where $\lambda' = M_{\tau'}(s_0, s_0, s_0)$. It is well known that the $|\Delta \vec{I}| \leq \frac{3}{2}$ rule[2,6,8] gives $\lambda' = \lambda/2$. It can be shown that

$$g_{K^{+*}} = -g_{K^{0*}}/\sqrt{2},$$

and, if we assume the $|\Delta \vec{I}| = \frac{1}{2}$ rule,

$$f_{K^{+*}} = \sqrt{2} f_{K^{0*}},$$

so that

$$M_{\tau'} = \frac{1}{2}\lambda \left[1 - 2 \frac{g_{K^{0*}} f_{K^{0*}}}{\lambda} \left(\frac{2m_K Q}{m_{K^*}^2} \right) y \right]. \qquad (8)$$

Note that the factors multiplying y in Eqs. (7) and (8) are in the ratio 1:-2 which is the same result as obtained by Weinberg[6] on the basis of the $|\Delta \vec{I}| = \frac{1}{2}$ rule. Now taking as before $g_{K^{0*}} f_{K^{0*}} \approx \lambda$, Eq. (8) becomes

$$M_{\tau'} = \frac{1}{2}\lambda [1 - 2\tfrac{1}{10} y], \qquad (9)$$

which is consistent with the experiment.[6,7]

Note that for $\tau^{+'}$ decay another diagram, which is obtained from Fig. 1 by replacing $k_1(\pi^0)$ with $k_3(\pi^+)$, is also possible. But it is easy to see that on symmetrization between k_1 and k_2 this gives zero.

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VECTOR MESONS AND POSSIBLE VIOLATIONS OF CHARGE SYMMETRY IN STRONG INTERACTIONS

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The two vector bosons, $\rho \to 2\pi$ [1] and $\omega \to 3\pi$,[2] needed to understand the main features of the electromagnetic form factors of the nucleon, have been recently observed in several experiments, the masses of the ρ and ω being very close but the observed width of the ρ being much larger than that of ω.

A very important result has recently been obtained by the Berkeley group[3] which found that the wide ρ^0 resonance is split into two levels ρ_1^0, ρ_2^0 whose experimental widths are of the same order of magnitude as that of ω^0. The first tentative attribution of quantum numbers identifies the vector boson with the higher level ρ_2^0.

So the present very preliminary values of the masses of ρ^0 and ω^0 are the following:

$$m_{\omega^0} = 787 \pm 10 \text{ Mev}, \quad m_{\rho^0} = 775 \pm 10 \text{ Mev}.$$

The observed widths, ~10 Mev, coincide with the experimental resolution.

The equality, within experimental errors, of m_{ρ^0} and m_{ω^0} is quite intriguing since both particles have the same quantum numbers except

isospin (the 2π decay mode requires $T=1$ and the 3π, $T=0$), and both widths are smaller than 10 Mev and might well turn out to coincide.

Another important regularity appears if one considers the role of ρ^0 and ω^0 in the explanation of the main features of the electromagnetic form factors of the nucleon.[4] The equality of the masses together with the observed vanishing charge radius of the neutron imply that the residues of the ρ^0 and ω^0 poles in the charge form factors are nearly equal.

It seems unlikely that, if confirmed by future experiments, these amazing coincidences should be due to pure chance.

A first way of dealing with this situation is to assume the existence of some new kind of symmetry law, which must be satisfied very accurately by strong interactions leading to the near equality of the masses in the supermultiplet $\rho\,\omega^0$. This interpretation is somewhat artificial since we do not have in elementary particle physics other supermultiplets with such a small mass difference. For the supermultiplet $\Lambda\Sigma$, for example, the mass difference is about 70 Mev.

Another possibility is that ω^0 and ρ^0 are two decay modes of the same particle (which we shall denote by Γ), which, like the photon, does not have a well-defined isotopic spin.

In this Letter we wish to discuss the theoretical implications and experimental consequences of the existence of a neutral vector meson of mass of 780 Mev which can decay both into two pions and three pions.[5]

First of all, we have to consider whether the violation of charge symmetry (C.S.) in strong interactions, caused by the existence of the Γ meson, is in contradiction with the present experimental evidence for C.S. At first sight one would say that, since the width of Γ is certainly less than 10 Mev and probably even smaller, the coupling of Γ to the other strongly interacting particles is of the order of magnitude of the electromagnetic coupling and so the C.S. violation due to the presence of Γ will be rather small and compatible with experiment. This interpretation is, however, incorrect since we know that Γ's are produced in about 50% of the $p\bar{p}$ annihilation events.

So the question of the size of the C.S. violation induced by the Γ depends in our theory upon the role played by Γ in the different reactions and in particular on the manner in which its long lifetime can be reconciled with the large production rate.

