Violation of Parity Conservation and General Relativity

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TABLE I. Theoretical values of asymmetry parameter α and back/front ratio B/F for given values of ρ, ξ, and η.

ρ	η	ξ	$\|A\|$	α	B/F
0.667	−1	+1	0.889	−0.405	0.98
0.667	0	+1	0.889	−0.296	0.86
0.600	0	+1	0.800	−0.266	0.90
0.667	−0.75	+0.75	0.889	−0.301	0.99
0.640	−0.75	+0.75	0.853	−0.323	1.04

We use absolute value signs to emphasize that $|A|$ and $|B|$ must be real and positive.

For completely polarized μ mesons, the μ mesons decaying at rest, one obtains

$$dN_1=2x^2[(3-2x)+\xi\cos\theta(1-2x)]dxd\Omega/4\pi,$$
$$dN_2=12x^2(1-x)(1+\eta\cos\theta)dxd\Omega/4\pi,$$

where

$$\xi=(f_A{}^*f_V+f_V{}^*f_A)/[|f_A|^2+|f_V|^2],$$
$$\eta=(g_Sg_P{}^*+g_S{}^*g_P)/[|g_S|^2+|g_P|^2], \quad (5)$$

x = electron momentum/maximum electron momentum, and θ = angle between electron momentum and spin direction of the μ.

These expressions for dN_1 and dN_2 have been given by the authors of reference 1. (dN_2 is the same regardless of whether or not we say the number of light fermions are conserved.)

We now note that the value of ρ is $\frac{3}{4}|A|$, where $|A|$ is a function of the coupling constants and so may be chosen to fit the experiment.

In Table I some examples are given. Here, α refers to the asymmetry parameter in the Lederman experiment.[2]

$$\int_0^1 dN=(1+\alpha\cos\theta)d\Omega/4\pi. \quad (6)$$

B/F is the integrated asymmetry from 0 to 10 Mev, as previously discussed.

The last two cases are of particular interest since they would yield the same results for α and B/F, if ξ and η were actually +1 and −1, respectively, but the μ mesons were only 75% polarized.

Lederman has found that $\alpha=-0.305\pm0.033$ in carbon. The Lee and Yang results were $\alpha=-0.333$ for $\xi=+1$.

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[3] I. A. Pless *et al.* (to be published).

[4] This type of term has been discussed previously. See, for example, E. J. Konopinski and H. M. Mahmoud, Phys. Rev. **92**, 1045 (1953).

Violation of Parity Conservation and General Relativity

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THE significant experimental results recently obtained by Wu, Ambler, Hayward, Hoppes, and Hudson,[1] Garwin, Lederman, and Weinrich,[2] and Friedman and Telegdi[3] prove the violation of parity conservation in weak interactions. These experiments were suggested by Lee and Yang.[4] According to these authors, the observed right-left asymmetry can be attributed either to a cosmological distinction between right and left, or to an accidental local preponderance of right-handed nucleons over the left-handed ones (which must amount to nearly 100% in order to avoid contradiction with the Pauli exclusion principle).

We wish to point out the rather trivial fact that *a cosmological asymmetry is perfectly compatible with Riemannian space-time of ordinary general relativity.* Indeed, a "field" $\epsilon_{[\alpha\beta\gamma\delta]}(x)$ (totally antisymmetric tensor in four-dimensional space) can be introduced, whose covariant derivative vanishes everywhere:

$$\nabla_\rho\epsilon_{[\alpha\beta\gamma\delta]}=0.$$

The parity-violating part of the energy-momentum tensor $\theta_{\alpha\beta}$ may then be written as a true tensor,

$$(1/4!)(\epsilon_{[\mu\nu\lambda\rho]}\gamma^\mu\gamma^\nu\gamma^\lambda\gamma^\rho)\theta'_{\alpha\beta}.$$

Riemannian space-time, characterized by the symmetry of the metric tensor $g_{(\alpha\beta)}$ and of the affine connection $\Gamma^\rho{}_{(\alpha\beta)}$, follows from the postulate that the covariant derivative of $g_{(\alpha\beta)}$ vanishes:

$$\nabla_\rho g_{(\alpha\beta)}=0.$$

This has as consequence

$$\Gamma^\nu{}_{(\rho\nu)}=\partial_\rho(-g)^{\frac{1}{2}}/(-g)^{\frac{1}{2}},$$

g being the determinant of $g_{(\alpha\beta)}$, and

$$\nabla_\rho\epsilon_{[\alpha\beta\gamma\delta]}=(-g)^{\frac{1}{2}}\partial_\rho[\epsilon_{[\alpha\beta\gamma\delta]}(-g)^{-\frac{1}{2}}]=0.$$

As $g\neq0$ everywhere, $\epsilon_{[\alpha\beta\gamma\delta]}$ takes the *same value* at every event in space-time, in a local geodesic, right-handed and orthochronous (or left-handed and pseudochronous) Lorentz frame. Thus the mean lifetimes of particles are time standards for atomic clocks, independent of whether such weak interactions are involved or not.

