Tritium beta polarization

Koks, Fransiscus Wilhelmus Jozef

Publication date:
1977

CHAPTER 7 POLARIZATION MEASUREMENTS

7.1. Experimental procedure

The longitudinal polarization of β^--particles from the decay of tritium has been investigated at energies between 5.5 and 16.0 keV. Before the start of these measurements the Mott polarimeter was recalibrated, as described in sect. 5.4. After finishing the actual polarization measurements the influence of depolarization in the source was investigated both experimentally and numerically, as described in sect. 6.3.

During the polarization measurements we performed at each energy setting a series of asymmetry measurements with the tritium source as well as with the source simulator. The tritium measurements were interrupted regularly for background counting.

Before starting polarization measurements at a certain energy setting, the electron beam was aligned with the aid of the forward-angle detectors 3 and 4 that monitor the asymmetry $\delta(45^o)$. The deflector position and voltage were adjusted so that $|\delta(45^o)| < 0.1$ in the plane of deflection ($\phi = 0^o, 180^o$). Then, more critically, $|\delta(45^o)|$ in the plane in which the polarization asymmetry is measured ($\phi = 90^o, 270^o$) was reduced to less than 0.03 by small adjustments of current and position of lens L_3.

At each energy setting a number of measurement cycles was collected, each consisting of two runs with alternate counter positions. The duration of the cycles ranged from 20 to 80 minutes. The counting rates for the polarization sensitive detectors 1 and 2 ranged between 210 c/s at the lowest and 2 c/s at the highest energy setting.

Background measurements were performed in various ways: usually by measuring with the source covered by an absorber, but also by measuring without high voltage on the main accelerator or by closing a valve (fig. 5.2) between lens L_3 and the deflector. All three methods gave the same result within statistical accuracy amounting to about 0.6 c/s for detectors 1 and 2. This is only about 30% of the total counting rate at the highest energy setting. The background was constant in time and independent of the preacceleration voltage V_p. A part of the background may be attributed to some radioactive contamination of the polarimeter chamber by previous experiments with ^{147}Pm. The background contribution for detectors 3 and 4 was 3% at most.

Zero-measurements with the source replaced by a source simulator were performed with the same adjustments of the apparatus as during the tritium measurements. The simulator gave the same forward asymmetry $\delta(45^{\circ})$ as the tritium source within a difference of about 0.005 for all azimuthal angles ϕ. This indicates that the simulator replaced the source properly.

Data storage and polarimeter rotation were automatized, so that non-stop measurements could be performed. Read out occurs when the content of a timer exceeds a preselected number. This number, the position of the polarimeter and the content of the four counters are recorded by a Sodeco printer and by a paper tape puncher. After each run the polarimeter is rotated automatically over 180° and a new counting period is started. The information on the paper tape was put on punch cards by means of an external interface system. The data on the punch cards were further processed at the TR4 computer of the Rekencentrum of the Groningen University (see next section).

Several times a day the stability of the various currents and voltages was checked. Sometimes small readjustments of the current through lens L_3 (fig. 5.2) and the deflection voltage were necessary in order to keep the forward asymmetry $\delta(45^{\circ})$ within acceptable limits (see above). Runs for which $\delta(45^{\circ})$ was too large were skipped. Regularly, scintillation spectra of the detectors were collected and spectra of the tritium source (see fig. 5.4) were measured in order to check the proper functionating of the various components of the apparatus. The consistency of the results presented in the subsequent section indicates that the influence of instabilities is small compared with statistical fluctuations.

7.2. Data analysis and results

Following the procedure sketched in the previous section we performed polarization measurements at nine settings between -10 kV (accelerating) and +2 kV (retarding) of the preacceleration voltage V_p, using the 23 μg/cm^2 source (see ch. 4) and arrangement II (see ch. 5). The analysis of the data obtained during these measurements is explained in this section; results are presented in table 7.1.

