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Superallowed Fermi β decay: Lifetimes of ^{34}Cl, ^{38}K^m, ^{42}Sc, ^{46}V, and ^{50}Mn†

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The half-lives of the Fermi superallowed β transitions of ^{34}Cl, ^{38}K^m, ^{42}Sc, ^{46}V, and ^{50}Mn have been measured by multiscaling β rays detected in a plastic scintillator. The activities were produced in the reactions ^{32}S$(t,n)^{34}$Cl at $E_t = 3.0$ MeV, ^{35}Cl$(\alpha,n)^{38}$K^m at $E_\alpha = 8.0$ MeV, ^{42}Ca$(p,n)^{42}$Sc at $E_p = 10$ MeV, ^{46}Ti$(p,n)^{46}$V at $E_p = 10$ MeV, and ^{50}Cr$(p,n)^{50}$Mn at $E_p = 10$ MeV. Results for the half-lives (in msec) were as follows: ^{34}Cl, 1525.2 ± 1.1; ^{38}K^m, 922.3 ± 1.1; ^{42}Sc, 680.98 ± 0.62; ^{46}V, 424.01 ± 0.47; and ^{50}Mn, 282.72 ± 0.26. Comparisons are made with previous measurements; the systematics of the superallowed Fermi β emitters are discussed. The value for the vector coupling constant $g^R_{\beta V}$ including the "inner" radiative correction is deduced to be $g^R_{\beta V} = (1.412\,20 \pm 0.000\,43) \times 10^{-49}$ erg cm^3.

[RADIOACTIVITY ^{34}Cl, ^{38}K^m, ^{42}Sc, ^{46}V, and ^{50}Mn; measured $t_{1/2}$; compared with systematics.]

I. INTRODUCTION

The interest in accurate measurements of superallowed pure Fermi β decay, viz., that within isobaric multiplets of $J=0$ is well known[1-3] and will be elaborated in the Discussion to this paper; very briefly it is that such decay measures the vector coupling constant appropriate to nuclear β decay and that, assuming conservation of the vector current and within the assumption of universality in the Cabibbo sense, its comparison with muon decay brings us information about the intimate anatomy of the β-decay process and the inner structure of the nucleon.

Extraction of the coupling constant from the superallowed decays involves many steps both experimental and theoretical of which the most critical are the determination of the following quantities: (i) the energy release, (ii) the half-life, (iii) the branching ratio, (iv) the matrix element. Of these steps the first two are experimental, the third is partly experimental and partly theoretical, and the fourth is theoretical; steps (iii) and (iv) we return to in the Discussion. The experimental history of steps (i) and (ii) is long and chequered and is surely not over; the experimental problems in the measurement of mass differences and half-lives to accuracies of a few hundredths of a percent are formidable indeed as experience has shown.

We will not here review the history of the relevant measurements, because this has been done very recently,[3] but simply state that for the eight superallowed decays where ft values appear to be known to ±1/3% or better, viz., ^{14}O, ^{26}Al^m, ^{34}Cl, ^{38}K^m, ^{42}Sc, ^{46}V, ^{50}Mn, and ^{54}Co, the percentage confidence levels for the internal consistency of the several measurements of the half-lives arising in the literature in the respective cases are[3]: 0, 19, 0, 0, 0, 50, 1, and 73. We seek in this paper, to make a contribution to the improvement of this deplorable state of affairs by remeasurement of the half-lives of ^{34}Cl, ^{38}K^m, ^{42}Sc, ^{46}V, and ^{50}Mn; we also take the opportunities of reviewing the present overall position.

