if the K^- were to participate in a strong production process, there would be annihilation of two pion pairs, as expected from the change in strangeness by two units. The reaction (36) involves both pair creation and annihilation, and does not proceed via a strong interaction either. These arguments are based on the graphic representation of the interactions, and a stronger determination of the rate at which a particular reaction proceeds has to be based on calculations.

In figure 29 we show a more complex process, where a Ξ^- is created in two steps,

$$\pi^- + p \rightarrow n + K^+ + K^-, \qquad (37)$$

$$K^- + p \rightarrow \Xi^- + K^+, \qquad (38)$$

and the overall process shows no pair creation or annihilation. A neutral kaon analogue of this process,

$$\pi^- + p \rightarrow n + K^0 + \bar{K}^0, \qquad (39)$$

$$\bar{K}^0 + p \rightarrow \Xi^- + K^+ + \pi^+, \qquad (40)$$

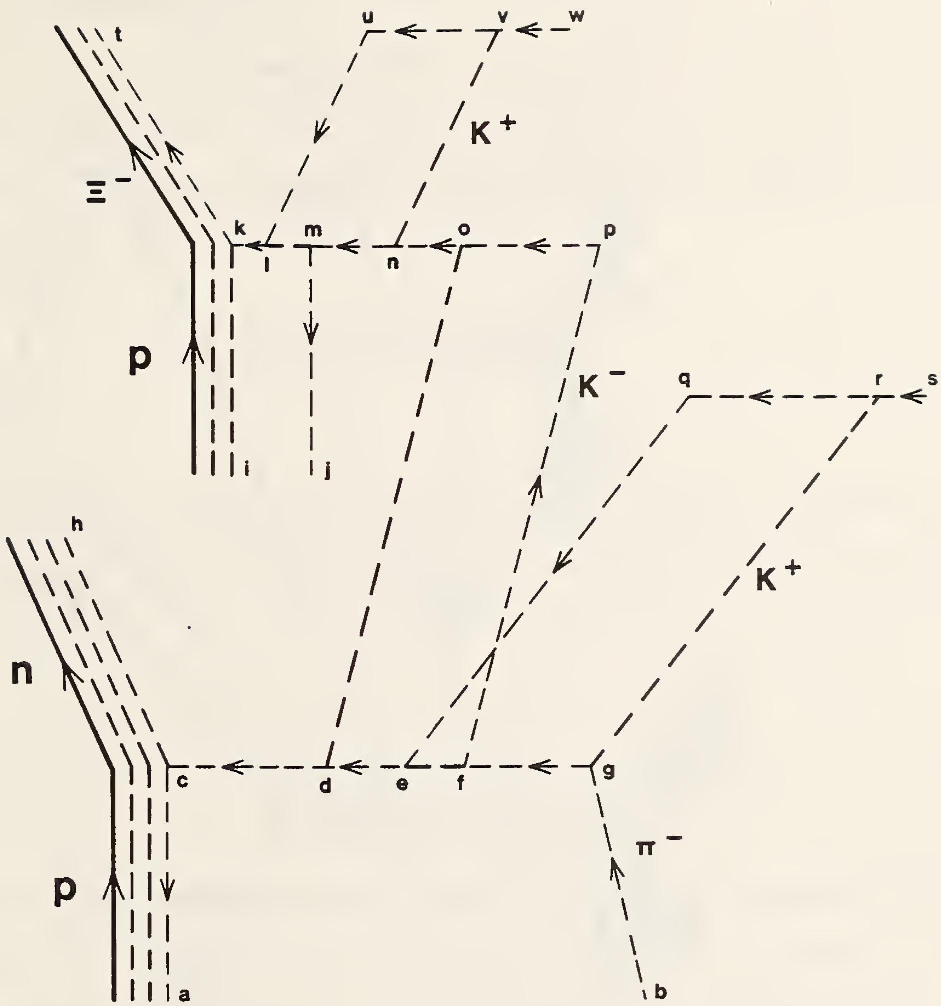

Figure 29. Associated production of a Ξ^- by a K^- produced in a previous reaction. The pion paths are bgrqefpodch, hca, srgfedonvulmj, wvnmlki, ikt. There is no pair creation. The weak decay of the K^+ is not shown, and here it would involve the creation of a neutrino pair.

is shown in figure 30. The tracing of the pion lines shows that one pair is created, which we attribute to the weak decay of the K^0. The difference between the K^0 and the $\overline{K}^0$ in this process is that the π^- in the $\overline{K}^0$ come from the future, while the π^- in the K^0 is the incident π^-. If the K^0 were to decay into two

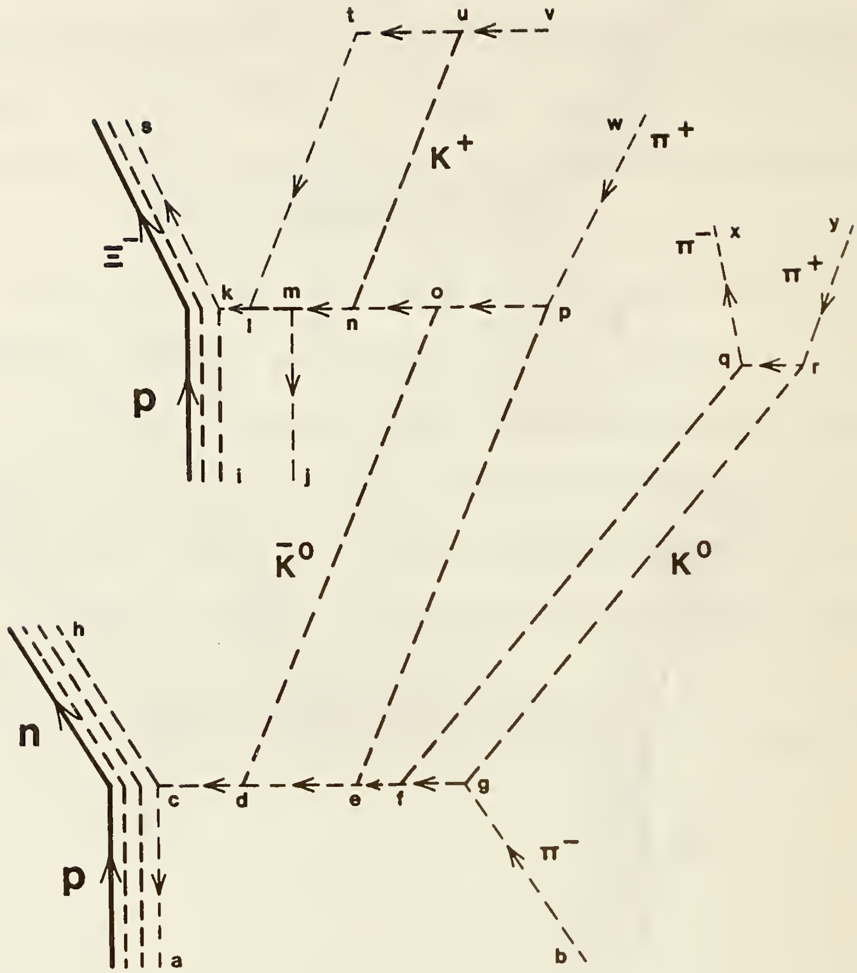

Figure 30. Associated production of a Ξ^- by a $\bar{K}^0$. The pion lines are bgrqfepodch, hca, yrgfqx, wpedonutlmj, vunmlki, iks. One pion pair is created, as expected from the weak decay of the K^0.

neutral pions by the decay shown in figure 15b, pion tracing would show a decrease by one in the number of pion lines, but there still would be pair creation (we would change figure 30 by moving points d and e between f and g, and point n between o and p).

8.2 The nature of the neutral kaon

A process [6f] that helps us understand the behavior of the neutral kaon is the production of a K^0 by charge exchange, where a K^+ is produced via the reaction (33) followed by

$$K^+ + n \rightarrow K^0 + p. \qquad (41)$$

In the standard view of these reactions, as the K_S^0 decays, a component of $\bar{K}^0$ appears in the beam, which then subsequently produces Λ-particles by the reaction

$$\bar{K}^0 + p \rightarrow \Lambda + \pi^+. \qquad (42)$$

In figure 31a we show the production of the K^0 according to reactions (33) and (41), and in figure 31b we show the production of a $\bar{K}^0$ via a similar process where one pair is created and one is annihilated, thus describing a weak reaction (note that the π^- comes from the future). The contribution of the second reaction becomes significant as the beam ages due to the weak decay of the K^0, and the $\bar{K}^0$ then allows the reaction (42) to proceed strongly. Both the K^0 and the $\bar{K}^0$ in figure 31 are shown decaying into two pions.

It is not sufficient to have two strange particles in the final state to have the copious associated production of strange particles. For instance, the reaction

$$n + p \rightarrow \Lambda + \Lambda + \pi^+ \qquad (43)$$

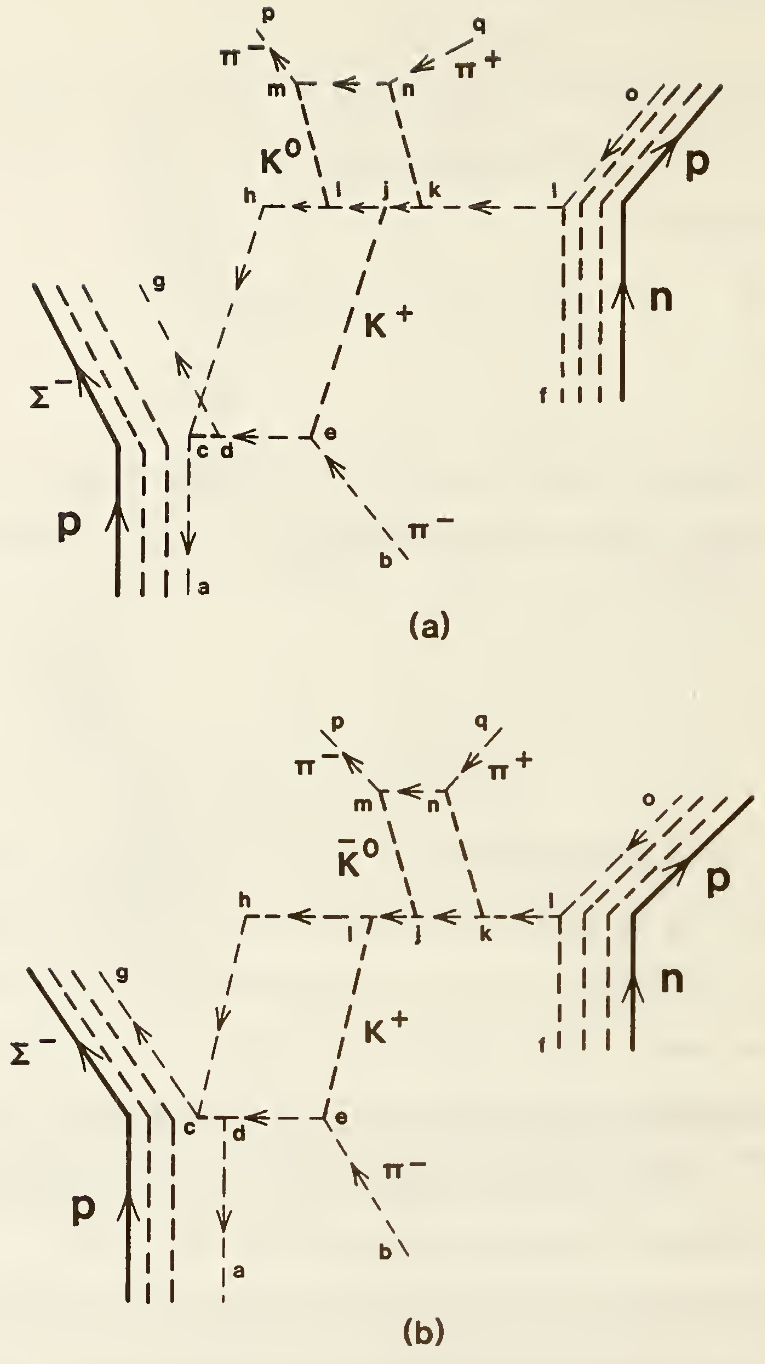

Figure 31. Production of the K^0 by charge exchange. The pion paths are (a) bejimp, flknmihcdg, olf, qnkjedca, (b) beihcda, flknmjiedcg, olf, qnkjmp. No pair is created or annihilated in (a), while one is created and another one is annihilated in (b).

