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Radiative corrections to ^{10}C superallowed Fermi β decay

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In view of new data on the ^{10}C superallowed Fermi β decay, the radiative corrections have been reevaluated. In particular we calculate and include the nuclear-structure-dependent part of the axial-vector-induced contribution to the $O(\alpha)$ radiative correction. The resulting V_{ud} is appreciably larger than a value recently published, which was based on the same data.

Recently a new value has been published [1] for the branching ratio for ^{10}C superallowed Fermi β decay [BR $=0.01473(7)$]. From this value and recent values of the end-point energy [$E_0=885.72(9)$ keV [2]] and the total nuclear half-life [$t_0=19.290(12)$ s [3]], the ft value for the superallowed decay can be calculated. At present the uncertainty in the ft value is dominated by the uncertainty in the branching ratio. As further experimental work may, however, reduce this uncertainty, one should calculate the charge and radiative corrections as well as possible. The ^{10}C ft value could then be used, together with the ft values of the eight precisely measured superallowed decays [4], to determine the quark-mixing matrix element V_{ud} and to test the unitarity relation for the first row of this matrix.

The radiative corrections for the eight precisely measured superallowed decays were recalculated in [5]; in addition, the nuclear-structure dependent part (called $C_{\rm NS}$) of the axial-vector induced contribution to the $O(\alpha)$ radiative correction was calculated for the first time. It turned out that its inclusion is essential at the present level of precision.

In this paper we give the value of $C_{\rm NS}$ for the decay of ^{10}C. We also include the radiative and other corrections to get a value for V_{ud}. Due mainly to the inclusion of $C_{\rm NS}$ (which was not available in [1]), our value of V_{ud} is larger than that of [1] by approximately their uncertainty. This emphasizes the importance of this correction, which is especially big in the case of ^{10}C. Our notation and approach for ^{10}C are consistent with those used in [5] for the other eight cases.

We first comment on the calculation of the uncorrected ft value. For the value of E_0 given above, we take the integrated statistical rate function $f=2.3000(10)$ as calculated by Behrens (private communication) with a uniform nuclear-charge distribution corresponding to $r_0=1.47$ fm including atomic screening. The correction for a modified Gaussian nuclear-charge distribution is completely negligible. From the values of t_0 and BR given above, and applying the electron-capture correction of 0.31% [1], we get the partial half-life

$$t=1.0031\frac{t_0}{\rm BR}=1313.6(63)\ {\rm s}\,.$$

Corresponding to the values in Table II, column (1) of [5] we therefore have

$$ft=3021.3(145)\ {\rm s}\,.$$

Comparison of Table V, column (5) of [5] with Table 14.3 of [6] shows that, with sufficient accuracy, we can take the correction due to the shape factor for ^{10}C from Table 14.3. This leads to $\overline{C(E)}=0.9998$, corresponding to Table II, column (2) of [5]. Thus

$$ft\overline{C(E)}=3020.7(145)\ {\rm s}\,.$$

The recoil correction [Table III, column (2) of [5]] is -0.7 s, giving

$$ft\overline{C(E)}=3020.0(145)\ {\rm s}\ \text{(recoil corrected)}\,. \tag{1}$$

The uncertainty in (1) is obviously dominated by the uncertainty in BR. When the ft value given in [1], which was obtained by a completely different method, is corrected for electron capture,

$$ft=3011.5(144)\ {\rm s}\times 1.0031=3020.8(144)\ {\rm s}\,,$$

the agreement with (1) is as good as can be expected.

The value (1) is the basis to which we apply the radiative and other corrections. The isospin nonconservation correction is taken as $\delta_c=0.18\%$ from [7]; rather arbitrarily we assign to δ_c an uncertainty equal to half its value. This value corresponds to Table II, column (4) of [5]; there is no value available corresponding to column (3). The radiative corrections corresponding to Table I, columns (1)–(5) of [5] are calculated to be (in percents) 1.48, 3.98(8), 0.18, 0.00, and 4.16(8), respectively.

In the previous calculation of $C_{\rm NS}$ for the eight precisely measured cases [5], the initial and final states in each case were assumed to have only two valence particles (or holes) relative to a 0^+, $T=0$ core. In the same approximation, the ^{10}C states belong to the $(1s1/2)^4(1p3/2)^6$ configuration or $(1p3/2)^{-2}$ relative to a ^{12}C closed-shell core. With $r_p=1.693$ fm, corresponding to the value of r_0 given above, one obtains $C_{\rm NS}=C_0=-1.43$. Values of $C_{\rm NS}$ now have been calculated [8] for mixed-configuration wave functions based on the best interactions available, using values of the two-body transition densities obtained from the Oxford-Buenos Aires-MSU shell-model code [9] and values of the two-body matrix elements calculated separately. For ^{10}C, the preferred interaction of van Hees and Glaudemans [10] within the $(1s)^4(1p)^6$ space gives only 51% of the 0^+, $T=1$ state belonging to the $(1p3/2)^6$ configuration and $C_{\mathrm{NS}}=-1.73$ [the (8–16) POT interaction of Cohen and Kurath [11] gives $C_{\mathrm{NS}}=-1.94$]. Therefore we take $C_{\mathrm{NS}}=-1.73(20)$. These correction terms taken together give the factor

$$(1+\Delta_s+\delta_2+\delta_3+\alpha/\pi C_{\mathrm{NS}})(1-\delta_c)=1.0357(13)\,.$$

Multiplying the value in (1) by this factor and subtracting the atomic excitation correction of 2.5 s (taken from [12]), corresponding to Table III, column (3) of [5], gives finally [corresponding to Table III, column (5) of [5]]

$$ft=3125.3(155)\ \mathrm{s}\,. \tag{2}$$

The uncertainty in (2) is still about three times the typical uncertainty for the other eight cases and so would not appreciably affect the average. Nevertheless the value (2) is consistent with the systematic and unexplained linear Z-dependence of the ft values of the other eight cases, which has been commented on in [13]. In comparison with the value $|V_{ud}|=0.9752(24)$ given in [1], we find from Eqs. (2) and (5.2) of [5] the value

$$|V_{ud}|=0.9772(24)\,.$$

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