II. EXPERIMENTAL METHODS

Half-lives were measured by multiscaling β rays detected in a 5-cm diam. by 2.5-cm thick NE102 scintillator following procedures which have been described previously.[4] The specifics of the various experiments are as follows:

^{34}Cl

The ^{34}Cl activity was made in the ^{32}S$(t,n)^{34}$Cl reaction using 3-MeV tritons from the 3.5-MeV Van de Graaff accelerator of the Brookhaven National Laboratory. Because of evidence of weak contaminant activities in the previous work[4] on ^{34}Cl at this Laboratory, sulfur enriched to 99.86% in ^{32}S, containing negligible amounts of impurities, was used together with pure Ag foils to make thick AgS targets for the present experiment. The bombarded targets exhibited the 1.5-sec ^{34}Cl activity together with the 32-min half-life due to $^{34}Cl^m$. Since the isomer decays 50% to the ^{34}Cl ground state it is not possible to eliminate this long-lived component by biasing the β-ray energy. Under conditions of approximate equilibrium in a long run, irradiating the target for 1.5 sec and counting for 30 sec in each cycle, the counting rate of the long-lived activity was 1.5–2 % of the initial rate of 1.5-sec ^{34}Cl. In order to enhance the short-lived activity six targets were used, each for a period of 12 minutes of cycling after which it was set aside allowing the 32-min activity to decay. The long-lived background was thereby reduced to ~0.5% of the initial ^{34}Cl counting rate. The multiscaler was operated at 0.1 sec per channel for 300 channels in each cycle and runs were continued until 20 000–30 000 counts had been accumulated in the first channel. As many as 12 changes of target were made in some of the runs.

Fifteen runs were made on the ^{34}Cl half-life using β biases ranging from 0.25 to 2.5 MeV and incident beam currents of 4 to 25 nA. Computer fits to the data were made assuming two components, the 1.5-sec ^{34}Cl unknown and the 32-min half-life of $^{34}Cl^m$. It was established that the natural background was negligible, so a third component in the fitting was not needed.

$^{38}K^m$

$^{38}K^m$ was studied[4] previously at Brookhaven using the $^{36}Ar(t,n)^{38}K^m$ reaction. It was felt that a new measurement using the $^{35}Cl(\alpha,n)^{38}K^m$ reaction would be desirable, the latter having been employed recently by Squier *et al.*[5]

The target, consisting of KCl puddled onto a thick Au backing, was bombarded with 200–300 nA of 8.0-MeV α particles from one of the Brookhaven MP Tandem Van de Graaff accelerators. As pointed out by Squier *et al.*[5] this beam energy is just below the threshold for the $^{39}K(\alpha,n)^{42}Sc$ reaction and thus avoids the production of ^{42}Sc activity. However, the 7.7-min ground-state decay of ^{38}K is present and cannot be biased out completely, even though the β end point is 2 MeV lower than that of $^{38}K^m$, because of β-γ summing in the scintillator. A relative decrease in the summing effect was achieved by moving the detector away from the target by ~3 cm and under these conditions the long-lived background was 0.2–0.3 % of the initial $^{38}K^m$ counting rate when using a total cycle time of approximately 20 seconds (1.5 sec for irradiation followed by counting at 0.07 sec per channel for 256 channels), and for β-ray biases above 2 MeV. At a β bias of 1 MeV the 7.7-min decay was measured and it was established that the natural background was negligible in comparison.

Ten runs were made on $^{38}K^m$ at β biases ranging from 2.0 to 3.1 MeV and initial counts per channel of 10 000–23 000. Computer fits to the data were made assuming two components, the short-lived $^{38}K^m$ and the 7.7-min background.

^{42}Sc

In some previous work[4] the ^{42}Sc half-life was measured using the $^{40}Ca(t,n)^{42}Sc$ reaction for producing the activity. Meanwhile we have determined[6] the half-life of the long-lived isomer $^{42}Sc^m$ (62.0 ± 0.3 sec) by using the $^{42}Ca(p,n)^{42}Sc^m$ reaction and measuring the decay of the γ rays. This same ^{42}Ca target has been employed in the present experiments in which a beam of 3–6 nA of 10-MeV protons irradiated the target for one second and β rays were multiscaled at 0.05 sec per channel for 256 channels. For β-ray biases above 1.5 MeV the long-lived background was typically only ~0.03% of the initial ^{42}Sc counting rate and thus in the two-component fits to the data the long-lived activity was assumed to be infinite.

Thirteen runs were made at β biases ranging from 1.5 to 3.3 MeV and initial counts per channnel of 11 000–20 000.