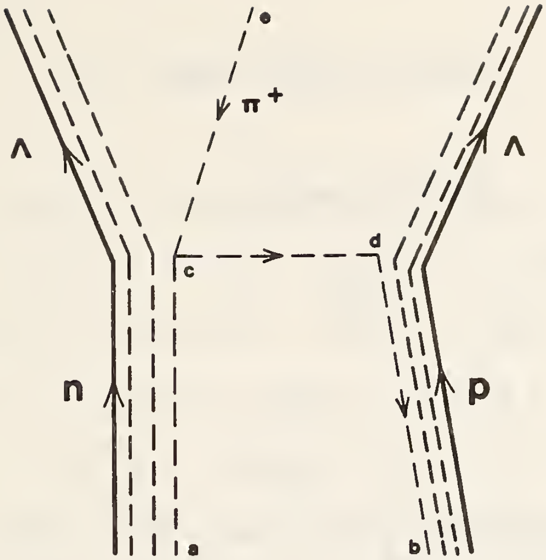

Figure 32. Production of two strange particles in a reaction that does not conserve strangeness. The pion paths are acdb, eca. There is pair annihilation which makes this process weak.

shown in figure 32 requires the production of a pion pair and is not allowed as a strong reaction; the initial state has S = 0 and the final state has S = 2.

8.3 Production of the Ω^-

In figure 33 we show a diagram for a reaction that produces an Ω^-, which has strangeness -3. A K^- is first produced by a reaction such as (37), as shown in figure 29. This K^- contains a pion that comes from the future (it has strangeness -1) and reacts with a proton to produce an Ω^- and two strangeness +1 kaons,

$$K^- + p \rightarrow \Omega^- + K^+ + K^0. \tag{44}$$

In figure 33 we also show the decay

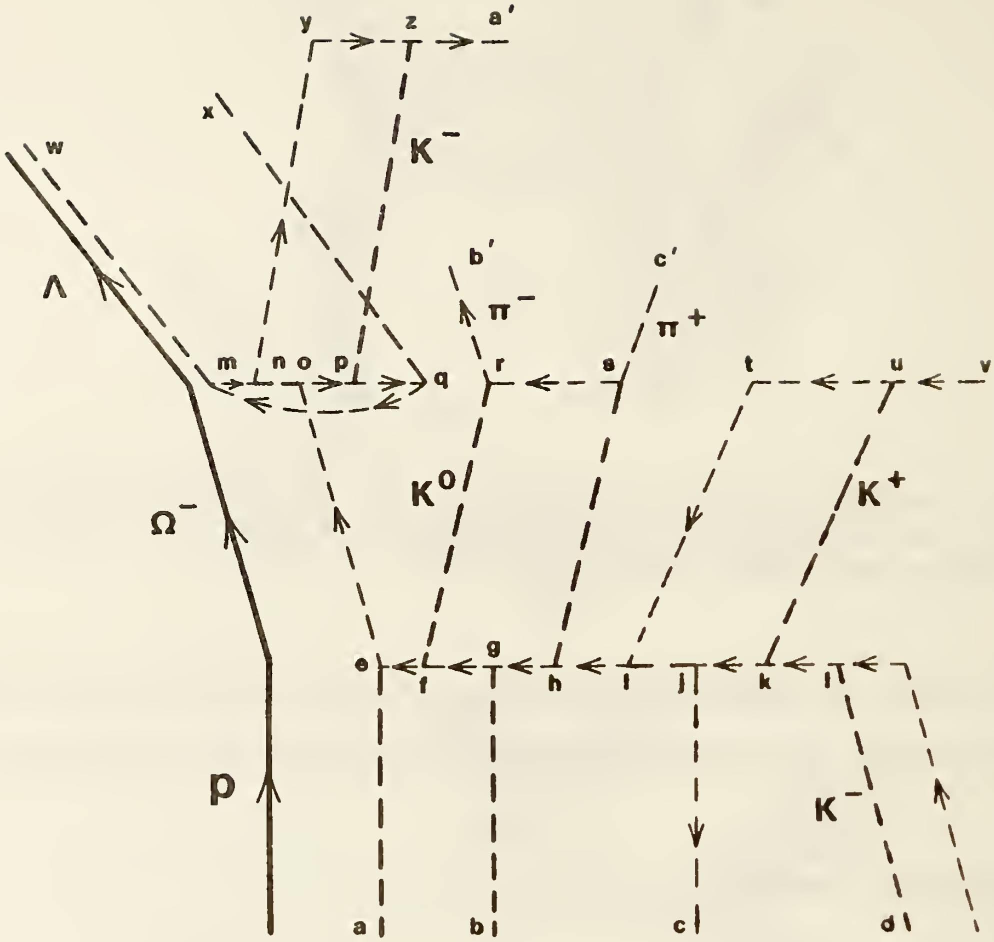

Figure 33. Associated production and subsequent decay of the Ω^-. The pion in the K^- really comes from the final time, as in figure 29. The pion paths are aeonyzpqx, bgfrb', dlkutijc, vukjihsrfea, c'shgb, xqmw, wmnopza'. There is no overall pair creation unless the K^- produced by the Ω^- decays weakly.

$$\Omega^- \rightarrow \Lambda + K^-, \tag{45}$$

where pion tracing shows that the π^- in this K^- also comes from the future.

9. OTHER STRANGE BARYONS

There are other possible configurations for stable particles that have not yet been clearly identified with observed particles. Some of these configurations are shown in figure 34. They are the archyon, with S = -3, which we have designated by Ω^0, and two particles with S = -2, the Ξ^+ and a neutral particle, the Ξ'^0. The Ξ'^0 can decay electromagnetically into the Ξ^0 in a reaction similar to the decay of a Σ^0 into a Λ. If the pattern of masses for the known baryons holds also for these particles, we expect the mass of the Ω^0 to be close to that of the Ω^-, that of the Ξ^+ to be close to that of the Ξ^- and Ξ^0, and that of the Ξ'^0 to be somewhat larger than that of the Ξ^0.

The spin of the composite particles may be determined by calculation of the properties of bound states. We expect the archyon to have spin 1/2, mainly because this is the simplest hypothesis. The theory of spin-3/2 particles is complicated and the Rarita-Schwinger formalism is essentially a combination of those for spin 1/2 and spin 1.

Unless we later find a need to introduce charm and beauty in this model, the particles that are classified in these categories are available for identification with further strange particles, and we do so in section 11.

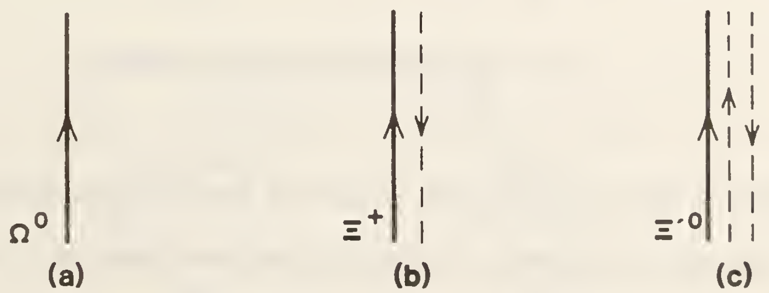

Figure 34. Configurations for additional baryons.

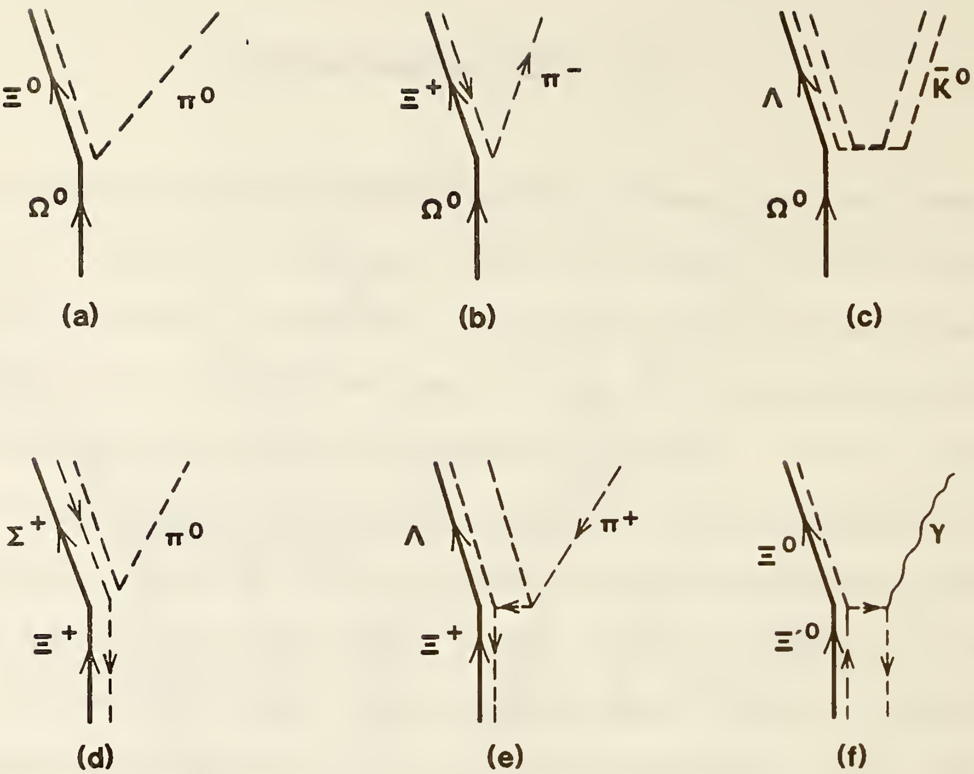

Figure 35. Possible decay modes of the additional baryons.

Additional configurations may be unstable and they would be observed as resonances.

The decay modes of these baryons depends on the actual masses; they could be those shown in figure 35.

