sample of Brazilian muscovite. Some micas contain over ten times as much Fe and may be correspondingly more sensitive.

The high spatial resolution of the electron microscope may make this method of track detection useful both for the study of short-time decay events and for studies of recoil nuclei in typical scattering experiments. The emission of a single nucleon of 10 Mev would sometimes give an observable kink in the track of a spallation recoil of mass 40. A kink occurring within 100 Å of the origin would be detectable and would correspond to a decay time of $10^{-15}$ sec. This is a long time for most nuclear processes but is shorter than has heretofore been possible to measure directly. The main advantage in scattering experiments would probably be the ability to measure angular distributions for near head-on collisions. The electron microscope detection of tracks will obviously become more useful when the sensitivity is increased to include lighter mass particles.

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# ELECTROMAGNETIC TRANSITIONS BETWEEN VECTOR MESONS

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It has been remarked[1,2] that, owing to the closeness of the isoscalar 3-pion resonance,[3] $\omega$, and the neutral isovector 2-pion resonance,[4] $\rho^0$, and their comparatively narrow widths, electromagnetic transitions between them might be important and lead to amplified violations of charge symmetry.

There is now evidence[5] that the $\rho$ resonance can be resolved into two peaks, and that the higher of these, $\rho_2$, may be very close to the $\omega$ resonance indeed and have as small a half-width, probably less than 10 Mev. It is therefore possible that the $\rho_2{}^0$-$\omega$ transition effect might be very marked. It is the purpose of this Letter to provide a few more details than have been published by Glashow,[1] since they are now more likely to be relevant.

We shall assume that, in the vicinity of one of the resonances, the strong Hamiltonian is sufficiently described by the spectrum of states with the quantum numbers in question; and that this spectrum is well characterized by just the mass and width of the resonance. We then introduce electromagnetic interactions, and these will be significant if the transition amplitude between the isoscalar and isovector resonances is comparable with their separation and widths.

The amplitude, $\alpha$, for electromagnetic $\rho_2{}^0$-$\omega$ transitions is presumably of the same order as electromagnetic mass differences, say 1 to 10 Mev. An estimate[2] of the contribution to $\alpha$ from the virtual process $\omega \to \gamma \to \rho_2{}^0$ gave a value of 2 or 3 Mev.[6]

Let $M_{S,V}$ and $\frac{1}{2}\Gamma_{S,V}$ be the mass and half-width of the isoscalar and isovector ($\rho_2$) states in the absence of electromagnetism. The states with a simple exponential time dependence, $\psi_1$ and $\psi_2$, come from diagonalizing the matrix

$$\begin{pmatrix} M_S-\frac{1}{2}i\Gamma_S & \alpha \\ \alpha & M_V-\frac{1}{2}i\Gamma_V \end{pmatrix}. \tag{1}$$

If we write $M_{S,V} - \frac{1}{2}i\Gamma_{S,V} = M - \frac{1}{2}i\Gamma \pm (m - i\gamma)$, then the eigenvalues of matrix (1) have the form $M - \frac{1}{2}i\Gamma \pm (m' - i\gamma')$. In terms of a complex number $\theta$ defined by $m - i\gamma = \alpha \sinh\theta$, one finds $m' - i\gamma' = \alpha\cosh\theta$. It follows that $|m'| \geq |m|$ and $|\gamma'| \leq |\gamma|$. In view of these inequalities the smallness of the observed separation, $2m'$, is all the more remarkable.

The states $\psi_1$ and $\psi_2$ are given in terms of the eigenstates of isotopic spin by

$$\psi_1 = p\psi_S + q\psi_V,$$
$$\psi_2 = q\psi_S - p\psi_V, \qquad (2)$$

where $p$ and $q$ are normalized to $|p|^2 + |q|^2 = 1$, and $p/q = e^\theta$. The inverse equations to (2) are

$$\psi_S = (p^2+q^2)^{-1}(p\psi_1 + q\psi_2),$$
$$\psi_V = (p^2+q^2)^{-1}(q\psi_1 - p\psi_2). \qquad (3)$$

Suppose, for example, that 2-pion states are being observed. If an isovector state is produced, it is a coherent mixture of $[q/(p^2+q^2)]\psi_1$ and $[-p/(p^2+q^2)]\psi_2$. The amplitude for $2\pi$ decays of $\psi_1$ ($\psi_2$) is proportional to $q$ ($-p$); and so the total $2\pi$-decay amplitude contains the resonance factor,

$$R_{VV} = (p^2+q^2)^{-1}\{q^2[E - M + \tfrac{1}{2}i\Gamma + (m' - i\gamma')]^{-1} + p^2[E - M + \tfrac{1}{2}i\Gamma - (m' - i\gamma')]^{-1}\}$$
$$= (E - M_S + \tfrac{1}{2}i\Gamma_S)[(E - M + \tfrac{1}{2}i\Gamma)^2 - (m' - i\gamma')^2]^{-1}. \qquad (4)$$

Similarly, if an isoscalar state is produced, its 2-pion decay amplitude contains the factor

$$R_{SV} = \frac{pq}{p^2+q^2}\{[E - M + \tfrac{1}{2}i\Gamma + (m' - i\gamma')]^{-1} - [E - M + \tfrac{1}{2}i\Gamma - (m' - i\gamma')]^{-1}\}$$
$$= \alpha[(E - M + \tfrac{1}{2}i\Gamma)^2 - (m' - i\gamma')^2]^{-1}. \qquad (5)$$

In the total probability for all 2-pion decays these two amplitudes combine incoherently.

Unless the separation, $2m'$, is larger than the average width, $\Gamma$, the two peaks in (4) and (5) will not be separately observable. The more readily observable effect is likely to be the presence of non-charge-symmetric decays. The proportion of these will be controlled by the factor $|R_{SV}|^2$. For simplicity, let us consider this factor in the special case $\gamma' = 0$. Then

$$|R_{SV}|^2 = \alpha^2\{[(E-M)^2 - m'^2 - \tfrac{1}{4}\Gamma^2]^2 + \Gamma^2(E-M)^2\}^{-1}. \qquad (6)$$

For $m'^2 > \frac{1}{2}\Gamma^2$, (6) has two peaks at $E = M \pm m'$. For $m'^2 < \frac{1}{2}\Gamma^2$, there is a single maximum at $E = M$, where

$$|R_{SV}|^2 = \alpha^2/(m'^2 + \tfrac{1}{4}\Gamma^2).$$

A measure of the height of the charge-symmetry-violating peaks compared to an ordinary resonance is therefore $4\alpha^2\Gamma^2/(4m'^2 + \Gamma^2)$. For $\alpha = 5$ Mev, $\Gamma = 10$ Mev, $m' = 5$ Mev, this quantity is equal to $\frac{1}{4}$.

The possibility cannot be entirely excluded that the observed structure[5] of the $\rho$ resonance is due to electromagnetic effects, but this would require a very large value of $\alpha$.

The effects described above are independent of the cause of the near-degeneracy of the $\omega$ and $\rho_2$ resonances, provided they are really two different states. But if Fubini's[7] idea—that they are manifestations of one particle with strong interactions which violate charge symmetry—were the true one, the present theory would be inapplicable.

It is amusing to note that the charge-symmetry violations which Fubini predicts must necessarily be present if $m'$ is really very small or zero, independently of the cause. If there are two vector-meson states, however, the charge-symmetry violation parameter is $4\alpha^2/\Gamma^2$ even if $m' = 0$, whereas in Fubini's theory it is presumably 1.

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