^{46}V

A target consisting of four thicknesses of Ti foil totaling 0.005 cm thick was clamped in a rabbit and bombarded with 10-MeV protons. After transfer to a remote location the β rays entered the NE102 detector and were multiscaled at 0.03 sec/channel for 256 or 512 channels. Nine runs were made at β biases ranging from 2.0 to 3.6 MeV with initial counts per channel of 10 000–50 000.

^{50}Mn

In previous work[7] on the ^{50}Mn half-life at Brookhaven the activity was produced in the $^{50}Cr(p,n)^{50}Mn$ reaction using $E_p = 10$ MeV and a target of Cr_2O_3 150 $\mu g/cm^2$ thick, enriched in ^{50}Cr to 96.8%, and evaporated onto a thick Au backing. Weak contaminant activities were present and this limited the accuracy and reliability of the results. For the present work the same $^{50}Cr_2O_3$ powder sample was used, but it was puddled onto a Au backing to a thickness of several mg/cm^2. This allowed beams of much lower intensity to be used for producing a given activity level and insured that the yield of any background contaminant was coming from the target and not from activities induced in surrounding materials. Data were taken using an advance rate of 0.02 sec per channel for 256 channels.

Fits to the decay curves with only two components, the longer being infinite, were bias dependent and it was clear that a weak activity of several seconds half-life was present. It was then noted that the main impurity, as given in the spectroscopic analysis of the sample, was 0.1% of silicon and thus one could expect a contribution due to 4.21-sec ^{29}P produced in the ^{29}Si$(p,n)^{29}$P reaction (other reactions on the silicon isotopes can be ruled out). Fits carried out assuming three components, including $T_2 = 4.21$ sec and $T_3 = \infty$ gave consistent bias-independent results. Thus at low bias the initial rate of the 4.21-sec component was ~0.1% as great as the ^{50}Mn initial rate, while the $T_2 = \infty$ rate was ~0.003% as great. At higher biases the fits showed that the relative contribution of the 4.21-sec ^{29}P decreased, as to be expected from its β end-point energy of 3.9 MeV compared with the ^{50}Mn end point of 6.6 MeV.

Fourteen runs were made on ^{50}Mn at β biases ranging from 1.4 to 3.3 MeV and at beam currents of 1.5–10 nA with initial counts per channel of 10 000–19 000.

III. RESULTS

The several values of the half-life t, determined for each isotope as a function of β bias, were corrected for the rate-dependent pile-up effect as described elsewhere[8] (where the present results for ^{42}Sc are presented in detail as an illustration of the method). The many runs showed acceptable mutual compatibility with χ^2/ν values for ^{34}Cl, ^{38}K^m, ^{42}Sc, ^{46}V, and ^{50}Mn of 1.29, 1.06, 1.27, 1.19, and 1.20, respectively. Our experience has taught us that, despite good internal consistency it is wise to inflate purely statistical errors somewhat before quoting. We therefore give, in Table I, our results with the errors inflated by the factors that would increase $P(\chi^2, \nu)$ to 0.95 in each case.

TABLE I. Present and earlier half-life measurements (in msec). The column headed "Adopted" is arrived at as described in the text.

Body	Present	Earlier	Adopted
^{34}Cl	1525.2 ± 1.1	1534 ± 3 [a] 1526 ± 2 [b]	1525.4 ± 1.0
^{38}K^m	922.3 ± 1.1	925.6 ± 0.7 [c]	Present
^{42}Sc	680.98 ± 0.62	684.5 ± 1.2 [d]	Present
^{46}V	424.01 ± 0.47	425.3 ± 2.0 [e] 423.4 ± 2.0 [f]	424.04 ± 0.45
^{50}Mn	282.72 ± 0.26	284.0 ± 0.4 [f] 282.8 ± 0.3 [g]	282.75 ± 0.20

[a] Reference 4.
[b] Reference 9.
[c] Reference 5.
[d] Reference 4.
[e] Reference 7.
[f] Reference 10.
[g] Reference 11.