The average energy of the analysed β⁻-particles ranged from 5.5 to 16.0 keV. Values of E_{av} shown in column 1 of table 7.1, were calculated from the relation:

$$E_{av}(E') = \frac{\int E\, N_s(E)\, G_a(E;E',\sigma_a)\, dE}{\int N_s(E)\, G_a(E;E',\sigma_a)\, dE} . \tag{7.1}$$

Here, $N_s(E)$ refers to the energy distribution of the β-particles when they leave the source. The integrals were calculated numerically with the aid of a computer program, using the source spectrum N_s measured with the double-focusing spectrometer (sect. 4.3) and using the window curve G_a of the apparatus, discussed in sect. 5.3 (see the inset of fig. 5.5). At an energy setting E' = 15.5 keV (V_p = 0), for example, the calculated average energy is 14.5 keV. Similarly, the average value of the velocity v/c was calculated: results are given in column 2 of table 7.1.

The observed degree of polarization is also an average over the transmitted energy window and depends on the quantity

$$P_{av}(E') = \frac{\int P_s(E)\, N_s(E)\, G_a(E;E',\sigma_a)\, dE}{\int N_s(E)\, G_a(E;E',\sigma_a)\, dE} , \tag{7.2}$$

where $P_s(E)$ refers to the polarization of the β-particles when they leave the source (see eq. 6.14). Upon expanding $P_s(E)$ in the neighbourhood of E' as a Taylor series, eq. 7.2 can be written as:

$$P_{av}(E') = P_s(E') + \left(\frac{dP_s}{dE}\right)_{E'} (E - E')_{av} + \frac{1}{2}\left(\frac{d^2P_s}{dE^2}\right)_{E'} \left[(E - E')^2\right]_{av} + \ldots\ldots \tag{7.3}$$

$P_s(E_{av})$, the polarization of electrons leaving the source with energy E_{av}, can be expanded as:

$$P_s(E_{av}) = P_s(E') + \left(\frac{dP_s}{dE}\right)_{E'} (E_{av} - E') + \frac{1}{2}\left(\frac{d^2P_s}{dE^2}\right)_{E'} (E_{av} - E')^2 + \ldots.. \tag{7.4}$$

The zeroth- and first-order terms of the expansions 7.3 and 7.4 are equal. We checked by calculation that the second-order terms are approximately equal; it turns out that

$$P_{av}(E') = P_s(E_{av}) \tag{7.5}$$

to within about 0.3%, for the entire energy range under consideration. A correction for this small difference was included in the depolarization factor D_a, to be introduced in eq. 7.9.

From the numbers of counts observed during the polarization measurements, asymmetries were calculated with the aid of a computer program. The observed asymmetry $\delta_{obs}(117^o)$ was obtained from

$$\delta_{obs}(117^o) = \frac{(N_{1A}N_{2B}/N_{2A}N_{1B})^{\frac{1}{2}} - 1}{(N_{1A}N_{2B}/N_{2A}N_{1B})^{\frac{1}{2}} + 1}, \tag{7.6}$$

where N_{1A} is the number of electrons, corrected for background, registered by detector 1 while the polarimeter chamber is in the position 'A' ($\phi_1 = 90^o$, $\phi_2 = 270^o$; ϕ_1 and ϕ_2 being the azimuthal positions of the detectors 1 and 2, respectively), N_{1B} is this number with the polarimeter chamber in position 'B' ($\phi_1 = 270^o$, $\phi_2 = 90^o$) etc. The asymmetries $\delta_{obs}(45^o)$ for the source and $\delta^0_{obs}(117^o)$ and $\delta^0_{obs}(45^o)$ for the source simulator were calculated from relations similar to eq. 7.6. As shown in refs. Kli65,66a, errors due to differences between the detectors are eliminated by using these expressions.

Values for $\delta_{obs}(117^o)$ are given in column 3 of table 7.1. These values, like most of the data of the table, are averages for the various measurement cycles collected at the energy setting under consideration.

