Direct experimental tests of the Lüders theorem are difficult because the two processes directly related by the theorem are time inverses of each other, and the time inverse of a weak (decay) process is not easily performed. If, however, the weak interaction is effective only in first order, the need for observing the time-inverse process may be circumvented by an appeal to the principle of detailed balance.[3] The Lüders theorem in conjunction with the principle of detailed balance allows one to equate the transition rate for the process $\alpha\rightarrow\beta$ to the transition rate for $\tilde{\alpha}\rightarrow\tilde{\beta}$, where α and β represent eigenstates of the strong-interaction Hamiltonian and $\tilde{\alpha}$ and $\tilde{\beta}$ represent the corresponding *CPT*-inverse states. If the final states may be chosen as plane-wave states (i.e., if these are eigenstates of the strong reactions) then the *CPT*-inverse of a state is a state with the same momentum but with opposite spin and charge (more precisely a particle is changed to its antiparticle and its spin is reversed). A number of consequences of the Lüders theorem may be deduced immediately. One of these is the equality of the reaction rates of the processes $\pi^+\rightarrow\mu^++\nu$ and $\pi^-\rightarrow\mu^-+\bar{\nu}$. Similarly the reaction rates of the two processes $\mu^\pm\rightarrow e^\pm+\nu+\bar{\nu}$ must be equal. These results have been obtained somewhat less directly by Lee, Oehme, and Yang.[4] Additional consequences are easily obtained. In particular the polarizations (spin expectation values) of the μ^+ and μ^- produced in the decay at rest of π^+ and π^- must be equal but opposite if the Lüders theorem is valid. This result may be distinguished from the consequences of invariance under charge conjugation. If this latter invariance is maintained, one again finds the equality of the reaction rates for the two charge states, but the polarizations of the μ^+ and μ^- must now be equal both in magnitude and in direction. A measurement of the relative polarizations of the μ^+ and μ^- produced from the decay of π^+ and π^- would therefore permit a decision as to whether it is invariance under *C* or under *CPT* that is preserved in the weak interactions[5] or whether both are violated.

Similar conclusions may be obtained from the measurement of the angular distributions and polarizations of the $e^\pm$ produced from the decay of polarized $\mu^\pm$. If the spins of the μ^+ and μ^- are oppositely aligned and *CPT* invariance is maintained, then the angular distributions of the e^+ and e^- will be the same but their polarizations will be opposite. On the other hand, if charge-conjugation invariance is maintained and if the spins of the μ^+ and μ^- are aligned (as they would be if charge-conjugation invariance were maintained in the production of the μ^+ and μ^- in $\pi^\pm$ decay), then the angular distribution of the e^+ and e^- would again be identical, but their polarizations would now be the same in both direction and magnitude.

The decay of long-lived neutral *K* particles (assumed unpolarized or of spin zero) can be analyzed in a similar way. If charge-conjugation invariance were maintained, the long-lived K^0 would be an eigenstate of charge conjugation and would be its own charge-conjugate state. This would imply the equality of the reaction rates into any two final states that are charge conjugates of each other. (It is assumed that the short-lived component has decayed and therefore gives no interference effects.) The polarization of the μ^+ and μ^- obtained from the decay of the long-lived neutral *K* will therefore be the same in both sign and magnitude if charge conjugation is maintained. If, on the other hand, the reaction is invariant under the product of charge conjugation and space inversion (i.e., under *CP*), as has been frequently suggested, then the components of polarizations of the μ^+ and μ^- that lie in the plane of production must be equal but opposite; the components of polarization perpendicular to the production plane must be equal both in sign and in magnitude. If in addition to *CP* invariance there is also invariance under *CPT*, then time-reversal invariance is required and, to the extent that final-state interactions are negligible, the components of polarization perpendicular to the plane of decay must vanish.

