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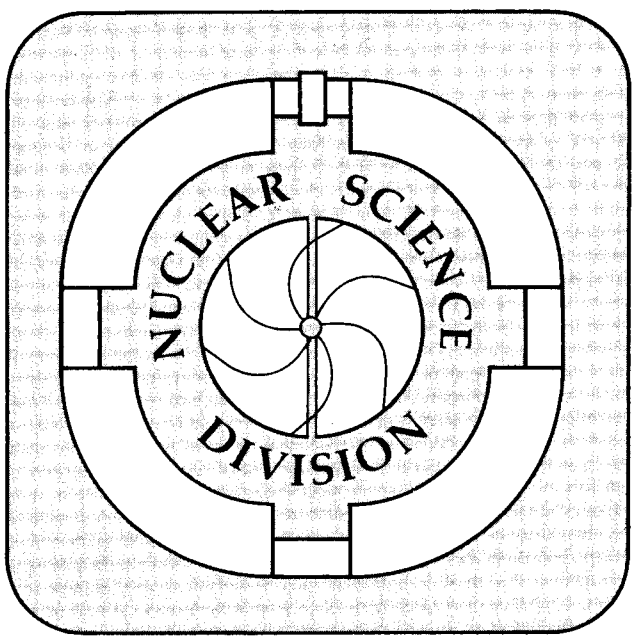

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ON NULL TESTS OF TIME-REVERSAL INVARIANCE

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On Null Tests of Time-Reversal Invariance, H. E. Conzett, Lawrence Berkeley Laboratory, University of California, Berkeley, CA 94720.

It has been proved[1] that there exists no null test of T-symmetry in nuclear and particle physics in any reaction with two particles in and two particles out. That is, there is no single experimental observable that is required, by T-symmetry, to be zero. This follows from the fact that T-symmetry equates a reaction observable to an observable in the inverse reaction so that the difference (or sum) of the two is zero. Even in elastic scattering, which is its own inverse reaction, two different observables are related by T-symmetry; e.g. polarization and analyzing power, so that $A_y - P_y = 0$. Because of this requirement to compare two experimental observables, one of which is often difficult to measure with precision (say 1%), it is easy to understand why such tests of T-symmetry have rarely attained the 1% level of experimental accuracy. In strong contrast, since null tests of parity conservation are available, e.g. $A_z = 0$ from P-symmetry, the weak interaction parity non-conserving contribution to A_z in pp scattering has been determined to the truly remarkable accuracy of 2.2×10^{-8} (ref. 2). Thus, it is clear that a comparable null test of T-symmetry would permit an improvement in experimental precision of 4 to 5 orders of magnitude.

Recent transmission experiments with slow neutrons have shown remarkable enhancements in two parity non-conserving (PNC) observables, the neutron spin rotation[3] and the neutron longitudinal analyzing power, A_z (ref. 4); and Stodolsky and Kabir have suggested that nuclear effects could also provide enhancements in time-reversal violating (TRV) neutron transmission observables which become accessible with polarized targets[5]. They have developed a formalism to describe the spin aspects of neutron transmission and have suggested some TRV observables to be measured. However, these again involve two observables and can be viewed as transmission analogues of A - P, even though they are really spin-correlation transmission experiments, which involve both projectile and target spins. Also, their treatment assumes neutron *coherent* forward scattering, and it describes the forward-scattering matrix simply in the 2×2 neutron spin-space. I have found that this is not an adequate treatment, and, in fact, their TRV amplitude must vanish in order that the requirement of helicity conservation in forward scattering be maintained[6].

Since target polarization is required in order to provide a TRV term in the forward scattering matrix, it is necessary for that matrix to encompass *both* the projectile and target spin-matrices. That is, an observable that involves only the projectile (target) polarization can be expressed in terms of the projectile(target) spin-matrix ampitudes alone, but the combined spin-space amplitudes are required for an observable that involves both projectile and target polarizations.

To investigate, then, the possibility of finding a TRV observable in transmission experiments, I have considered in detail, as prototypes, the cases with spin-1/2 projectile and spin-1/2 or spin-1 targets[6]. Choosing the projectile helicity frame, unit vectors along the coordinate axes are taken to be

$$\boldsymbol{z} = \boldsymbol{k}, \quad \boldsymbol{y} = \boldsymbol{s}, \quad \boldsymbol{x} = \boldsymbol{y} \times \boldsymbol{z}, \tag{1}$$

where **k** and **s** are the neutron momentum and the target polarization. These unit

vectors then have the same behavior under P and T transformations as do the corresponding ones in non-forward scattering with **y** taken as normal to the scattering plane. Then imposing R_z symmetry, i. e. invariance under rotation around the z-axis, which corresponds to helicity conservation, with a spin-1/2 target

$$F(o) = C_{oo} + C_{oz}\sigma_o\sigma_z + C_{zo}\sigma_z\sigma_o + C_{xx}(\sigma_x\sigma_x + \sigma_y\sigma_y) + C_{zz}\sigma_z\sigma_z + C_{xy}(\sigma_x\sigma_y - \sigma_y\sigma_x) \qquad (2)$$

is the complete R_z-invariant PNC and TRV forward-scattering matrix. Here the σ_j, with $j = o, x, y, z$, $\sigma_o = 1$, are the 2 X 2 Pauli spin-matrices, and in each term the first (second) σ_j is the projectile (target) spin operator. The C_{oz} and C_{zo} terms are PNC and the C_{xy} term is both PNC and TRV. However, the C_{xy} term is a double spin-flip amplitude which changes the target spin-state and, thus, cannot contribute to the *coherent* scattering. In this instance, then, coherent forward scattering does not provide a TRV observable.

However, and more importantly, the term C_{xy} in the forward scattering matrix suggests that a corresponding PNC, TRV observable is available in the more ordinary and widespread possibilities for *incoherent* transmission experiments in nuclear and particle physics at all energies. The appropriate treatment then features transmitted *intensities* rather than amplitudes; and the spin-dependent observables, the total cross-sections, are then related to the forward-scattering amplitudes by the optical theorem. The very clear and simple result is that

$$\Delta T_{xy} = -Im\, C_{xy}, \quad \text{with } C_{xy} << 1, \qquad (3)$$

where ΔT_{xy} is the *transmission asymmetry* of the x-polarized beam for opposite states of the target y-polarization, and *vice versa.*

Target spin > 1/2 is required in order to have a uniquely TRV (parity conserving) forward amplitude, because tensor polarization (alignment) is the necessary additional condition. With a spin-1 target , then, the obviously comparable result is that

$$\Delta T_{x,yz} = Im\, C_{x,yz}, \quad with\ C_{x,yz} << 1. \qquad (4)$$

As the notation indicates, this corresponds to projectile polarization p_x in combination with the target tensor polarization P_{yz}, i.e. alignment along the direction y = z. These, then, are true null tests of T-symmetry, and their exploitation throughout nuclear and particle physics should provide the indicated several orders of magnitude improvement in the level to which T-symmetry has been tested.

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