10. THE TAU-LEPTON DECAY MODES

The decay modes [5] of the τ-lepton follow the pattern set by other particle decays in this model. There is some ambiguity in the identification of the neutrino that is produced in these decays; we assume that it is the ν' or μ^0 that we defined in subsection 3.2. Very similar diagrams could be used to show decays in which the neutrino that is produced is the basic ν.

We show the leptonic decays

$$\tau^- \rightarrow \nu' + \mu^- + \nu, \qquad (46)$$

$$\tau^- \rightarrow \nu' + e^- + \bar{\nu}, \qquad (47)$$

in figures 36a and b. We show some of the decays that involve hadrons in figures 36c, d, and e. In figure 36e we show a possible diagram for the electromagnetic decay

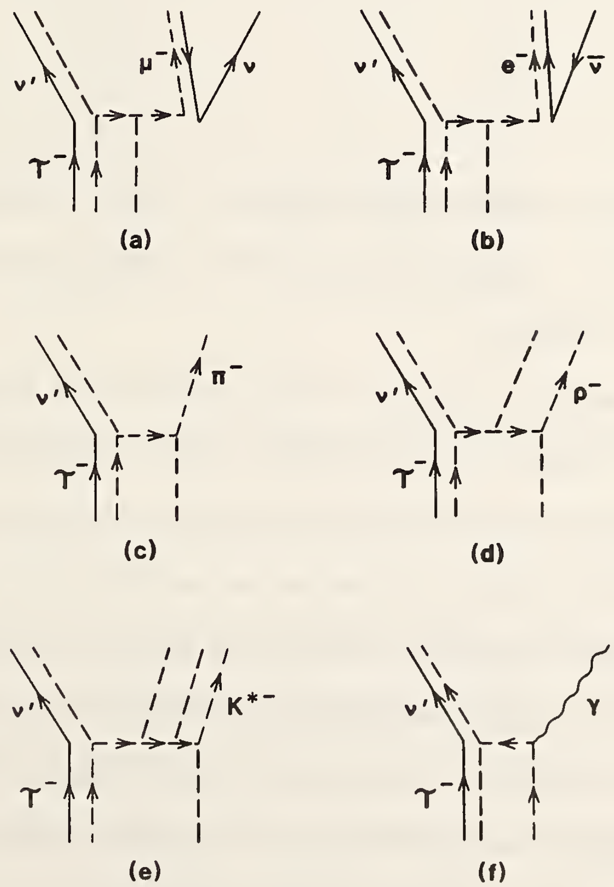

Figure 36. Decay modes of the τ-lepton.

$$\tau^- \rightarrow e^- + \gamma, \tag{48}$$

but the similar decay

$$\tau^- \rightarrow \mu^- + \gamma \tag{49}$$

is not allowed in our model.

The decays of the τ'^- would be similar to those of the τ^-, but they would involve a $\bar{\nu}'$ insted of the ν'. The electromagnetic decay of the τ' into a τ or an electron would be forbidden, but it could decay via

$$\tau'^+ \rightarrow \mu^+ + \gamma. \tag{50}$$

We can accommodate higher-mass leptons or lepton resonances by increasing the number of pions in the particle; their stability or width would depend on the computed binding energy.

If the tauon-neutrino is not the basic neutrino as expected and if it has a nonzero mass, it can decay in several ways. The decay products depend on its mass, and we show some of the possible reactions in figure 37. The assumed mass has to have successively larger values as we go from the decay products $\nu\gamma$ to $e\pi$, $\mu\pi$, and $\nu\pi\pi$. Another possible decay mode is the dissociation into $\nu\pi^0$.

As in previous sections, we learn more about these particles by considering a complete chain of reactions starting with the production process followed by the decays. In figure 38 we show one such reaction [19], and here we assume that the intermediary in the annihilation-creation process is a photon. As a consequence, the tauon-neutrino has to decay into two charged particles to avoid

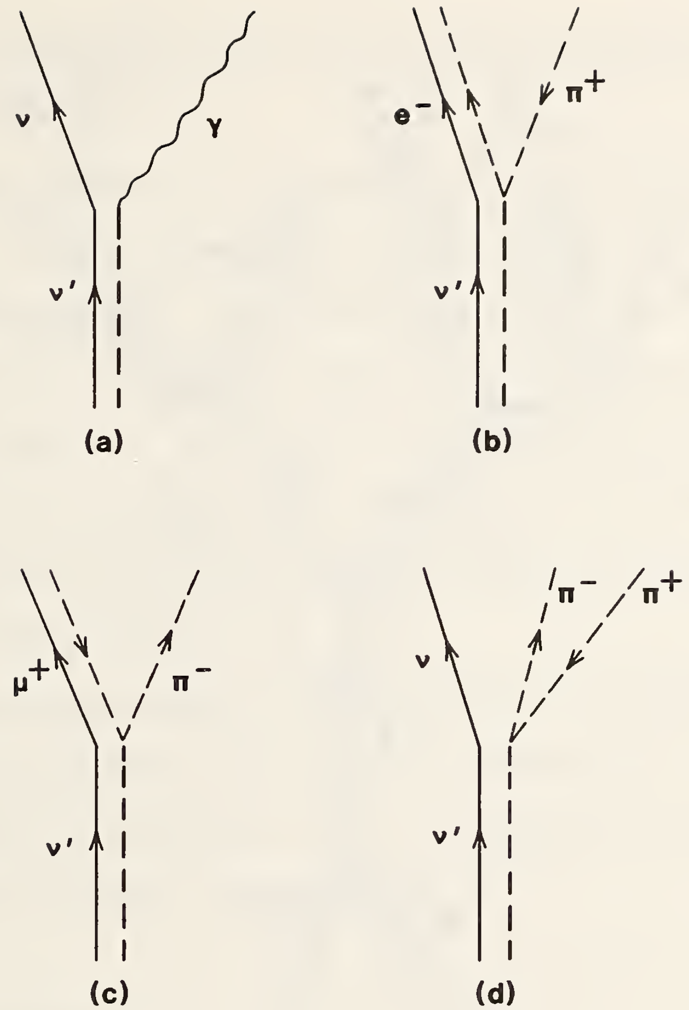

Figure 37. Decay modes of the tauon neutrino.

a closed pion loop in the diagram. This is not so if the pion lines from the electron-positron pair continue to the tauon pair. The π^0 in the other tauon-neutrino is assumed to decay into photons and represents an excursion of the same pion line. We indicate the beginning and the end of the pion lines by a pair of symbols such as b and b'.

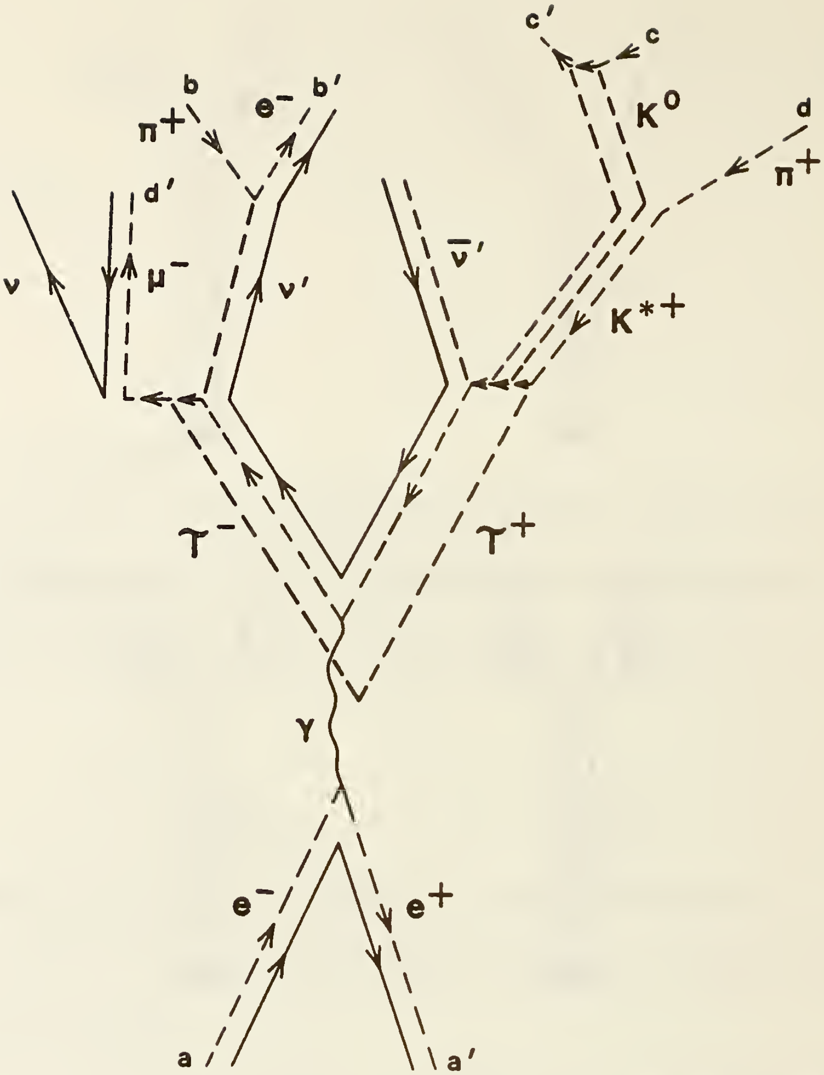

Figure 38. Creation and subsequent decay of a $\tau^+\tau^-$ pair. The beginning of a pion lines is marked with a letter such as b and the end of the same pion line is marked by b'.

11. CHARM AND BEAUTY

In the standard theory, inclusion of a c-quark in the composition of a hadron gives it a new quantum number called charm. Observation in a variety of reactions have identified the charmed mesons D^+ and D^0, the strange charmed meson F^+, the charmed baryon Λ_c^+, and their antiparticles. There is also evidence for a set of Σ_c^{++}, Σ_c^{+}, and Σ_c^{0}, and there are expectations of finding further charmed baryons [20].

Similarly, the inclusion of a b-quark in a particle gives it the quantum number of beauty. There are obsevations that give evidence of the beauty mesons B^+ and B^0, the beauty baryon Λ_b^0, and their antiparticles [6e, 21].

Less is known about the charmed and beauty particles than about those that were discovered longer ago. We find that it is possible to give an account of many of the reactions and decays of these new particles by extending the model of the older particles and we see no reason to complicate the model at this time by introducing new basic particles.

We discuss the charmed meson D in subsection 11.1, the charmed baryons in subsection 11.2, the strange charmed meson F in subsection 11.3, and the beauty meson B and baryon Λ_b^0 in subsection 11.4. We examine the relationship between strangeness, charm, and beauty in subsection 11.5.

11.1 The charmed meson D

This meson has been produced in e^+e^- collisions and in associated production modes similar to those of strange particles.

The D-meson decays mainly into pions and kaons, and there is no reason to assume that it is composed of particles other than pions. To differentiate them from kaons, we assume that they are composed by three pions in a resonant state, that is, we separate the components of one neutral pion. It is also possible to add more neutral pions to each kaon.