A correction for instrumental asymmetries due to a possible small misalignment of the incident beam and the rotation axis of the polarimeter was obtained from the observed asymmetry for the forward detectors. The corrected asymmetry, tabulated in column 4 of table 7.1, is given by (Kli65,66a; Dui69)

$$\delta_{corr}(117^o) = \delta_{obs}(117^o) - C\,\delta_{obs}(45^o). \qquad (7.7)$$

Here $C = a(117^o)/a(45^o)$, where $a = (dI/d\theta)/I$ is a measure for the dependence of the scattering probability on angle. We used the experimentally determined value $C = 0.29 \pm 0.01$ (fig. 7.1).

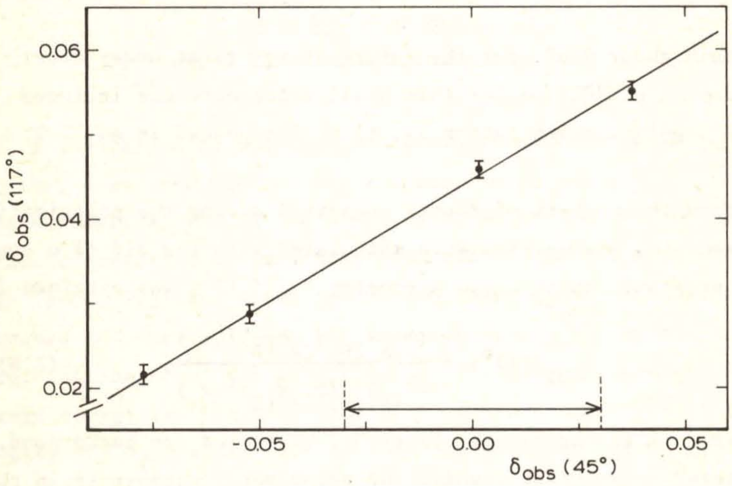

Fig. 7.1. Dependence of $\delta_{obs}(117^o)$ on $\delta_{obs}(45^o)$, as observed by varying the adjustment of the electron beam. During the polarization measurements $\delta_{obs}(45^o)$ was restricted to the region indicated by the arrow.

A tentative theoretical estimate, using screened relativistic single-scattering cross sections (Lin64 ; Büh68) gave $C \simeq 0.25$. However, the influence of plural and multiple scattering processes in the polarimeter foil is not taken into account for this estimate. Expression 7.7 is correct in first order up to a small residual term (Dui69), which, for the geometry of the present experiment, amounts to about $0.003\ y$ (y in mm). The quantity y denotes the component in the measuring plane of the shift between the axis of

TABLE 7.1.

Results of tritium β-polarization measurements with the 23 μg/cm² source and arrangement II [a].

Average energy (keV)	Average velocity v/c	Observed asymmetry $\delta_{obs}(117^o)$	Corrected asymmetry $\delta_{corr}(117^o)$	Corrected zero-asymmetry $\delta^o_{corr}(117^o)$	Polarimeter efficiency $-S_{an}$	Depolarization factor D_sD_a	Degree of longitudinal polarization $-P$	$-P/(v/c)$	Consistency information [b]
16.0(2)	0.2445(15)	0.0556(10)	0.0493(10)	0.0033(6)	0.1992(29)	0.925(14)	0.2496(84)	1.021(35)	0.79/113/0.95
15.3(2)	0.2394(16)	0.0507(11)	0.0487(11)	0.0047(5)	0.2000(29)	0.914(15)	0.2407(84)	1.005(36)	1.15/48/0.23
14.5(2)	0.2333(16)	0.0449(6)	0.0435(6)	0.0018(7)	0.2005(29)	0.900(17)	0.2311(72)	0.991(32)	0.97/78/0.55
12.8(2)	0.2197(17)	0.0382(8)	0.0384(8)	0.0025(10)	0.2013(28)	0.86(3)	0.208(10)	0.95(5)	0.67/11/0.75
11.0(2)	0.2042(19)	0.0311(3)	0.0314(3)	0.0024(7)	0.2019(28)	0.79(4)	0.182(11)	0.89(5)	0.92/33/0.60
9.1(2)	0.1862(20)	0.0240(4)	0.0253(4)	0.0033(7)	0.2021(28)	0.70(5)	0.156(13)	0.84(7)	0.71/31/0.88
7.3(3)	0.1672(34)	0.0244(4)	0.0196(4)	0.0036(6)	0.2027(28)	0.61(7)	0.129(16)	0.77(10)	0.68/15/0.80
6.3(3)	0.1556(37)	0.0229(6)	0.0184(6)	0.0041(5)	0.2027(28)	0.53(9)	0.133(24)	0.85(15)	1.43/6/0.21
5.5(4)	0.1455(53)	0.0170(3)	0.0152(3)	0.0032(4)	0.2029(28)	0.46(9)	0.128(26)	0.88(18)	1.15/27/0.28

