What’s Wrong with the Weak Interaction?

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12.15.-y Electroweak interactions

11.30.-j Symmetry and conservation laws

Abstract

A group-theoretical argument is given which shows that the weak interaction does not violate parity symmetry. Two corresponding experiments are discussed. As a consequence, charge conjugation can not be considered an independent symmetry operation. Furthermore, the more general question is asked whether there is any fundamental need at all for a weak force.

Introduction

The concept of weak interactions has been introduced by Enrico Fermi to describe the beta decay of unstable nuclei [1]. His 4-particle interaction was later replaced by a theory with a short-range force, mediated by so-called Gauge Bosons (W and Z), through the work of Glashow [2], Salam [3], and Weinberg [4], who in addition constructed a unification with the electromagnetic interaction.

A conspicuous aspect of weak interaction is that it is supposed to break inversion symmetry. Yang and Lee postulated that the weak force, may violate parity symmetry [5]. In a corresponding experiment Chien-Shiung Wu measured the beta decay of 60 Cobalt in a polarized probe [6]. The result of this experiment was that the electrons left in a direction opposite to the nuclear polarization and that they were exclusively polarized in a single handedness. This result seemed to verify the postulate of Yang and Lee for which they were subsequently honored by the Nobel prize. However, Wolfgang Pauli was very critical of this idea [7].

More recently, experiments on weak interaction are used to search for effects hinting at possible theories beyond the standard model of elementary particles. In particular a weak charge of atomic nuclei is now measured with increasing accuracy from helicity-specific electron scattering. For protons, e.g., the final value of this weak charge is obtained from taking the limit of zero momentum transfer [8]. However, the naive reader may be somewhat baffled by the idea that this limit should contain information on an interaction which is supposed to decay over distances considerably shorter than the radius of the proton.

Remark

Elementary particles can be characterized by their transformation behavior (irreducible representation) under the symmetry operations of space-time. These representations can be described by two half-integers (j,k). For an even sum $2(j + k)$ we have single-valued representations, scalars (0,0), electromagnetic field (½,½) etc. [9]. An odd sum $2(j + k)$ describes two-valued representations (spinors), in particular electrons and positrons, neutrinos and antineutrinos, (½,0) and (0,½).

The representations (j,k) and (k,j) are related by improper symmetry operations, like parity P or time reversal T [10]. For the cases $j \neq k$ this yields the somewhat unfamiliar situation that parity eigenstates need a combination of two representations. However, the two representations (j,k) and (k,j) can be named left- and right-chiral states, as transpires from the two corresponding relations of boost and rotation for the respective representations [9]. Clearly, if we apply the time reversal symmetry operation, T, to an electron (a (½,0)-representation, left-chiral) we obtain a positive-frequency right-chiral (0,½)-representation, a positron. On the other hand, if we apply a parity transformation, P, to a moving electron we obtain once more a right-chiral (0,½)-representation, again a positron. The corresponding negative-frequency state can be transformed to a positive-frequency state by applying the combination (PT), a proper Lorentz transformation which preserves representation type. This indicates that we actually need two copies of the representation to correctly represent a single particle. The mutual amplitudes of these representations vary with the choice of the inertial system and one of them vanishes in the rest system (see reference [11]).

Thus, two electrons moving with equal speed in opposite directions are not related by an inversion transformation, because this would also change an electron into a positron. In other words, left chirality is an intrinsic property of the electron.

In order to obtain the two components of the spin parallel and anti-parallel to an electron moving at speed $v=\tanh(2w)$ in the observers frame we must consider the corresponding spinor transformation [12]

$$D^{(w)}=\left(\cos\left(\frac{w}{2}\right)-i\sin\left(\frac{w}{2}\right)P_z\right)\left(\cosh\left(\frac{w}{2}\right)+I\sinh\left(\frac{w}{2}\right)P_z\right) ,$$

where, for a movement in z-direction, P_z is the Pauli matrix. The operator I (which was, incorrectly, missing in reference [12]) is the representation of the symmetry element (PT) and switches between positive- and negative-frequency components of the spinor field. Since the positive-frequency components contribute negatively to the norm of the wave-function, acceleration preserves the norm owing to the "Pythagorean" formula of the hyperbolic functions.

Evaluating the expectation values of the z-component of the spin shows that the plus-component grows exponentially with increasing parameter w, while the minus-component shrinks exponentially.

For the 'weak-charge' scattering experiment [8] it is now obvious that we must expect different results for the two polarizations just because of spinor kinematics. Thus, as the limit of zero momentum transfer also suggests, the short-range weak interaction does not play any role in the essential result of this experiment.

For beta-decay experiments the speed of the emerging electrons (positrons) is, in general, quite close to one which signifies that the amplitude of the minus (plus) spin component essentially disappears. Considering that the angular momentum carried away by the spinning electron (proportional to the rest mass) goes to zero for the minus component, it is obvious that the decay into the plus-component must be more likely, because it can carry away more easily the strong angular momentum change of the decaying nucleus. However, a detailed account of reaction kinematics is out of reach of this note.

In addition, beta-decay experiments obviously observe parity symmetry, because the emerging left-chiral electron always and exclusively occurs in combination with a right-chiral anti-neutrino, and the right-chiral positron with a left-chiral neutrino. Going one step further, one may wonder, whether the concept of weak interaction is a necessary construct at all. A comparison with molecular chemistry is in place now. Here, the decay of an (unstable) molecule is often activated by thermal energy transfer but can also occur by spontaneous quantum mechanical tunneling, without need of any additional interaction.

At this point it may be added, that for spinor representations the operator *I* can have two possible effects. Because positive- and negative-frequency states have each two sheets, the operator *I* can relate them in two different ways. This explains the occurrence two types of fermions (electron and neutrino). That they react differently to electromagnetic fields is plausible, but must be the subject of a separate investigation.

The educated physicist is probably irritated here because the so-called charge-conjugation symmetry, *C*, has not been mentioned in this note. However, as follows from above, *C* is not a independent symmetry operation. Rather, any improper operation, such as parity or time reversal, mediates between particles and their anti-particles and is responsible for the opposite reactions to the electric field, and, by the way, to the gravitational field as well.

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