The charmed meson resonance D^* is obtained from the D by adding a pion that can be separated from the others in a strong decay that does not involve pair creation or annihilation. A determination of a weak decay sometimes requires the examination of the complete reaction starting with the creation of the particles.

Some of the decay modes of the D^+ [5] are shown in figure 39, and it is straightforward to get others by adding pion lines in the appropriate places. Similarly, some of the decays of the D^0 are shown in figure 40.

The identification of pion lines in figures 39 and 40 shows that there are three different pions involved in the D^+ or the D^0, while only two appear in each kaon.

In figure 41 we show the diagram that represents a very interesting event that begins with a weak neutrino reaction followed by a series of decays and a secondary reaction [6e]. A D^{*+} is created in the interaction

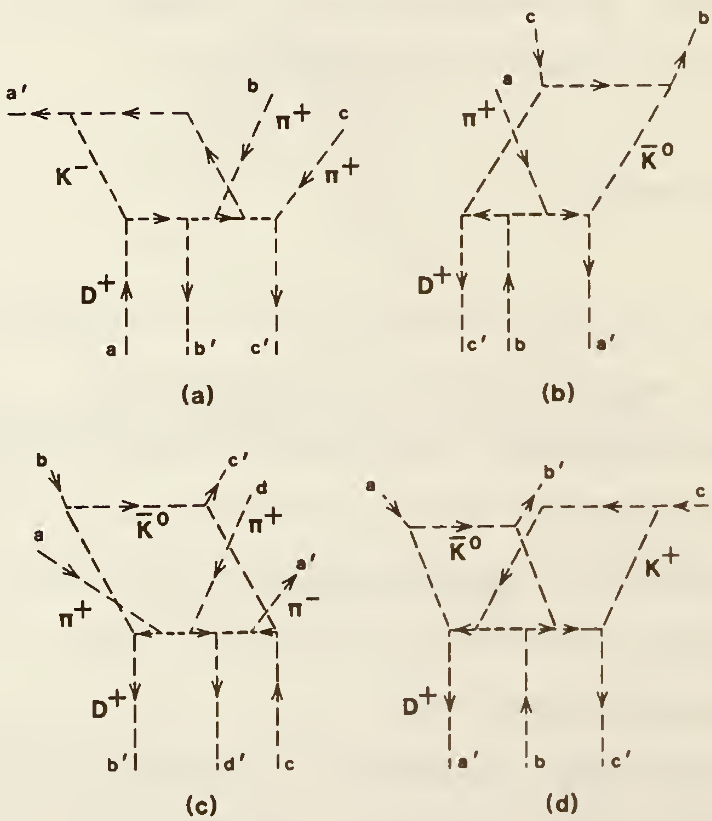

Figure 39. Decay modes of the charmed meson D^+.

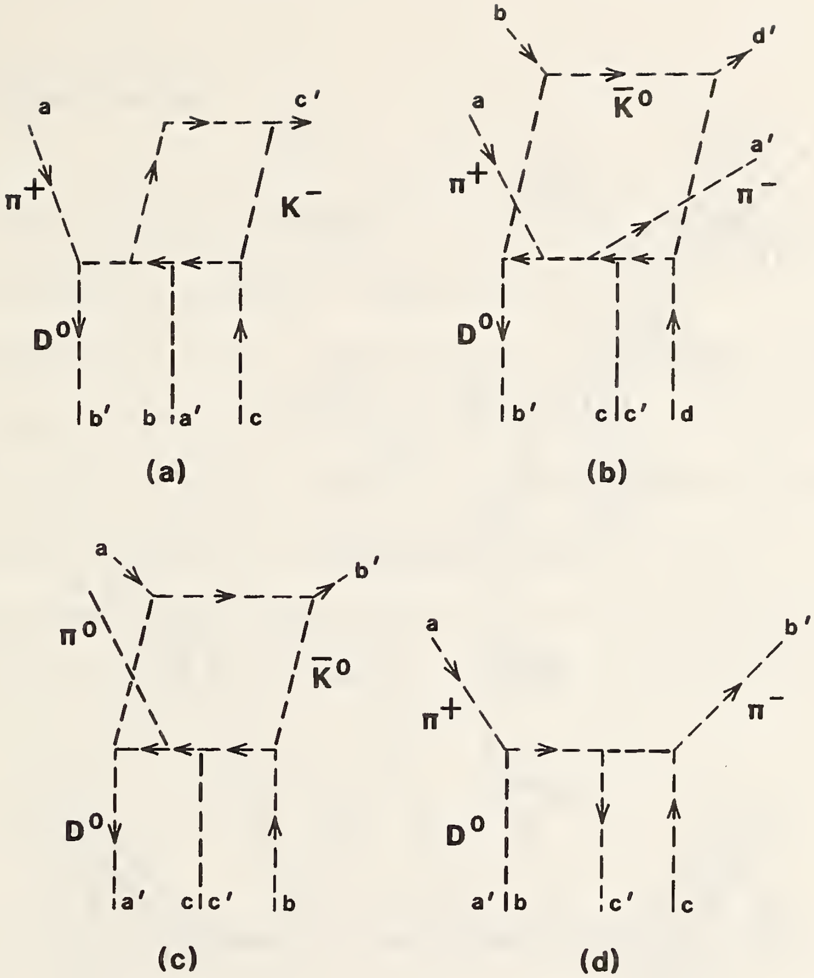

Figure 40. Decay modes of the charmed meson D^0.

$$p + \bar{\nu} \rightarrow p + D^{*+} + \mu^- . \qquad (50)$$

This charmed meson resonance decays strongly producing a D^0, which decays weakly into a kaon and a pion. The K^- then interacts strongly with a proton in the reaction

$$K^- + p \rightarrow \Sigma^- + \pi^+ , \qquad (51)$$

and the Σ^+ then decays weakly into a neutron and a pion.

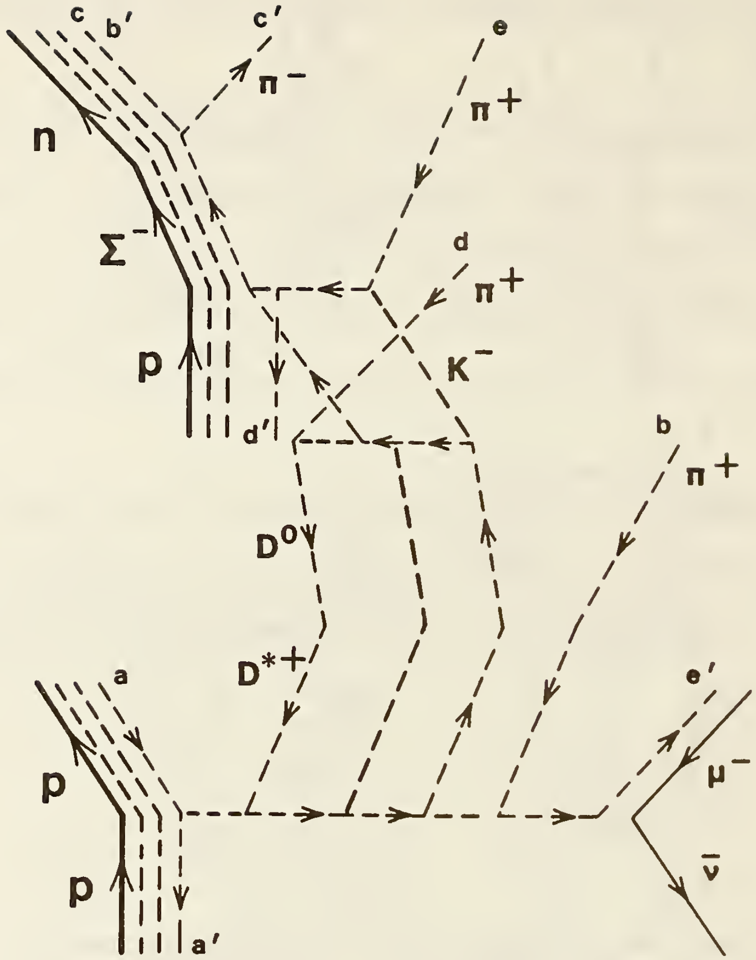

Figure 41. Representation of an observed reaction. Production of a charmed meson resonance D^{*+} via weak interactions, which decays strongly into a D^0, which decays weakly into a K^-, which interacts strongly with a proton creating a Σ^-, which decays weakly into a neutron.

In this series of reactions, three pion pairs are created, and one of the two other pions that are involved makes a significant detour in time before resuming its original direction of propagation.

11.2 The charmed baryons

The charmed baryons are expected to show the same groupings as the strange baryons with a charge increase of one unit [20].

In figure 42 we show the composition of the better established charmed baryons, the Λ_c and the Σ_c. We see that the Λ_c^+ corresponds to our proposed strange baryon Ξ^+ and that the Σ_c^0 corresponds to the proposed Ξ'^0. The configuration of the Σ_c^+ is that of a Σ^+ and must be an excited state; alternatively, the neutral pion in the Σ_c^+ may be replaced by two charged pions. The Σ_c^{++} shown in figure 42b correctly leads to the observed strong decay [20]

$$\Sigma_c^{++} \rightarrow \Lambda_c^+ + \pi^+. \qquad (52)$$

The main decay modes of the Λ_c^+ [5] are shown in figure 43. The decay in figure 43b is the one shown before in figure 35e; the others involve the

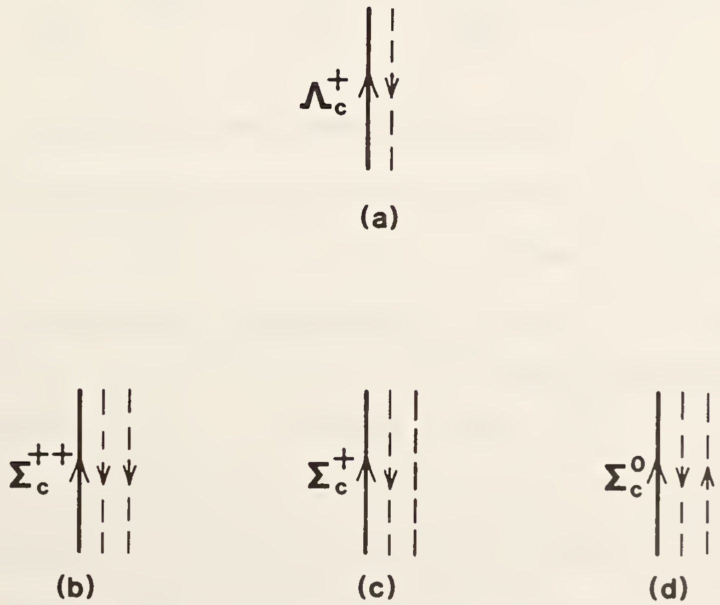

Figure 42. Components of the charmed baryons Λ_c and Σ_c. The pion components of the Σ_c^+ could also be two π^+ and one π^-.