a) This table is explained in detail in sect. 7.2. Uncertainties in least significant figures are given in brackets.

b) Presented are: reduced chi-square value/number of cycles/probability that a larger chi-square is found when the experiment is repeated.

rotation and the centre of the beam spot on the scattering foil. This and possible other residual correction terms were measured in the additional zero-measurements with the source simulator.

The degree of transverse polarization of the beam entering the polarimeter, P_T, is deduced from

$$P_T S_{an} = \delta_{corr}(117^o) - \delta^0_{corr}(117^o). \qquad (7.8)$$

Here, $\delta^0_{corr}(117^o)$ is the corrected asymmetry for the source simulator, calculated from a relation similar to eq. 7.7. These additional zero-measurements are necessary for high-precision experiments. Most values of $\delta^0_{corr}(117^o)$ (see column 5 of table 7.1) are positive and of order 0.003. This size, though small with respect to $\delta_{corr}(117^o)$, is not completely understood. A beam shift y of about 1 mm would explain it, but shifts larger than 0.5 mm seem rather unrealistic. For the result 7.11 (see later) which is compared with theory, the magnitude of $\delta^0_{corr}(117^o)$ is, on the average, about 7% of $\delta_{corr}(117^o)$.

The values of S_{an} given in column 6 of table 7.1 were deduced from the calibration value 5.6, applying small corrections for energy differences, as explained in sect. 5.4.

The degree of longitudinal polarization P_s of the analysed β-particles at the moment of leaving the source follows from

$$P_T(E') = D_a P_s(E_{av}) \qquad (7.9)$$

(see eqs. 7.2 and 7.5). The factor D_a accounts for depolarization in the apparatus. We concluded from relations given by Tolhoek (Tol56) for the motion of polarized particles in electromagnetic fields, that the longitudinal electrostatic fields in preaccelerator and main accelerator and the longitudinal magnetic fields of the lenses leave the electron polarization unchanged. Transverse magnetic field components due to fringing fields of the lenses rotate the direction of the electrons at the same rate as the longitudinal electron spin and leave the degree of longitudinal polarization of the beam unaffected. The influence of incomplete spin rotation in the deflector is smaller than 0.1%. Thus, depolarization in the apparatus is mainly due to the aperture of the diaphragm system of lens L_1 (subsect. 5.2.4). By averaging the longitudinal spin component over this aperture we obtained D_a = 0.980 ± 0.005 (including the small correction discussed in connection with eq. 7.5).

Our results for P_s (not given explicitely in table 7.1) are presented in fig. 7.2.