Table I also shows other recent accurate measurements of the same half-lives. For purposes of our subsequent discussion we have used the following procedure to arrive at the value of the half-life shown in the "Adopted" column of Table I: If all available values combine with an acceptable χ^2 we adopt the resultant value (this is the case for ^{46}V only); if, with three values available but with an unacceptable χ^2, elimination of one value gives an acceptable χ^2 for the remaining two, the value given by combining the remaining two is adopted (this is the case for ^{34}Cl—where the earlier Brookhaven result is eliminated—and for ^{50}Mn—where the Chalk River result is eliminated); if there are only two results with an unacceptable χ^2 we have chosen our own (rejecting the Harwell result for ^{38}K^m and the earlier Brookhaven result for ^{42}Sc).

IV. OTHER DATA

We now survey other data relevant to the superallowed Fermi problem. This consists chiefly of the half-lives of the other three bodies mentioned in the Introduction, namely, ^{14}O, ^{26}Al^m, and ^{54}Co and the energy releases in the decay of all eight bodies.

For the half-life of ^{14}O we use 70.592 ± 0.031 sec (see references in Ref. 2); for that of ^{26}Al^m we use 6.3465 ± 0.0035 sec (see references in Refs. 2 and 12); for that of ^{54}Co we use 193.14 ± 0.23 msec (see references in Ref. 3).

The energy releases E_0, the maximum positron kinetic energy, are given in Table II which also gives the half-lives t corrected by standard means for electron capture and for branching to other than the analog state (the latter significant only for ^{14}O where the literature figure has been used[3]) and various other quantities to be discussed later.

V. DISCUSSION

Our discussion follows closely that recently presented[2] and so will be rather brief.

If we could switch off the electromagnetic interaction and if the residual strong interaction were completely charge-independent, conservation of the vector current would give for the ft values of the $T = 1$ transitions in question:

$$ft = \frac{\pi^3 \hbar^7 \ln 2}{m^5 c^4 g_{\beta V}^2} = \frac{6.153 \times 10^{-95}}{g_{\beta V}^2}\ \mathrm{erg^2\,cm^6\,sec}\,,$$

where $g_{\beta V}$ is the vector coupling constant for nucleon β decay.

With the participation of the electromagnetic interaction this becomes:

TABLE II. Superallowed Fermi decay. The half-lives t have been corrected for electron capture and branching. The numbers in parentheses in the f^R and t columns are the associated errors in %.

Body	E_0 (keV)	f^R	t (msec)	ϵ(%)	$\mathcal{F}t$ (sec)
^{14}O	1809.98 ± 0.35 [a]	43.512(0.083)	71 136 (0.046)	0.13	3091.3 ± 4.2
^{26}Al^m	3210.84 ± 0.48 [b]	485.92 (0.067)	6 351.8 (0.055)	0.18	3081.0 ± 4.1
^{34}Cl	4467.7 ± 1.3 [c]	2024.8 (0.13)	1 526.6 (0.066)	0.41	3078.5 ± 5.5
^{38}K^m	5022.9 ± 3.1 [d]	3355.3 (0.28)	923.1 (0.12)	0.37	3085.9 ± 9.9
^{42}Sc	5399.9 ± 2.2 [e]	4535.1 (0.19)	681.64(0.091)	0.40	3079.0 ± 7.2
^{46}V	6018.8 ± 2.8 [e]	7278.2 (0.22)	424.45(0.11)	0.29	3080.3 ± 8.2
^{50}Mn	6609.9 ± 1.4 [f]	10 933 (0.10)	283.04(0.071)	0.33	3084.3 ± 4.9
^{54}Co	7219.0 ± 1.6 [g]	16 046 (0.11)	193.37(0.12)	0.39	3090.7 ± 6.0

[a] References 13 and 14.
[b] References 14–17.
[c] References 14, 15, and 17.
[d] References 5 and 18.
[e] References 17.
[f] References 14 and 17.
[g] References 17 and 19.

$$f^R t = \frac{6.153\times 10^{-95}}{g_{\beta V}^{R2}(1-\epsilon)}\ \mathrm{erg}^2\,\mathrm{cm}^6\,\mathrm{sec}. \qquad (1)$$

f^R differs from f by the "outer" radiative corrections (of order α, $Z\alpha^2$, and $Z^2\alpha^3$ which is probably adequate in practice for the nuclei that we are concerned with here) which are energy-release-dependent but which do not depend significantly on β-decay anatomy or nucleon structure. These outer radiative corrections have been discussed in detail elsewhere[2,3] and appear to be under good control.