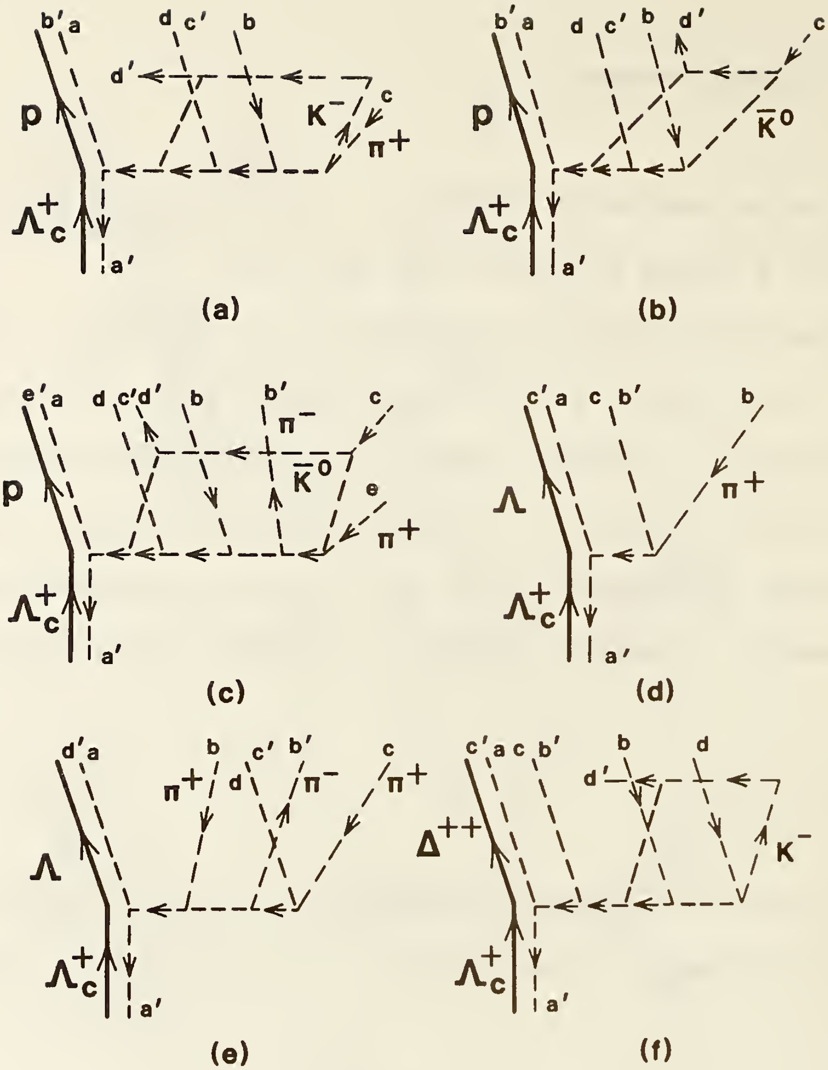

Figure 43. Decay modes of the Λ_c^+.

creation of more pion pairs.

In figure 44 we show the associated (photo)production of a charmed meson and a charmed baryon [22],

$$p + \gamma \rightarrow \Lambda_c^+ + D^0, \tag{53}$$

followed by the subsequent decay of the charmed particles.

If we disregard the charm quantum number and apply the strangeness

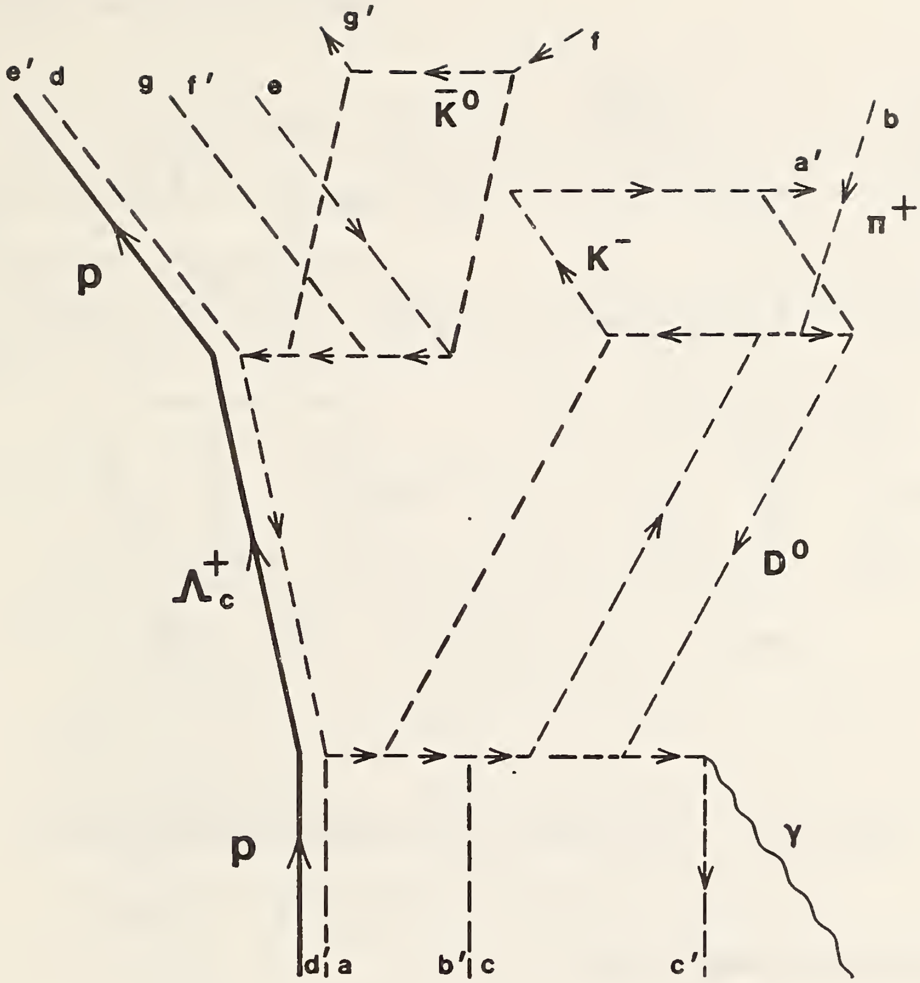

Figure 44. Associated photoproduction and subsequent decays of the charmed baryon Λ_c^+ and the charmed meson D^0.

classification to the Λ_c^+, it receives a strangeness of -2 according to the prescription for stable baryons. Then the reaction (53) and conservation of strangeness imply that the strangeness of the D^0 is +2. Correspondingly, the D^+ would also have strangeness +2, and the D^- and the $\bar{D}^0$ would have strangeness -2. But, just as was the case with the K^0 and the $\bar{K}^0$, we find no essential difference between the D^0 and the $\bar{D}^0$.

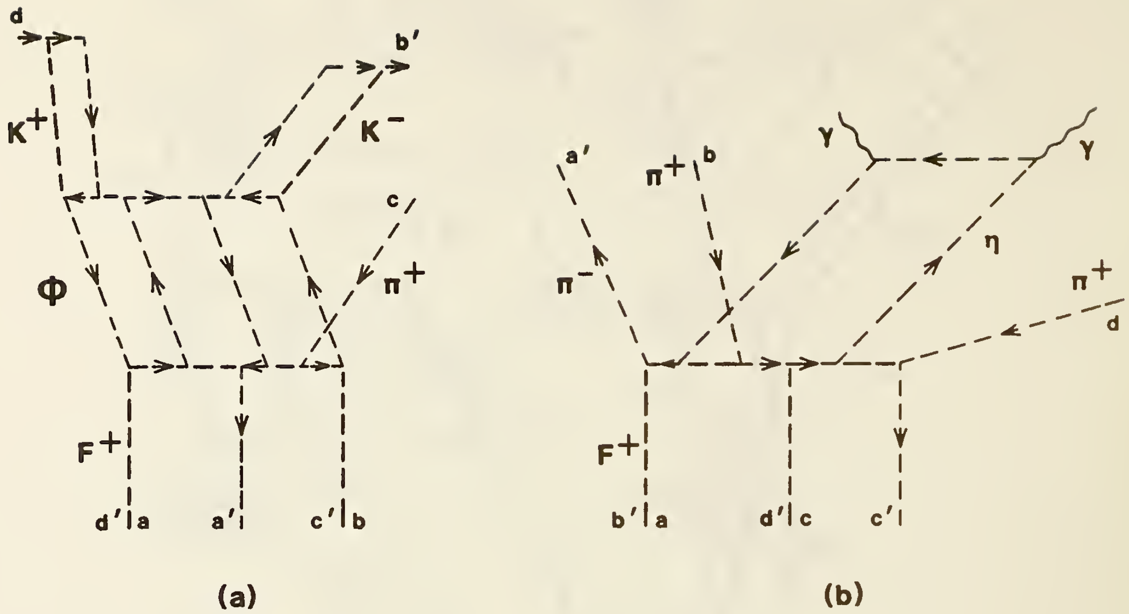

Figure 45. Decay modes of the charmed strange meson F^+.

11.3 The charmed strange meson F

Not much is known about the meson that has both charm and strangenes, the F^+ [21]. We propose a composition of two neutral pions and a positive pion for the F^+, which agrees with the available information.

We show two of the seen or possibly seen decay modes [5] in figure 45. There are four pion lines involved in the F^+. The other decay modes possibly seen for the F^+ [5] are not very different from those shown.

The F^+ is usually classified as a particle with strangeness 1 and charm 1, but if we want to assign it only a strangeness, it would be strangeness 3. The pattern seems to indicate that one unit of charm is equivalent to two units of strangeness.

11.4 The beauty mesons and baryons

The beauty quantum number adds another pion layer to the configuration of mesons, that is, the mesons B^+ and B^0 are obtained from the D^+ and the D^0 by adding a π^0 to their configuration.

Decay modes of the B^+ and the B^0 [5] are shown in figures 46 and 47.

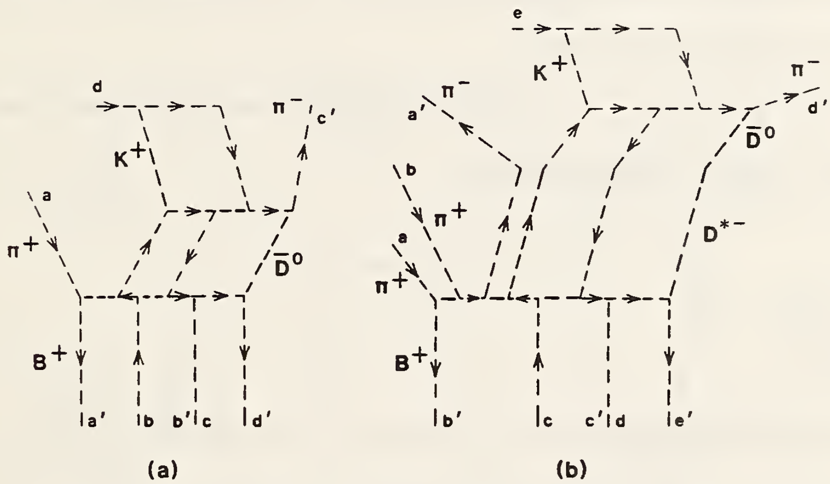

Figure 46. Decay modes of the beauty meson B^+.