Invariance under *CPT*, together with the assumption that the short lifetime of the neutral K^0 is very small in comparison with the long lifetime, allows one to consider the long-lived K^0 particle to be its own *CPT* inverse.[4] The transition rates into any two final states that are *CPT* inverses of each other will then be equal and the polarizations of final μ^+ and μ^- must consequently be equal but opposite.

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[1] L. D. Landau, in *Niels Bohr and the Development of Physics*, edited by W. Pauli (McGraw-Hill Book Company, Inc., New York, 1955), p. 52.

[2] The role of the space-time point in current theories is that of an elementary unanalyzable parameter which provides the framework in which the theory is set. This may be distinguished from alternative treatments in which, for instance, space-time separations emerge as well-defined quantities only in a limiting case, much as the notions of simultaneity in time and simultaneous position and momentum become valid only in the classical limit of the relativistic quantum theory.

[3] J. Blatt and V. Weisskopf, *Theoretical Nuclear Physics* (John Wiley and Sons, Inc., New York, 1952).

[4] Lee, Oehme, and Yang, Phys. Rev. **106**, 340 (1957).

[5] It is frequently stated that the parity-nonconserving experiments have also demonstrated that charge-conjugation invariance is violated. Actually it is *P* and the product *PT* that are not conserved. Therefore either *C* or *CPT* is not conserved. It seems premature to decide in favor of *CPT* conservation, particularly since *CPT* is more intimately associated with the somewhat suspect properties of space time than is *C*.

Quadrupole Moment of O^{17}†

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THE quadrupole hyperfine structure due to the O^{17} nucleus has been measured in the $2_{20}\leftarrow 2_{21}$ rotational transition of HDO by conventional techniques of microwave spectroscopy, and the value

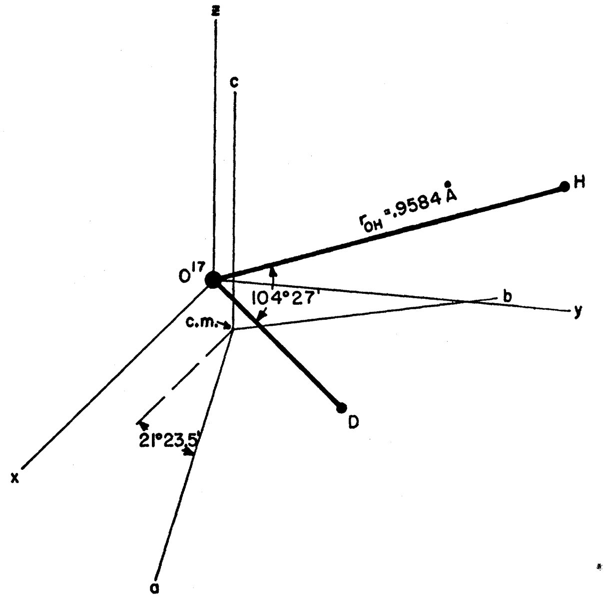

FIG. 1. Structure of the HDO molecule: a, b, c are the principal axes of inertia; y axis bisects the bond angle so that the electric fields are symmetrical about the y, z plane.

$(-0.026\pm0.009)\times10^{-24}$ cm^2 calculated for the quadrupole moment of O^{17}.

The molecule HDO^{16} has been studied extensively by Posener and Strandberg[1] and its structural parameters are well known. Figure 1 shows the structure of the molecule and the principal axes of inertia, a, b, c. Structural parameters for HDO^{17} obtained from the rigid-rotor model are sufficiently accurate for the present quadrupole energy calculations. These were made from the expressions of Bragg and Golden.[2]

In addition to the quadrupole interactions, magnetic hyperfine interactions had to be included to fit the experimental data well. In general, the magnetic interaction term in the Hamiltonian of an asymmetric rotor is

$$H_{\text{mag}}=\sum_{gg'} a_{gg'} I_g J_{g'},$$

where $a_{gg'}$ are components of a symmetric tensor. Since the entire magnetic interaction is small, and is not expected to be very different for the two rotational states involved, the simpler expression

$$H_{\text{mag}}=a\mathbf{I}\cdot\mathbf{J}$$

was taken as an adequate approximation.