$g_{\beta V}^R$ differs from $g_{\beta V}$ by the "inner" radiative correction of order α, $\Delta_{\beta V}^{\alpha}$:

$$g_{\beta V}^R = g_{\beta V}(1+\tfrac{1}{2}\Delta_{\beta V}^{\alpha}) .$$

$\Delta_{\beta V}^{\alpha}$ depends on the details of the β-decay process and on nucleon structure but is essentially energy-release-independent and so is conveniently absorbed into the effective vector coupling constant $g_{\beta V}^R$.

The quantity ϵ that appears in Eq. (1) represents the SU(2) nuclear symmetry breaking, the miss-match between initial and final state wave functions, due to the electromagnetic interaction; it must be calculated or estimated semiempirically as we shall see in a moment.

Our approach to analysis of the empirical data presented in the earlier sections begins with the computations of f^R from the energy release E_0 as listed in Table I; this we do as described elsewhere[2] and list the values in Table II.

As before[2] we make two approaches to ϵ. The first is by direct computation; we use the same values as previously[2] and show them in Table II. Equation (1) then leads us to expect constant values of

$$\mathcal{F}t = f^R t(1-\epsilon) .$$

The several $\mathcal{F}t$ values are listed in Table I; their mean value is

$$\overline{\mathcal{F}t} = 3084.5 \pm 1.9\ \mathrm{sec}$$

with $\chi^2 = 6.5$ for seven degrees of freedom.

The second approach is via the Ademollo-Gatto theorem[20] which tells us that the renormalization of coupling constants within symmetry multiplets goes as the square of the mass splittings. While we have no reason to suppose that this theorem permits us directly to relate say ^{50}Mn with ^{14}O it at least suggests the gross order of dependence on the Coulomb energy differences that we might expect ϵ to display. Figure 1 shows the energy split-

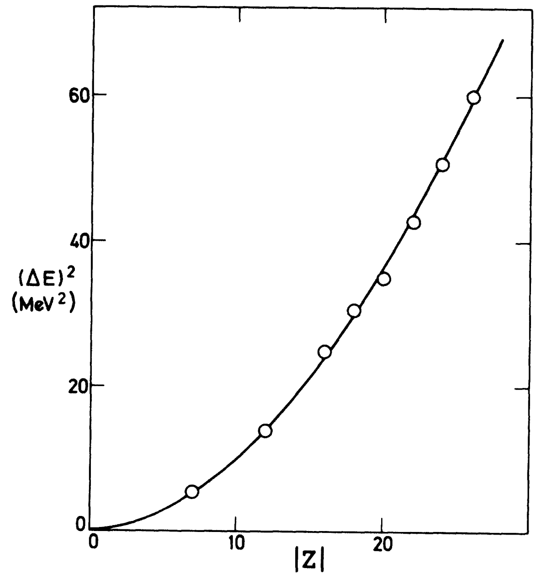

FIG. 1. Squares of the mass-splitting ΔE (MeV) between the analog states in question as a function of Z shown fitted to $Z^{1.86}$.

tings ΔE of the multiplets in question from which we see that $(\Delta E)^2 \sim Z^{1.86}$ is an excellent representation. We now fit the $f^R t$ values of Table II by:

$$f^R t = (f^R t)_{Z=0} + aZ^{1.86}$$

finding

$$(f^R t)_{Z=0} = 3089.5 \pm 4.4 \text{ sec}$$

with $\chi^2 = 4.8$ for six degrees of freedom which is nicely consistent with the $\overline{\mathfrak{F}t}$ value quoted above. For further discussion we adopt the value 3085.3 ±1.9 sec from $\overline{\mathfrak{F}t}$ and $(f^R t)_{Z=0}$ which then yields

$$g^R_{\beta V} = (1.41220 \pm 0.00043) \times 10^{-49} \text{ erg cm}^3 .$$

To go further we must consider muon decay which we characterize through the effective coupling constant g^R_μ which is related by the "inner" radiative correction Δ^α_μ to the purely weak coupling constant g_μ:

$$g^R_\mu = g_\mu (1 + \tfrac{1}{2} \Delta^\alpha_\mu) .$$

We have[2]

$$g^R_\mu = (1.4358 \pm 0.0001) \times 10^{-49} \text{ erg cm}^3 .$$

Cabibbo universality, which we adopt at this point, gives

$$g_{\beta V} = g_\mu \cos\theta_C ,$$

where θ_C is the Cabibbo angle.