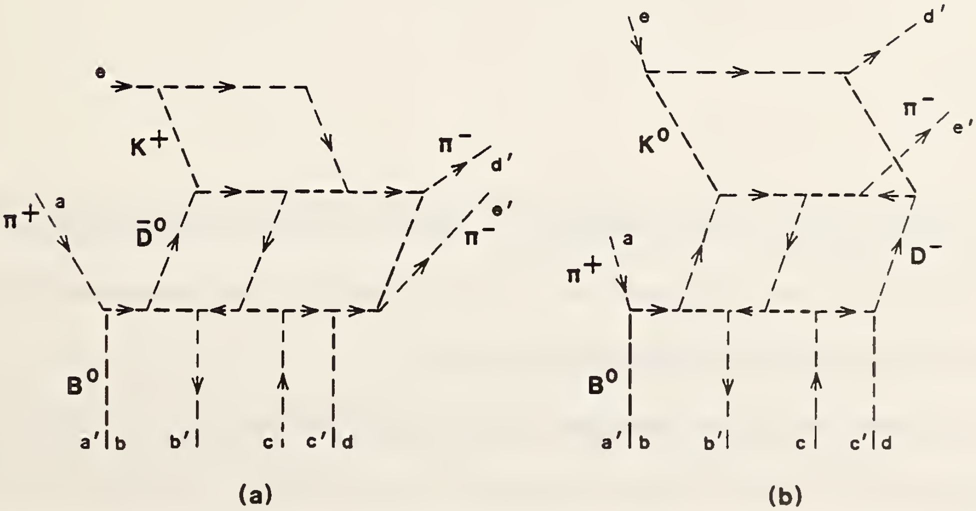

Figure 47. Decay modes of the beauty meson B^0.

Other decay modes can be obtained from these by the usual variations. These figures show that there are four pion lines involved in the B^+ and the B^0, although a different way of representing a decay can give a different number of pion lines.

There also is evidence of a beauty baryon, which should have one fewer pion than the corresponding charmed baryon. Hence we propose that the archyon be identified with the beauty baryon Λ_b^0.

The associated production of beauty particles has been observed in proton-proton scattering [23], in the reaction

$$p + p \rightarrow p + B^0 + \Lambda_b^0 + \pi^+. \qquad (54)$$

This reaction is shown in figure 48, followed by the decays

$$B^0 \rightarrow \bar{D}^0 + \pi^+ + \pi^-, \qquad (55)$$

$$\Lambda_b^0 \rightarrow p + D^0 + \pi^-, \qquad (56)$$

followed by the decays of the D-mesons. Since we do not differentiate between the D^0 and the $\bar{D}^0$ or between the B^0 and the $\bar{B}^0$, the designations in the reactions (54) to (56) are somewhat arbitrary.

Since in this model strangeness, charm, and beauty are all associated with the configuration of pion lines, there is no reason to make a distinction between a strangeness -3 baryon such as the Ω^0 and the beauty baryon Λ_b^0. The reaction (54) implies that the B^0 and the B^+ also have strangeness 3 like the F^+. Thus, one unit of beauty is equivalent to three units of strangeness.

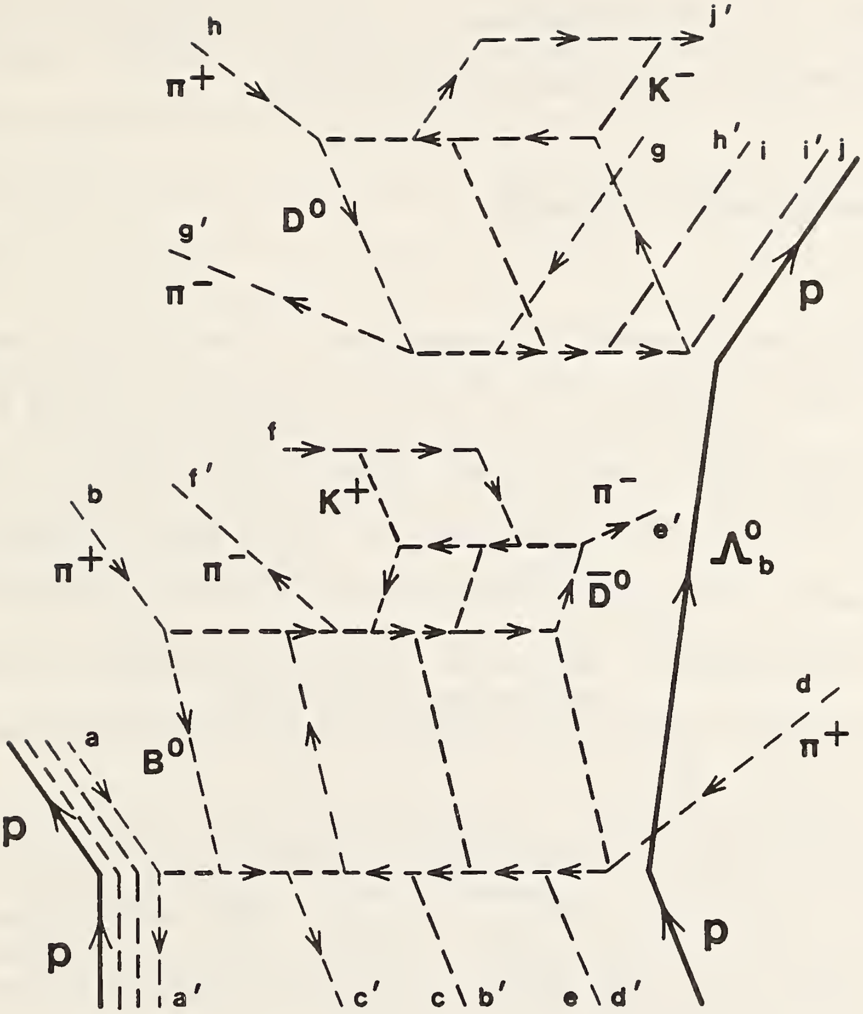

Figure 48. Associated production and subsequent decays of the beauty baryon Λ_b^0 and the beauty meson B^0.

There is evidence [23] of a resonance that corresponds to a Σ_b^+ in the products of the reaction (54). The beauty Σ-baryon decays strongly via

$$\Sigma_b^+ \to \Lambda_b^0 + \pi^+, \tag{57}$$

which suggests that the configuration of the Σ_b^+ is the same as that of the Λ_c^+, that is, that the Σ_b^+ is an excited state of the Λ_c^+.

11.5 Strangeness, charm, and beauty

The traditional concept of strangeness, or the closely related one of hypercharge, was introduced in the theory of baryons and mesons to explain why some particles were stable under strong interactions, that is, why they took such a long time to decay. Then came the quark model of hadrons with three fundamental quarks; this model agreed quite well with the particles known at the time. Later experimental results led to the introduction of two more quarks, named charm and beauty quarks, as components of newly discovered particles. One of the three original quarks is the strange quark s.

There are no quarks in our model, although they are not excluded as components of the basic pion and archyon. There is no reason to define strangeness of particles other than to connect the long lifetimes of certain particles with a notion familiar to physicists.

We defined the strangeness of a stable baryon as the number of positive pions in the baryon minus 3. Since we have no reason to introduce further quantum numbers, we have identified charmed and beauty baryons with the unknown baryons in figure 34, to which we had already applied the definition of strangeness. Thus, the proton and the neutron have strangeness 0, the Λ and the Σ have strangeness -1, the Ξ and the Λ_c^+ have strangeness -2, and the Ω and the Λ_b^0 have strangeness -3. This definition does not apply to resonances that decay via the strong interactions, such as the Δ.

The strangeness of mesons is more difficult to define, in part because we have no good reason to define some of them as particles and some as antiparticles. This is especially true for neutral mesons; we do not distinguish between the K^0 and the $\overline{K}^0$, the D^0 and $\overline{D}^0$, or the B^0 and $\overline{B}^0$, and we have used that notation only to follow the conventions in the literature. We can define the strangeness of stable mesons from associated production processes, and we have done so in several cases. The magnitude of the strangeness of a meson turned out to be equal to the number of different pions in the meson minus 1. Thus, the pion and the η have strangeness 0, the kaon has strangeness 1, the D-meson has strangeness 2, and the F-meson and B-meson have strangeness 3. Again this definition does not apply to resonances that decay via the strong interactions, such as the ρ or the ω.

12. PSIONS AND UPSILONS

A number of other narrow states have been discovered in the e^+e^- annihilation. The first family of vector particles, the psions, is interpreted in terms of bound states of $c\overline{c}$, that is, charmonium [21]. The ground state is the J/ψ particle. More recently another family of vector mesons, the upsilons [24], have been discovered as narrow resonances at very high energies. These particles are interpreted as bound states of $b\overline{b}$. Similar states are expected for the top quark.

The proposed components of the J/ψ and the Υ are shown in figure 49. The J/ψ has the same composition as positronium, but the neutrino and the electron are not bound together in an electron. Computation of binding energies may show that more pions are required to give the right masses for these particles or resonances.

Some of the decay modes of the J/ψ are shown in figure 50, and the others that are listed [5] can be represented in a similar manner.

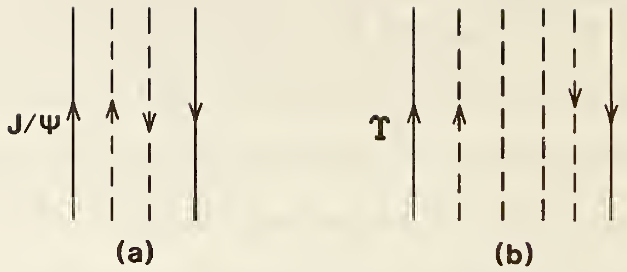

Figure 49. Components of the J/ψ and the ϒ.

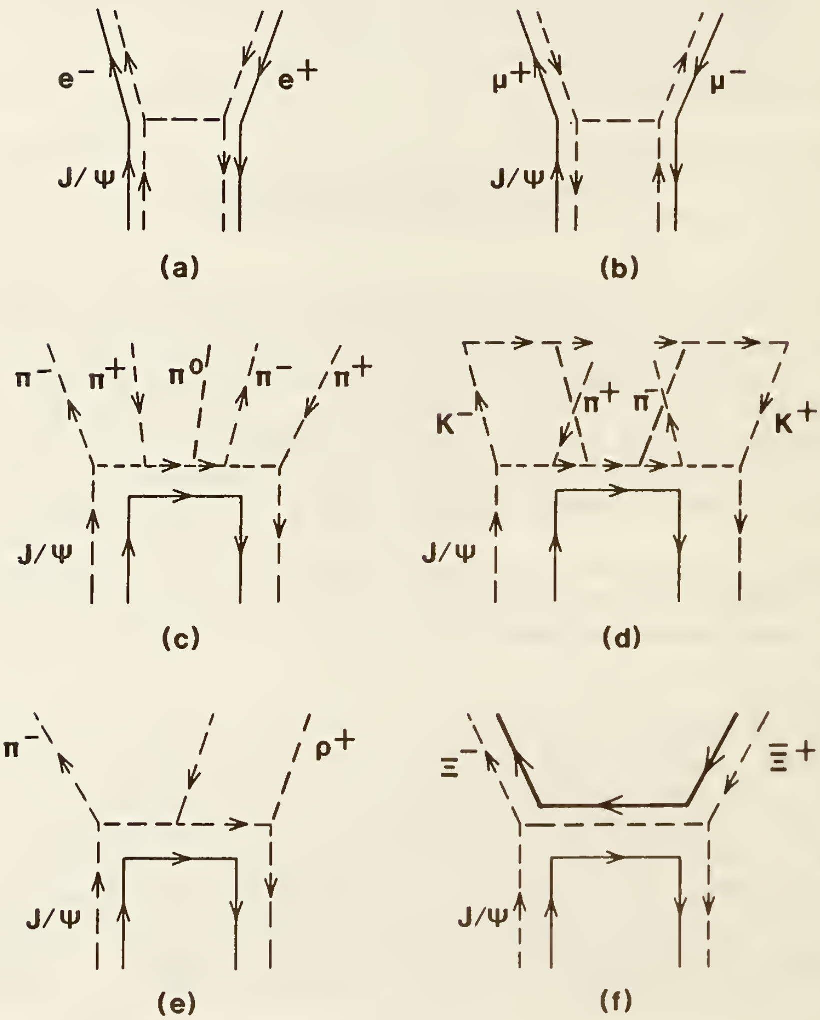

Figure 50. Decay modes of the J/ψ.