A simple physical model is the following. The Γ is strongly coupled to nucleons but, due to its large mass, its density will be large only in the inner part $[\sim 1/(5.6\,m_\pi)]$ of the nucleon cloud. So the probability of producing a Γ will be quite large in those phenomena, like $p\bar{p}$ annihilation, in which the nucleon cores are essentially involved.

On the other hand, the 2π and 3π decay processes have to pass through a nucleon-antinucleon virtual state. This means that the interaction region has a very small radius $\sim 1/2M$. The small decay rates of the Γ might be therefore due to the strong effect of the centrifugal barrier since the pions are produced in p waves.[6]

Coming back to the question of charge symmetry, we observe that the only existing experimental tests of C.S. come from nuclear physics and low-energy pion physics at energies in which no real Γ can be produced so that the C.S. violation will only come from exchange of virtual Γ's. This effect can enter in two different manners: first in renormalizing the fundamental pion-nucleon vertex, secondly in the direct Γ exchange, for example, in nuclear forces.

Now the first effect is small due to the weak effective coupling ($\Gamma\pi$); the second is unimportant at low energy, because of the short range of the contribution of nuclear forces from Γ exchange (1.5 times shorter than the range of the repulsive core). We think therefore that the large Γ mass together with its weak coupling to pions will probably make the C.S. violations small enough not to contradict the existing experiments.

We now come to the question of possible experimental checks of the validity of the proposed scheme. The most direct test has been suggested to me by J. Prentki. In the hypothesis of the unique Γ particle the ratio of the number of ρ^0 to that of ω^0 produced in any reaction will not depend on the kind of reaction, but only on the branching ratio $(\Gamma \to 2\pi)/(\Gamma \to 3\pi)$. For example, one can verify that the ratio of ρ^0 to ω^0 produced in $p\bar{p}$ annihilation is then the same as the ratio in pion-nucleon collisions.[7]

The violations of C.S. due to the existence of the Γ meson will occur mostly in those reactions in which the important effects come from the inner part of the nucleon cloud. So one expects important deviations from C.S. in nucleon-antinucleon annihilation and in pion-nucleon and nucleon-nucleon elastic scattering at large energy ($\sim$ Bev) and large angles. A possible experiment is to

verify deviations of the branching ratio,

$$p + p \nearrow He^3 + \pi^0$$
$$\searrow H^3 + \pi^+,$$

from the value $\frac{1}{2}$ predicted by charge independence.

The existence of the Γ meson leads to an explanation of the main features of the nucleon form factors by means of a unique particle. The absence of any charge structure of the neutron at small momentum transfers can be now interpreted by saying that the coupling of the Γ to the nucleon is of the form $(1 + \tau_3)/2$. The similarity of the Γ to the photon is now very striking: Both particles have the same quantum number and violate charge symmetry in the same manner.

It is amusing to note the analogy existing between our problem and the θ-τ puzzle. In the latter case one had two particles with equal masses and lifetimes having all the same quantum numbers except parity, the first decaying into two pions, the second into three. Also in that case two explanations were proposed: (1) a new kind of symmetry between couples of particles of opposite parity; the so-called "parity doublets." (2) θ and τ are two decay modes of the same particle which decays violating the conservation of parity. Nature has chosen the second possibility. One can also note the interesting analogy between the $(1 + \gamma_5)$ appearing in parity-nonconserving interactions and the $(1 + \tau_3)$ appearing in the interactions violating charge symmetry: In both cases there is maximum violation of the symmetry law.

When the first results on nucleon structure were showing a large charge structure for the proton and none for the neutron, the first reaction of many physicists was to consider these experiments as an indication for a violation of charge symmetry. Maybe this naive point of view will finally turn out to be the correct one.

The author has benefited by very useful criticism from many people in the CERN Theoretical

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[5]The matrix element for Γ decaying into three pions is of the form

$$\sum_{\alpha\beta\gamma} \epsilon_{\mu\alpha\beta\gamma} k_\alpha^{(1)} k_\beta^{(2)} k_\gamma^{(3)} F(k^{(1)}k^{(2)}, k^{(1)}k^{(3)}).$$

So the three final pions must be either in a p or in a higher l state. In the first case the final-state wave function is antisymmetric in the exchange of any pair of pions, which (because of Bose statistics) must all have different charge. From this we can see that the charged partner of Γ (which must go into either $\pi^+\pi^+\pi^-$ or $\pi^+\pi^0\pi^0$) can only decay into three pions in d wave and so the centrifugal barrier will make this decay rate very small.

[6]See matrix element in reference 5.

[7]In the case of $N\bar{N}$ annihilation, one has to measure the ratio of the number of ρ^0 produced in $N + \bar{N} \rightarrow (n + 2)$ pions to the number of ω^0 produced in $N + \bar{N} \rightarrow (n + 3)$ pions since they both correspond to the process $N + \bar{N} \rightarrow \Gamma + n$ pions.