The most natural source of the Cabibbo angle for our purpose is hyperon β decay which measures $\sin\theta_C$; the large mass of data shows excellent internal consistency with no demand for symmetry-breaking corrections[21] and gives $\sin\theta_C = 0.232 \pm 0.003$. Another source of the Cabibbo angle is K_{e3} decay which gives[21] $\sin\theta_C = 0.220 \pm 0.002$. Since K_{e3} decay is rather remote from our present problem and suffers from some uncertainties that do not affect hyperon decay, we do not try to combine the two $\sin\theta_C$ values but rather take the significantly lower value coming from K_{e3} decay as a hint that perhaps the hyperon value may be on the high side and so reduce it by its own standard deviation and adopt

$$\sin\theta_C = 0.229 \pm 0.003 .$$

We have chosen to ignore the renormalization effects of SU(3) symmetry breaking on θ_C because there is no experimental demand for them and because, although they undoubtedly must exist, their theoretical estimation is model-dependent and by no means straightforward.[22] We will make a further remark on this in due course.

Putting together the above experimental values of $g^R_{\beta V}$, g^R_μ, and $\sin\theta_C$ now gives

$$\Delta^\alpha_{\beta V} - \Delta^\alpha_\mu = (2.09 \pm 0.16)\% .$$

Both Δ values depend on the specific model of the weak interaction; $\Delta^\alpha_{\beta V}$ depends further on nucleon structure. The general form of $\Delta^\alpha_{\beta V}$ has proved remarkably stable against changes in our ideas about the weak interaction[23] but it is only with the recent advent of the renormalizable gauge theories of the weak and electromagnetic interactions that Δ values free of divergences and other objectionable features have become available.

At present only one close examination of the Δ values has been made[24] and that in terms of the original Salam-Weinberg version of the gauge theories.[25] Sirlin finds,[24] for the limited range of quark models of nucleon structure that he treats:

$$\Delta^\alpha_{\beta V} - \Delta^\alpha_\mu = (\alpha/2\pi)[3 \ln(m_Z/m_N) + 6\overline{Q} \ln(m_Z/m_A)] . \tag{2}$$

Here m_N is the nucleon mass, m_Z is the mass of the neutral-current-propagating vector boson Z^0, and m_A is the effective mass of some axial structure such as we might associate with the A_1 meson (for which we use[2] 1300 MeV); $\overline{Q}$ is the mean charge of the quarks that make up the nucleon.

If we wish tentatively and speculatively to commit ourselves to the Salam-Weinberg scheme we can therefore use Eq. (2) to relate our experimental $\Delta^\alpha_{\beta V} - \Delta^\alpha_\mu$ to m_Z and $\overline{Q}$. This is done in Fig. 2. If the Salam-Weinberg scheme is correct $m_Z > 74.6$ GeV while present evidence on neutral currents makes it very likely that $m_Z < 100$ GeV.[2] As Fig. 2 shows, this range of m_Z leads to

$$\overline{Q} = 0.17 \pm 0.06 .$$

Comparison of deep inelastic neutrino and elec-

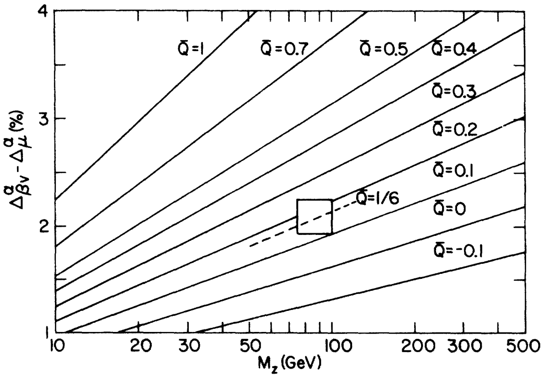

FIG. 2. The curves show the theoretical (Sirlin-Salam-Weinberg) expression for $\Delta^\alpha_{\beta V} - \Delta^\alpha_\mu$ as a function of m_Z, the mass of the neutral intermediate vector boson, for various values of $\overline{Q}$ the mean quark charge of the nucleon. The box shows the experimental value of $\Delta^\alpha_{\beta V} - \Delta^\alpha_\mu$ and the limits on m_Z as discussed in the text. [The value of the Cabibbo angle used in extracting the experimental value of $\Delta^\alpha_{\beta V} - \Delta^\alpha_\mu$ is uncorrected for SU(3) symmetry breaking—see text.]