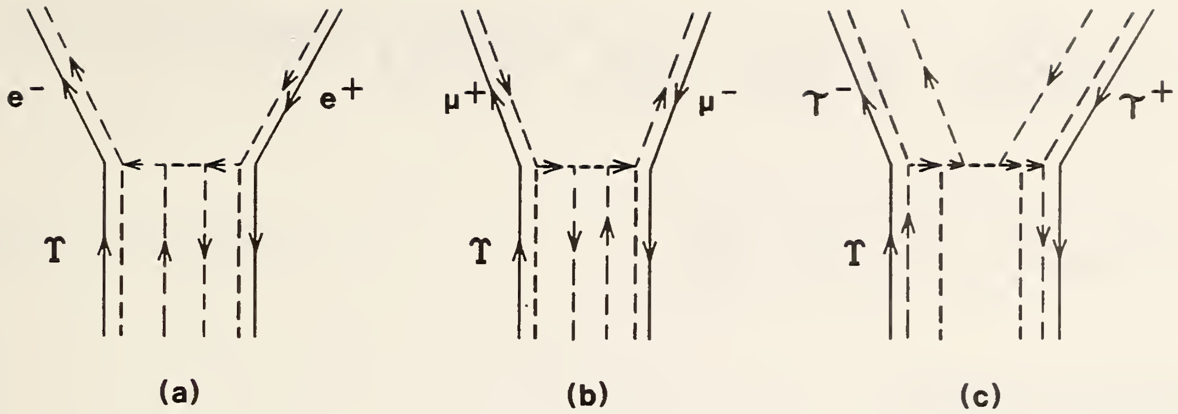

Figure 51. Decay modes of the ϒ.

In figure 51 we show the leptonic decay modes of the ϒ. The diagrams for the hadronic decay modes of the ϒ are very similar to those of the J/ψ.

The other members of these families can be excited states of the same systems, or states with one or more pions added.

13. INTERACTIONS

We have found a Lagrangian density that combines the free-field Lagrangian densities with the gauge-invariant electromagnetic interaction and a current-current interaction between the pion and the neutrino or the archyon. The massless neutrino is represented by a two-component spinor field χ_A, the pion by the complex (pseudo)scalar field ϕ, the electromagnetic field by the potentials A_μ, and the archyon by a bispinor field Ψ. The Lagrangian density is obtained by adding the usual free-field terms for the four fields, and the interaction is introduced by a substitution similar to the gauge-invariant substitution of electrodynamics. The result is

$$\mathcal{L} = \frac{1}{2}i(\chi^*_{\dot{A}}\sigma^{\dot{A}B}_\mu \chi_{B,\mu} - \chi^*_{\dot{A},\mu}\sigma^{\dot{A}B}_\mu \chi_B) - \frac{1}{4}F_{\mu\nu}F_{\mu\nu} + (\Delta^*_\mu\phi^*)\Delta_\mu\phi - m^2\phi^*\phi$$

$$- \frac{1}{2}i(\bar{\Psi}\gamma_\mu\Psi_{,\mu} - \bar{\Psi}_{,\mu}\gamma_\mu\Psi) - M\bar{\Psi}\Psi, \tag{58}$$

where the operator

$$\Delta_\mu = \partial_\mu - ieA_\mu + igj_\mu + ig'j'_\mu, \tag{59}$$

is a generalization of the operator D_μ defined in eq. (8),

$$F_{\mu\nu} = A_{\mu,\nu} - A_{\nu,\mu}, \tag{60}$$

$$j_\mu = \chi^*_{\dot{A}}\sigma^{\dot{A}B}_\mu \chi_B, \tag{61}$$

$$j'_\mu = \bar{\Psi}\gamma_\mu\Psi, \tag{62}$$

m is the mass of the pion, M is that of the archyon, and σ_μ and γ_μ are the Pauli and Dirac matrices. We have three coupling constants in this Lagrangian density, e, g, and g', and they may be related. We have chosen the vector current density (62), although it may be necessary to include the axial-vector current density. This Lagrangian density is not a strict generalization of the one proposed previously [14]. Minor differences come from the introduction of the operator Δ_μ which gives the equations a more elegant form.

The resulting equations of motion are

$$- i\sigma_{\mu}^{\dot{A}B}\chi_{B,\mu} + gJ_{\mu}\sigma_{\mu}^{\dot{A}B}\chi_{B} = 0, \tag{63}$$

$$(\Delta^{2} + m^{2})\phi = 0, \tag{64}$$

$$- i\gamma_{\mu}\Psi_{,\mu} + M\Psi + gJ_{\mu}\gamma_{\mu}\Psi = 0, \tag{65}$$

$$F_{\mu\nu,\nu} = - eJ_{\mu}, \tag{66}$$

where

$$J_{\mu} = i[\phi^{*}\Delta_{\mu}\phi - (\Delta_{\mu}^{*}\phi^{*})\phi] = i(\phi^{*}\phi_{,\mu} - \phi^{*}_{,\mu}\phi) + 2(eA_{\mu} - gj_{\mu} - g'j'_{\mu})\phi^{*}\phi. \tag{67}$$

The interactions are expressed in terms of the conserved particle current densities j_{μ}, j'_{μ}, and J_{μ}. The equations of motion thus insure the conservation of leptons, baryons, and electrically charged pions.

An alternative interaction that may be useful is obtained by using real coupling constants for the fermion currents in (59), which becomes

$$\Delta'_{\mu} = D_{\mu} + gj_{\mu} + g'j'_{\mu}. \tag{68}$$

The equations of motion (63) and (65) have to be replaced by

$$- i\sigma_{\mu}^{\dot{A}B}\chi_{B,\mu} - g\sigma_{\mu}^{\dot{A}B}\chi_{B}(\partial_{\mu} + 2g'j'_{\mu})(\phi^{*}\phi) = 0, \tag{69}$$

$$- i\gamma_{\mu}\Psi_{,\mu} + M\Psi + g\gamma_{\mu}\Psi(\partial_{\mu} + 2gj_{\mu} + 2g'j'_{\mu})(\phi^{*}\phi) = 0, \tag{70}$$

where the term in j_{μ} in (69) vanishes due to the properties of the σ_{μ} [14]. The pion current (67) reduces to

$$J_{\mu} = i[\phi^{*}D_{\mu}\phi - (D_{\mu}^{*}\phi^{*})\phi], \tag{71}$$

so that the fermion currents do not participate directly in the source of the electromagnetic field.

The parity transformation is not defined for a single two-component spinor field, and interactions involving the neutrino field violate parity conservation. Parity conservation in electromagnetic interactions is assured by the properties of the RQM of the scalar field, and the two helicity states of the electron have to be produced by different bound states of the pion-neutrino system. The antilinear transformation that is defined for the spinor field corresponds to a CP transformation.

The Lagrangian density (58) is not unique. Some variations were presented before [14] and others, such as a pion-pion interaction term, may be required to effect agreement with experiment.

14. CONCLUDING REMARKS

We have proposed a comprehensive model of the physics of elementary particles.

The model is based on the interactions of only four fundamental fields, obtained from a Lagrangian density with only two masses and three coupling constants. The number of parameters may effectively be further reduced if the masses and coupling constants are related.

The underlying framework is a dynamical theory, in the sense that we have equations of motion that determine the fields between the initial and final times from given time-boundary conditions. There is a conserved current for each of the basic particles, which implies that neutrinos, pions and archyons are neither created nor destroyed; they can be scattered and they can be reflected in time. The framework may be that of a many-times formalism in RQM or that of an equivalent formulation of QFT. At present there seems to be no need to quantize the electromagnetic field if RQM is used; although the quantization is straightforward as long as proper care is taken with the constraints. It is possible to let the initial time tend to $-\infty$ and the final time to $+\infty$ and define an S-matrix. In this S-matrix the initial states of the particles are grouped with the final states of antiparticles (input data suitable for the causal Green function) and the final states of the particles with the initial states of the antiparticles (results of the calculations); hence, it differs from the usual S-matrix.

All composite particles are formed with pions and at most one neutrino or one archyon. Pions are the only particles that carry electromagnetic charge, whence charge conservation is equivalent to conservation of the (algebraic) number of free and bound pions. Reactions between particles amount to a recombination of their components, analogous to chemical reactions, augmented by pair creation and annihilation. Strong and weak interactions of hadrons are represented by a single term in the Lagrangian density, and we attribute the difference to dynamical factors, especially pair creation and annihilation, energy barriers for virtual pions, and possibly the magnitude of the flux of antiparticles from the future.

Strangeness is a concept of limited usefulness that is related to the number of positive pions in a composite particle. Strangeness is conserved when pion lines go between the initial state and the final state.

The strength of the fundamental interaction is such that the binding energy in a bound state is greater than twice the mass of the lighter particle. Thus, pair creation is energetically possible and a decay product can be more complex than the decaying particle. Forces between nucleons are analogous to van der Waals forces between molecules.

Kaons are resonant states of pions, and they are best understood in the context of the associated production of strange particles. It is important to follow the pions that take part in the different stages of a multiple reaction to identify the particles and processes. There is no clear distinction between particles and antiparticles among kaons; the strangeness assignments are related to the origin in time of their pions. The standard theory also does not distinguish between the K^0 and the $\bar{K}^0$, as far as their weak decays are concerned. We also accept the view that the difference between the short-lived and the long-lived K^0 is dynamical in origin.

We have included in the model the newer particles, such as the τ-lepton, its neutrino, and mesons and baryons with charm and beauty. It is not necessary to change the model in any fundamental way, and thus there is nothing that sets these particles apart from the older ones other than their composition. There is no need to distinguish between particles and antiparticles among the charmed and beauty mesons either.

The choice of the components of the particles is not unique and may depend on the diagrammatic representation of the reactions; any choice has to be corroborated by calculations of masses, lifetimes, and reaction constants.