At our present state of knowledge, the existence of this "field" seems quite natural, because the number of dimensions $g^\alpha{}_\alpha=4$, the signature of the metric (1, 1, 1, −1) [or (−1, 1, 1, 1)], the rest masses m_ν, m_e, m_μ, $\cdots$ of the elementary particles, and the coupling constants g_P, e, C_S, C_V, $\cdots$ are universal constants, e.g., constant scalar "fields" ($\nabla_\rho C_S=\partial_\rho C_S=0$, $\cdots$) whose numerical value is given by the experiment. As pseudoscaler constant "fields" ($\nabla_\rho C_S{}'_{[\alpha\beta\gamma\delta]}=0$, $\cdots$) may equally well be introduced in Riemannian space-time, the suprising fact is that these $C_{S}'_{[\alpha\beta\gamma\delta]}, \cdots$ [universal constants in every local geodesic right-handed and orthochronous (or left-handed pseudochronous) Lorentz frame] appear only in the weak interactions.

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Energy Levels of Pb^{206}

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A DETAILED calculation has been made of the excited energy levels of the nucleus Pb^{206}, treating it as a system of two neutron holes moving in the presence of the double closed-shell core Pb^{208}. The possible states and energies of the individual holes are taken to be $p_{1/2}$, $f_{5/2}$, $p_{3/2}$, $i_{13/2}$, and $f_{7/2}$ at 0, 0.569, 0.894, 1.633, and 2.338 Mev, respectively[1,2] from the experimental data on Pb^{207}.

The neutron hole states couple to form states of given angular momenta (J). To first order the energies corresponding to these states of given J will be the sum of the single hole energies plus the energy of interaction between the holes, $E_{nn}(J)$.

The $E_{nn}(J)$ are calculated by using harmonic oscillator wave functions.

$$\Phi_{nlm}(r,\theta,\phi)=\frac{R_{nl}(r)}{r}Y_l^m(\theta,\phi)$$
$$=N_{nl}\exp[(-\tfrac{1}{2}\nu r^2)]r^l L_{n+l+\frac{1}{2}}{}^{l+\frac{1}{2}}(\nu r^2)Y_l^m(\theta,\phi),$$

where ν is determined by associating the nuclear radius of Pb^{206} with the point at which the probability density $[R_{nl}(r)/r]^2$ falls to a quarter of its maximum value.

The effective hole-hole interaction is taken to be a central-force mixture of the form

$$V(r_{12})=V_c\boldsymbol{\tau}_1\cdot\boldsymbol{\tau}_2(0.1+0.23\boldsymbol{\sigma}_1\cdot\boldsymbol{\sigma}_2)\frac{\exp\{-r_{12}/a\}}{(r_{12}/a)},$$

where $\boldsymbol{\tau}_1$=isotopic spin vector for nucleon 1 and $\boldsymbol{\sigma}_1$=spin vector for nucleon 1, with the range $a=1.37\times10^{-13}$ cm corresponding to a meson mass of 276 m_e.

V_c is regarded as a variable parameter. Configuration interaction between all states of the same J is allowed. The energy matrices for $J=0$ to 7 are calculated for V_c varying from 0 to 100 Mev in steps of 10 Mev and the eigenvalues and corresponding eigenvectors computed.

For $V_c=70$ Mev, there is very good agreement between theory and experiment,[3] all of the lowest seven excited states being predicted within 0.1 Mev of the experimental values, with the correct spins and parities.

Spin J	0+	2+	3+	4+	4+	7−	6−	5−
Exptl. energies (kev)	0	803	1341	1684	1998	2200	2385	2783
Theoret. energies (kev)	0	868	1312	1692	1937	2189	2373	2875

Configuration interaction is important especially for the 0+ and 2+ states (depressed by 0.66 and 0.36 Mev, respectively) and the eigenfunctions for these states show large admixtures of the higher energy configurations.

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