tron scattering gives, within the quark-parton model[26]:

$$\overline{Q^2} = 0.28 \pm 0.03 \, .$$

Combining these values of $\overline{Q}$ and $\overline{Q^2}$ we can find the effective charges of the "up" and "down" quarks:

$$Q_u = 0.67 \pm 0.05 \, ,$$

$$Q_d = -0.33 \pm 0.08 \, .$$

We may note that the close agreement of these numbers with the $Q_u = \frac{2}{3}$, $Q_d = -\frac{1}{3}$ of the original Gell-Mann–Zweig quark model does not necessarily imply that individual quarks are of nonintegral charge but only that the nucleon contains three of them; for example the Han-Nambu three-color model with integral quark charges would give the same result.

We finally remark that although our detailed analysis has been based on the Salam-Weinberg model its principles are not restricted to that model and the experimental value of $\Delta_{\beta V}^{\alpha} - \Delta_{\mu}^{\alpha}$ remains available for use in whatever framework may alternatively prove to be valid.

VI. FUTURE DEVELOPMENTS

The history of the measurement of the energy release and lifetime of these superallowed Fermi decays has been a troubled one as we have illustrated briefly in the Introduction in relation to the lifetimes. We cannot be happy with the present situation and further work on masses and lifetimes is needed and can be expected both for the range of bodies that we have analyzed here and also for others that may become susceptible to measurements of comparable precision to the present set.

The theoretical nuclear matrix element correction, that we have called ϵ, is very significant in that its magnitude, as at present understood, of, on the average, about 0.3% (see Table II) substantially exceeds the error on our adopted value of $g_{\beta V}^{R2}$, namely, about 0.06%. Our confidence in ϵ therefore becomes a limiting factor for future development. There is little point in improving experimental accuracy beyond the present point unless we can also refine our techniques, whether through the approach of directly computing ϵ from nuclear models or through the "Ademollo-Gatto" approach, for going from *ft* values to $g_{\beta V}^{R}$.

However, the major stumbling block for the ultimate confrontation of $g_{\beta V}^{R}$ with g_{μ}^{R} is the Cabibbo angle even if we are prepared to assume the rigorous validity of Cabibbo universality in the SU(3) limit. For values of $g_{\beta V}^{R}$, g_{μ}^{R}, and $\sin\theta_C$ that we have adopted here the major source of error in $\Delta_{\beta V}^{\alpha} - \Delta_{\mu}^{\alpha}$ is that in $\sin\theta_C$: without this error in $\sin\theta_C$ that in $\Delta_{\beta V}^{\alpha} - \Delta_{\mu}^{\alpha}$ would be ±0.06% rather than ±0.16%. But even worse than the experimental error in $\sin\theta_C$ is the uncertainty that lurks in the possible effects of SU(3) symmetry breaking. As we stressed in adopting our value for $\sin\theta_C$, we have applied no correction for symmetry breaking; but if we had used the only value available, namely, that of Langacher and Pagels,[22] we should have raised $\sin\theta_C$ from our 0.229 to 0.238, viz., by some 3 times its experimental error, and $\Delta_{\beta V}^{\alpha} - \Delta_{\mu}^{\alpha}$ would have correspondingly increased from 2.09 to 2.53% with the effect on $\overline{Q}$ in our Salam-Weinberg analysis that can be seen from Fig. 2. Improvement in our knowledge of $\sin\theta_C$ experimentally from the point of view of reconciling the values coming from hyperon decay and from K_{e3} decay and from the point of view of symmetry breaking is therefore urgently needed because that is the most serious present barrier.

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