Values of the three parameters needed to fit the five resolved lines are

$$eq_aQ=e(\partial^2V/\partial a^2)Q=-8.1_3\pm0.1 \text{ Mc/sec},$$

$$\eta=\left(\frac{\partial^2V}{\partial b^2}-\frac{\partial^2V}{\partial c^2}\right)\bigg/\frac{\partial^2V}{\partial a^2}=0.7\pm0.1,$$

$$a=-15\pm10 \text{ kc/sec}.$$

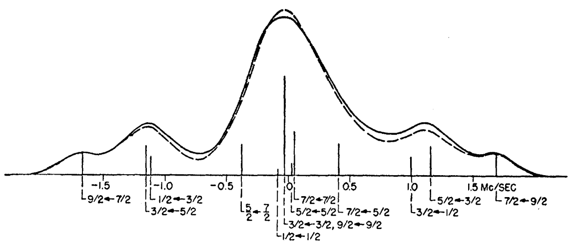

FIG. 2. Comparison of the observed line shapes (solid line) with the theoretical pattern (dashed line). The unsplit line position is 10 374.56 Mc/sec; the frequency of the strongest line is 10 374.31 Mc/sec.

The fit obtained between the experimental line shapes and the theoretical pattern is shown in Fig. 2. The unsplit line position is 10 374.56 Mc/sec.

Calculation of the quadrupole moment of O^{17} requires an evaluation of the second derivatives of the electric potential along all three principal axes. This evaluation can be made most easily in the x, y, z coordinate system in which the electric field is symmetrical about the y, z plane. If we let s be the percentage hybridization of the $2p$ oxygen orbitals and i the ionic character of the O—H bonds, the gradients of the electric field in the x, y, z coordinate system may be obtained by the usual method.[3] The resulting quantities must be transformed into the a, b, c coordinate system, which is rotated about the z axis by 21° 23.5′ relative to the x, y, z frame. The asymmetry parameter η is then a simple function of s and thus it determines one of the unknown parameters needed in evaluating eq_a. The ionic character of the O—H bonds is expected to be approximately $i=0.40$ with extreme limits of 0.25 and 0.50. Quantities which result from these considerations are tabulated in the first column of Table I.

The hydrogen nuclei will also contribute to the gradients of the electric field along all three axes because of the ionic character of the O—H bonds. This contribution is approximately 10% of the electronic field gradients. Any shielding or antishielding effects are presumably incorporated into the structure and hybridization of the O^{17} bonds, which are already allowed for. The second column of Table I gives the hybridization, eq_a, and the quadrupole moment values after this correction is made. Thus the best value for the quadrupole moment of O^{17} is $Q=(-0.026\pm0.009)\times10^{-24}$ cm^2. The error assigned to this value is almost entirely due to the uncertainty in determining the field gradients.

TABLE I. Calculated values of hybridization s, eq_a, and quadrupole of O^{17} assuming $i=0.40$, $\partial^2V/\partial z^2=-11\times10^{15}$ esu for one valence p electron with $m=0$.

	Without correction for proton gradient	With correction for proton gradient
s	0.38	0.37
eq_a	1.92×10^6 esu/cm^2	2.10×10^6 esu/cm^2
Q	$(-0.028\pm0.009)\times10^{-24}$ cm^2	$(-0.026\pm0.009)\times10^{-24}$ cm^2

The present value of Q for O^{17} is about a factor of five greater in absolute value than that of Geschwind *et al.*[4] Their value was too small because the amount of *s*-hybridization of oxygen orbitals, to which the hyperfine structure of OCS is quite sensitive, seems to be actually much greater than was expected from present molecular theory. This difficulty is also illustrated by the quadrupole coupling of O^{17} in CO.[5] Evaluation of Q from the HDO spectrum is far more reliable because hybridization of the orbitals is determined rather directly from η.