We have favored the simplest structure compatible with the decays and interactions we examined. A somewhat different choice might turn out to be better. For instance, pion lines can be folded over one more time in the kaon configuration; the only reason we see at this time that would favor this structure is the closeness of the mass of the kaon to that of three pions.

We have presented a number of new ideas that simplify the theory of elementary particle physics; much work remains to be done to determine its consequences and to adjust the details to assure agreement with experiments. There are other possible particle configurations and equations of motion, and only detailed calculations will show which alternatives are favored by nature. A good starting point may be a calculation of the mass and lifetime of the π^0, which is an interference state of a π^+ and a π^-, or of the masses of the electron and the muon in terms of the pion mass and a coupling constant. Difficulties remain in RQM related to the interactions between particles, and we still have to determine the best way to handle problems associated with the positive-definite charge density of the fermion fields. The anticommutation of fermion operators in the standard QFT changes the sign of one of the contributions to the charge operator, but this theory is afflicted by other serious problems related to divergent terms and undefined mathematical entities. We also require a general formalism for the computation of energy levels of bound states and resonances in RQM when the binding energies are comparable to the masses.

New methods to calculate observable quantities from the equations of motion for the fields have to be developed before comparison with experiment can discriminate between the many alternative interactions. In view of the strength of the interactions other than the electromagnetic one, it does not seem likely that perturbation expansions will be helpful in the determination of binding energies (masses) and lifetimes.

The weak and strong interactions of hadrons are different manifestations of a single interaction term between pions and archyons. The difference between the two is related only to the type of decay or reaction that is being considered, especially to the presence of pair creation or annihilation. This interaction is closely paralleled by the interaction between pions and neutrinos that gives rise to the weak interactions of the leptons, where the strength of this interaction shows in the binding energies of the composite particles. The pions also interact with the electromagnetic field in the usual manner; the form of this interaction is somewhat different from the other two.

We have presented a particular realization of our model. The basic concepts of strong binding, strict conservation of basic "particles," causal boundary conditions, time-reflection symmetry between particles and antiparticles, and probability amplitudes are more general than the particular composition of particles and Lagrangian density. We have chosen the components of the particles so that they fit a large number of reactions and decays, but they are not uniquely determined. We chose the Lagrangian density so that it describes the four fields and provides three conserved current densities in a simple and elegant form.

Other areas for future research are the cosmological implications of the time symmetry and the arrow of time, and the properties of a region of the universe where matter and antimatter are more evenly mixed.

Current theories of elementary particles have been developed over more than half a century, and the agreement with experiment is excellent in many cases.

On the other hand, the mathematical foundation of QFT is weak, and the number and complexity of the hypotheses required to reach this agreement is large. Our model is simple, yet it should be able to predict any experimental result in particle physics.

I thank Dr. E. Clayton Teague and Dr. Michael Danos for their helpful comments and encouragement.

15. REFERENCES

[1] Dirac, P. A. M. The origin of quantum field theory, chapter 2 in The birth of particle physics. L. M. Brown and L. Hoddeson, eds. Cambridge: Cambridge University Press; 1983. 39-55.

[2a] Stueckelberg, E. C. G. Remarque à propos de la création de paires de particules en théorie de relativité. Helv. Phys. Acta. **14**: 588-594; 1941.

[2b] Stueckelberg, E. C. G. La mécanique du point matériel en théorie de relativité et en théorie des quanta. Helv. Phys. Acta. 15: 23-37; 1942.

[2c] Feynman, R. P. The theory of positrons. Phys. Rev. **76**: 749-759; 1949.

[2d] Feynman, R. P. Space-time approach to quantum electrodynamics. Phys. Rev. **76**: 769-789; 1949.

[3a] Marx, E. Probabilistic interpretation of relativistic scattering. Nuovo Cimento. **60A**: 669-682; 1969.

[3b] Marx, E. Relativistic quantum mechanics of identical bosons. Nuovo Cimento. **67A**: 129-152; 1970.

[4a] Marx, E. Quantum electrodynamics of one scalar particle. Int. J. Theor. Phys. **18**: 819-834; 1979.

[4b] Marx, E. Scalar charged particle in the Lorentz gauge. Int. J. Theor. Phys. **24**: 217-221; 1985.

[5] Particle Data Group. Review of particle properties. Rev. Mod. Phys. 56 (No. 2, Part II): S1-S304; 1984.

[6a] Bernstein, J. Elementary particles and their currents. San Francisco: Freeman; 1968.

[6b] Bransden, B. H.; Evans, D.; Major, J. V. The fundamental particles. London: Van Nostrand; 1973.

[6c] Frazer, W. R. Elementary particles. Englewood Cliffs: Prentice Hall; 1966.

[6d] Gasiorowicz, S. Elementary particle physics. New York: Wiley; 1966.

[6e] Gottfried, K; Weisskopf, V. F. Concepts of particle physics, Vol. I. Oxford: Clarendon; 1984.

[6f] Cheng, D. C.; O'Neill, G. K. Elementary particles. Reading: Addison-Wesley; 1979.

[6g] Lee, T. D. Particle physics and introduction to field theory. Chur: Harwood; 1981.

[7] Marx, E. The causal Green distribution in relativistic quantum mechanics. J. Math. Phys., submitted for publication.

[8] Walter, J. F.; Marx, E. Pair annihilation at a potential barrier in time. Nuovo Cimento. 2B: 1-8; 1971.

[9] Dirac, P. A. M. Relativistic quantum mechanics. Proc. Roy. Soc. London. 136: 453-464; 1932.

[10a] Marx, E. Operators in a relativistic Fock space for fermions. Int. J. Theor. Phys. 6: 301-306; 1972.

[10b] Marx, E. Generalized relativistic Fock space. Int. J. Theor. Phys. 6: 359-363; 1972.

[10c] Marx, E. A modified quantization of the spinor field. Nuovo Cimento. 11B: 257-275; 1972.

[11] Marx, E. Current density in relativistic quantum mechanics. Int. J. Theor. Phys. 5: 151-159; 1972.

[12] Marx, E. Gauge invariance, Lorentz covariance and the observer. Int. J. Theor. Phys. 3: 467-482; 1970.

[13] Marx, E. Quasi-stationary states of hydrogen. Int. J. Theor. Phys. 5: 251-262; 1972.

[14] Marx, E. The composite electron. Int. J. Theor. Phys. 24: 685-700; 1985.

[15] Marx, E. The two-component spinor field. Physica. 49: 469-492; 1970.

[16] Marx, E. Alternative interaction between spinor and Yang-Mills fields. Nuovo Cimento. 81A: 759-769; 1984.

[17] Perl, M. L. The tau lepton, chapter 5 in e^+e^- annihilation: new quarks and leptons. R. N. Cahn, ed. Menlo Park: Benjamin/Cummings; 1985. 295-331.

[18] Konopinski, E. J. and Mahmoud, H. M. The universal Fermi interaction. Phys. Rev. 92: 1045-1049; 1953.

[19] Hayes, K. G. Recent results on the tau lepton, in New flavors and hadron spectroscopy, vol. II. J. Tran Thanh Van, ed. Dreux: Editions Frontières; 1981. 145-154.

[20] Chinowsky, W. Psionic matter, chapter 2 in e^+e^- annihilation: new quarks and leptons. R. N. Cahn, ed. Menlo Park: Benjamin/Cummings; 1985. 63-134.

[21] Appelquist, T.; Barnett, R. M.; Lane, K. Charm and beyond, chapter 3 in e^+e^- annihilation: new quarks and leptons. R. N. Cahn, ed. Menlo Park: Benjamin/Cummings; 1985. 135-247.

[22] Sacton, J. Photographic emulsions versus bubble chambers in charm and beauty searches, in The search for charm, beauty, and truth at high energies. G. Bellini and S. C. C. Ting, eds. New York: Plenum; 1981. 169-177,

[23] D'Ali , G. et al. Heavy flavor production in hadron-hadron collision, in The search for charm, beauty, and truth at high energies. G. Bellini and S. C. C. Ting, eds. New York: Plenum; 1981. 467-500.

[24] Franzini, P. and Lee-Franzini, J. Upsilon resonances, chapter 7 in e^+e^- annihilation: new quarks and leptons. R. N. Cahn, ed. Menlo Park: Benjamin/Cummings; 1985. 389-417.

NBS-114A (REV. 2-80)

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET (See instructions)	1. PUBLICATION OR REPORT NO. NBSIR 86-3370	2. Performing Organ. Report No.	3. Publication Date APRIL 1986

4. TITLE AND SUBTITLE

The Composite Proton

5. AUTHOR(S)

Egon Marx

6. PERFORMING ORGANIZATION (If joint or other than NBS, see instructions)

NATIONAL BUREAU OF STANDARDS
DEPARTMENT OF COMMERCE
WASHINGTON, D.C. 20234

7. Contract/Grant No.

8. Type of Report & Period Covered

9. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS (Street, City, State, ZIP)

10. SUPPLEMENTARY NOTES

[ ] Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

A model is proposed in which the proton and other baryons are particles composed of only two basic particles: an archaeobaryon (archyon) and one or more pions. Mesons are composed of pions alone. A third basic particle is the neutrino, which is a component of all leptons. The interactions between the three corresponding fields and the electromagnetic field are derived from a Lagrangian density that has only two masses and three coupling constants. The interactions are expressed in terms of conserved currents, one for each particle. All particle reactions are reduced to four processes: particle scattering, antiparticle scattering, pair creation, and pair annihilation. The last two correspond to the reflection of the wave function in the time direction. There is no longer a need for a separate theory of unstable particles. The pion is the only electrically charged particle, which accounts for the equality of the magnitude of all charges of elementary particles. Strong and weak interactions of hadrons are different manifestations of a single interaction; the distinction is related to pair creation or annihilation, energy barriers, and the flux of particles and antiparticles. Charmed and beauty particles are not different from other particles in any significant way. Strangeness, which is not a basic concept in this model, is related to the reluctance of particles to decay. Charm and beauty may be included in strangeness as defined here. The strangeness of stable baryons is the number of positive pion components minus 3, and that of stable mesons is the number of different pion components minus 1. Composite particles are bound states with a large binding energy, larger than twice the mass of the lighter component. This allows for spontaneous pair creation which makes the heavy component decay into the composite particle. Resonances can be long-lived in spite of large negative binding energies. Particle reactions are rearrangements of the basic components, much like those of chemistry, with the added possibility of pair creation and annihilation. Future calculations are to provide the masses and lifetimes of all particles and resonances, plus other information such as branching ratios, in terms of the five parameters in the Lagrangian density.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

beauty; bound states; charm; composite particles; electromagnetic interactions; elementary particles; hadrons; leptons; relativistic quantum mechanics; resonances; strangeness; strong interactions; weak interactions

13. AVAILABILITY

[X] Unlimited

[ ] For Official Distribution. Do Not Release to NTIS

[ ] Order From Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

[X] Order From National Technical Information Service (NTIS), Springfield, VA. 22161

14. NO. OF PRINTED PAGES

90

15. Price

$11.95

USCOMM-DC 6043-P80