
Neutrino oscillations reveal Dirac's form of interaction

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Abstract – We consider neutrino oscillations in both instant and point forms of Dirac's dynamics. Interacting generators of symmetry transformations are constructed explicitly and shown to satisfy Poincaré commutators exactly. Thus, our solutions for flavor probabilities conform to all requirements of relativistic invariance. Instant form calculations agree with experimental data but point form results are unacceptable: oscillation period shrinks as particle energy increases. We interpret this as an indication that neutrino mixing is controlled by the instant form of Dirac's dynamics.

Introduction. – Neutrino flavor mixing and oscillations [1] is now a well established fact. In the simplest case of two neutrino ($\nu_\mu - \nu_\tau$) mixing, time-dependent flavor probabilities contain a characteristic sinusoidal factor

$$\rho(t) \sim \sin^2 \frac{(m_2^2 - m_1^2)c^4 t}{4E\hbar}, \quad (1)$$

where m_2, m_1 are neutrino mass eigenvalues and E is particle energy. Early derivations [2] of this formula lacked relativistic rigor. Nevertheless, this result seemed satisfactory, not only because it agreed with experiments [3], but also because it reproduced the special-relativistic "time dilation" effect by exhibiting the direct proportionality between oscillation period T and particle energy

$$T \propto E \propto 1/\sqrt{1 - v^2/c^2}. \quad (2)$$

According to Wigner-Dirac relativistic quantum theory [4–6], Hilbert space \mathcal{H} of any isolated system (including oscillating neutrinos) carries a representation of the 10-dimensional Poincaré Lie algebra by means of Hermitian operators, which are identified with observables of total energy H , total linear momentum \mathbf{P} , total angular momentum \mathbf{J} and total boost momentum \mathbf{K} . In non-relativistic theories, the full interacting Hamiltonian H may be formed by adding "potential energy" V to the Hamiltonian H_0 of free particles

$$H = H_0 + V.$$

However, in the relativistic case such a construction violates Poincaré commutation relations. Dirac found out

that in order to preserve relativistic invariance, interaction terms have to be added to generators of other inertial transformations as well [5]. For example, in Dirac's instant form of dynamics a "potential boost momentum" should be added to the non-interacting generator of boosts \mathbf{K}_0 . In the point form dynamics, a "potential linear momentum" should be added to the non-interacting generator of space translations \mathbf{P}_0 . The question is what are observable effects, if any, of these relativistic interaction terms? Is it possible to distinguish various Dirac's forms of dynamics in experiments?

Sokolov and Shatnii proved that different forms of Dirac's dynamics are scattering equivalent [7, 8]. So, for S -matrix calculations we are allowed to choose any form of dynamics, as convenient. The canonical formulation of QFT was done in the instant form of dynamics [9], but Dirac's front form [10] and point form [11] also gained popularity in nuclear and particle physics.

In order to apply scattering theory to neutrino oscillations, Kleister and Polyzou [12] modified the standard S -matrix approach by considering two spatially separated scattering events (associated with neutrino production and neutrino detection), so that the oscillating neutrino was regarded as a virtual particle transmitting momentum-energy between these two vertices. By using instant form of Dirac's dynamics, the authors were able to reproduce the standard formula (1). They also inferred that the same result will hold in other forms as well. This conclusion was supported by Glazek and Traviński [13] who obtained formula (1) in the front form of modified scattering theory.

In this work we will approach neutrino oscillations from a different perspective. Instead of resorting to the S -

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