The experimental value, $Q=-0.026\times10^{-24}$ cm², is now in fair agreement with recent theoretical calculations,[6–8] which range from about -0.035 to -0.043×10^{-24} cm².

Substantially the above results have been reported earlier,[9] except that the correction for the field gradient due to the proton charge had not been included. Recently the quadrupole moment of O^{17} has also been measured at Oxford in atomic O^{17} by Kamper and Lustig,[10] who obtain a value for the quadrupole moment in good agreement with the one reported here.

The amount of hybridization given by quadrupole coupling of O^{17} indicates that the structure of bonds involving oxygen needs re-examination. Further experimental data and discussion of this situation will be reported later.

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[*] John Tyndall Fellow.

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Forward-Backward Asymmetry in K-μ-e Decay

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In recent years there have appeared a number of classifications of the fundamental particles. For pion, K-meson, nucleon, hyperon phenomena the schemes of Nakano and Nishijima,[1] Gell-Mann,[2] and Sachs,[3] which are essentially identical for these particles, have received considerable experimental support.[4] However, Sachs' scheme differs from the first two in that he has also included the light fermions in his classification. We wish to point out that, as a result of the recent experiments[5–9] relating to parity nonconservation,[10] some important consequences of Sachs' classification of the light fermions can be experimentally tested.

To see these consequences, recall that the central idea of his scheme is the assignment of an attribute quantum number designated by a to each particle. It is assumed that this number is additive when two or more particles are considered, is conserved in all "fast" reactions ($\sim10^{-22}$ sec) as well as reactions involving neutrinos (ν) or antineutrinos ($\bar{\nu}$), but is not conserved in "slow" reactions ($\sim10^{-10}$ sec) not involving ν or $\bar{\nu}$. Sachs showed that a may be chosen integral for photons, pions, K-mesons, nucleons, and hyperons. In particular, Sachs had $a=0$ for pions and photons, $a=-1$ for (K^+,K^0), and $a=+1$ for $(K^-,\bar{K}^0)$. For the light fermions, however, $|a|=\frac{1}{2}$.

For the determination of a for the individual light fermions, recent experimental information allows the use of a slightly more cogent chain of reasoning than that used by Sachs, for experiments[5,8,9] seem to indicate that

$$n\rightarrow p+e^-+\bar{\nu} \tag{1}$$

and

$$\mu^+\rightarrow e^++\nu+\bar{\nu}, \tag{2}$$

where the neutrino ν is completely polarized parallel to its momentum and the $\bar{\nu}$ antiparallel to its momentum.[11] Reactions (1) and (2), the process $\gamma\rightarrow e^++e^-$, and the fact that K particles undergo $K_{\mu2}$ decay point to attribute assignments as follows:

$$a_{\bar{\mu}}=a_{\bar{e}}=a_{\bar{\nu}}=-\tfrac{1}{2},$$

$$a_{\mu}=a_{e}=a_{\nu}=\tfrac{1}{2}.$$

Here μ^+ and e^+ are $\bar{\mu}$ and $\bar{e}$. The attribute rules then dictate that pions and K mesons decay by

$$\pi^+\rightarrow\mu^++\nu, \tag{3}$$

$$\pi^-\rightarrow\mu^-+\bar{\nu}, \tag{4}$$

$$K^+\rightarrow\mu^++\bar{\nu}, \tag{5}$$

$$K^-\rightarrow\mu^-+\nu. \tag{6}$$

From the above-mentioned polarized properties of ν and $\bar{\nu}$ and from conservation of angular momentum, a μ^+ originating from a π^+ at rest in (3) would be polarized along its momentum and a μ^- from (4) opposite to its momentum. For a spin-zero K particle decaying at rest, the μ^+ in (5) on the other hand would be polarized antiparallel to its momentum and the μ^- in (6) parallel to its momentum. Consequently, the forward-backward asymmetry of the positrons originating from the μ^+ decays in (5) should be just the