alone, the distribution of this separation has a spread of ± 0.20 μsec and a standard deviation of 0.06 μsec.

With the lead on one timing tray 200 showers have been observed, and with it on the other tray 229 showers were observed. In each case a time lag of about 2×10^{-8} sec was found to be associated with the shielded tray, the mean lag for the 429 showers being $2.1\pm 0.3_6\times 10^{-8}$ sec. As a check, 86 showers were observed with the lead on the intermediate tray. The timing trays should then be fired simultaneously, on the average, and in fact the observed lag of $0.7_4\pm 0.6_6\times 10^{-8}$ sec is not significantly different from zero. The origin of the time scale was found by feeding the same Geiger pulses into both channels, 47 observations resulting in a distribution with a standard deviation of 0.16×10^{-8} sec. Halfway through each run the counters in the timing trays were interchanged to cancel the effect of unequal average reaction times.

A further check on the performance of the apparatus had been provided by an earlier experiment designed to detect the time of flight of cosmic-ray particles able to penetrate 10 cm of lead. Over a path of 5.45 m the mean time of flight for 288 particles was $1.9\pm 0.5\times 10^{-8}$ sec, which is not significantly different from the 1.8×10^{-8} sec required at the velocity of light.

Because of a counter reaction time effect it is not necessary to assume that the soft and penetrating shower components arrive at different times. The shower rate of 1.5_4 per hour can be explained if 11 percent of the shower radiation penetrates 10 cm of lead. This means that the shielded tray is usually traversed by only one particle, whereas the unshielded tray is frequently hit by several particles and supplies a pulse having the shortest of the corresponding reaction times. This results in a time lag associated with the shielded tray.

Calculation of this effect[2] has been carried far enough to take into account 75 percent of the showers, and gives a time lag of $2.0_9\times 10^{-8}$ sec, in agreement with the observed value. The agreement is rendered uncertain by the presence of two compensating effects. Overlapping the counters reduced their effective diameter and therefore reaction times, but scattering and firing by photons reduced the effectiveness of overlapping. It therefore seems reasonable to conclude only that the majority of the shower particles probably arrive at the apparatus within a time $<10^{-8}$ sec. This is consistent with the theoretical expectation of 10^{-9} sec as an approximate upper limit to this time interval, and, with the thickness of lead so far used, does not necessarily conflict with the results of Mezzetti *et al.* They found many lags of 0.2 μsec and some as high as 0.8 μsec for the 1 to 2 percent of shower particles that penetrate 22.5 cm of lead. These are included in the 11 percent penetrating 10 cm of lead in the present experiment, but the few long lags thus introduced would not affect the mean lag appreciably.

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[2] Details of the electronics and the interpretation of results will appear in Aust. J. Sci. Research **4**, No. 4 (1951).

The Relative Phase of the Interaction Constants for Mixed Invariants in Beta-Decay*

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THE most general formulation of the (point) β-interaction involves an arbitrary mixture of the five invariants S, V, T, A, P formed by contracting bilinear covariants of the lepton and nuclear fields.[1] It is customary to assume real mixing (interaction) constants;[2] and, since complex constants can have an effect on the predicted results of the theory, the question arises as to whether the usual assumption of real constants is an unwarranted restriction. We have examined this question and conclude that the relative phases of the mixing constants must be zero (or π) and that the assumption of real constants is in fact no restriction on the theory.

For simplicity let us consider a mixture of scalar and vector interactions. The part of the total (hermitian) interaction energy corresponding to β^- emission then has the form,

$$H_\beta \sim (\Psi^+\Phi)(\psi^+\varphi)+(C_2/C_1)(\Psi^+\gamma^\mu\Phi)(\psi^+\gamma_\mu\varphi). \tag{1}$$

Writing the constant $C_2/C_1=A+iB$ we then consider the interaction (1) as a sum of three terms. Now by construction Eq. (1) is invariant to all continuous Lorentz transformations and, in addition, to space inversion. On the same footing as space-inversion invariance, time-inversion invariance of the physical predictions of the theory should also be required. The significant feature of time reversal is that it involves complex conjugation[3] and is, therefore, sensitive to the phase of the operators in Eq. (1). Using the correct time reversal operator,[4] we find that H_β' (the time-reversed H_β) is

$$H_\beta' \sim [(\Psi^+\Phi)(\psi^+\varphi)]^*+A[(\Psi^+\gamma^\mu\Phi)(\psi^+\gamma_\mu\varphi)]^* - B[(\Psi^+ i\gamma^\mu\Phi)(\psi^+\gamma_\mu\varphi)]^*. \tag{2}$$

Since we require that $H_\beta H_\beta^*$ be invariant under time-inversion (or equivalently $|\int H_\beta d\tau|^2$), we conclude that $B\equiv 0$ unless all cross terms sensitive to the reversal in sign vanish. These are terms $\sim B$; terms $\sim AB$ vanish identically. The cross terms ($\sim B$) do indeed vanish if we average over all spins, but they do not if we measure the spins of the particles involved. Since such an experiment is in principle meaningful, our conclusion on the relative phase of the interaction constants follows. The generalization to mixtures of all invariants is straightforward.

This result can be made somewhat more transparent by noting that the imaginary unit i is not a scalar under time reversal, and should be regarded strictly as an operator.[4] The covariants obtained with operators involving i, in order for physical results to be invariant under the extended group, must therefore be contracted into operators with similar tensor properties. The relative phase of the contracted covariants is then fixed.

The Tolhoek-de Groot symmetry principle[2] is dependent upon the phase of the mixing constants,[5] and the result that the (VT) and (SAP) invariants cannot mix may be relaxed for complex interaction constants. Our result shows that the Tolhoek-de Groot result on the nonmixing of (VT) and (SAP) is unique.

* This paper is based on work performed for the AEC at the Oak Ridge National Laboratory.

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The Absorption of Cosmic Radiation at High Altitudes*

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IT has been pointed out previously[1] that small thicknesses of interposed absorber (1 cm of Pb—7.5 cm of Pb) do not effectively absorb primary cosmic-ray particles entering in the vertical direction at geomagnetic latitude 52°N, whereas absorption commences between 7.5 cm and 18 cm of Pb. It must be recalled that absorption is defined here as the reduction below unity of the probability that each primary, or at least one of its progeny created within the apparatus, always has sufficient residual range and is propagated in the proper direction to actuate the coincidence train.

The convergence near the "top of the atmosphere" of the intensity *vs* altitude curves obtained with different small thicknesses of interposed absorber has been confirmed[2] by numerous experiments performed since the initial series of balloon flights. It was originally possible to compare the results for 7.5 cm of Pb with