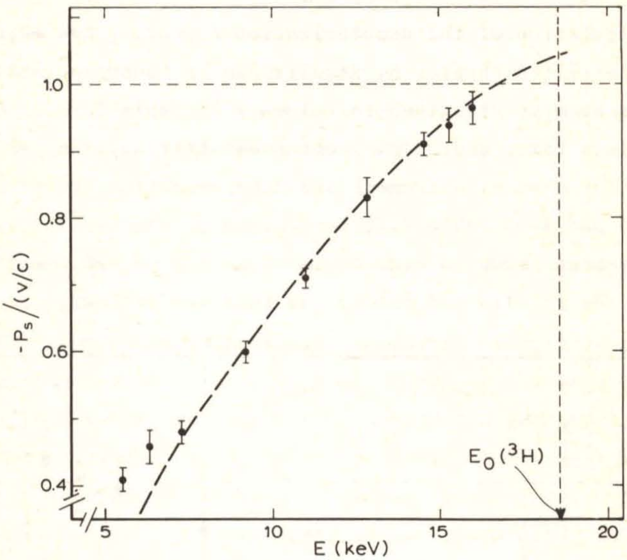

Fig. 7.2. Results for the polarization P_s of the β-particles at the moment of leaving the source, as function of energy. Indicated errors are statistical. The curve represents a least-squares fit of the data to a quadratic function. For comments, see main text.

Originally, we intended to extrapolate these results to the tritium end-point energy, having in mind that at this energy depolarization in the source is practically absent, so that the thus obtained polarization value can be directly compared with theory. For example, the fit to a quadratic function shown in fig. 7.2 gives as extrapolated polarization value (divided by $-v/c$): 1.04 ± 0.04. We abandonned this approach for two reasons. In the first place, the extrapolated result depends on polarization measurements at lower energies which are not very reliable, as discussed in sect. 5.3 and subsect. 6.3.3. Furthermore, the result of the extrapolation depends rather sensitively on the adopted functional dependence of P_s on E, which dependence is not sufficiently well known beforehand.

Instead, we applied a correction for depolarization in the source. According to eq. 6.14 the polarization P of the β-particles at the moment of emission by the tritium atoms follows from

$$P_s = D_s P. \tag{7.10}$$

The calculation of the depolarization factor D_s has been explained in detail in chapter 6. Results can be found in table 6.2, while values of $D_s D_a$ are given in column 7 of table 7.1.

The values for P and $P/(v/c)$ obtained after applying the above corrections for beam misalignment and depolarization are presented in columns 8 and 9 of table 7.1, respectively. The results for P have already been shown in fig. 2.2 as function of v/c. In fig. 7.3 we show the results for $P/(v/c)$ as function of energy.

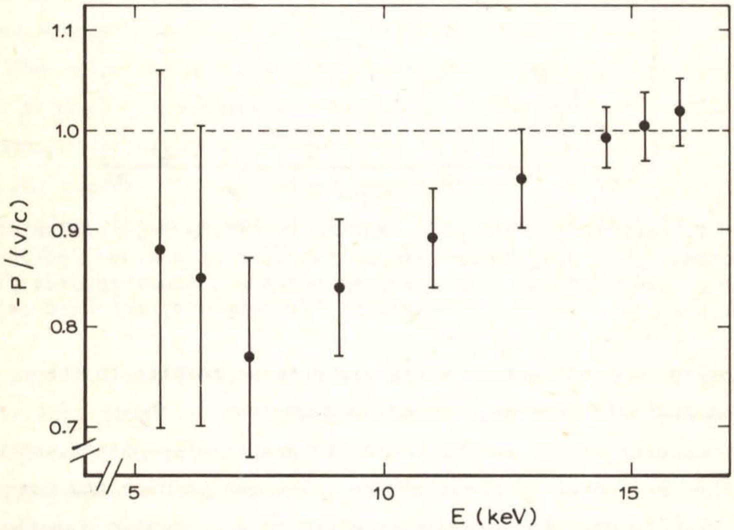

Fig. 7.3. Results for the polarization P of the β-particles at the moment of emission by the tritium atoms, as function of energy. Indicated errors include all known sources of error.

In the last column of table 7.1 an indication is given of the statistical consistency of the results for P of the various measurement cycles collected at one and the same energy setting.

Tabulated is: (i) the reduced chi-square value, i.e. the value of chi-square divided by the number of degrees of freedom, which is in our case one less than the number of cycles; (ii) the number of cycles and (iii) the probability that a larger chi-square is obtained when the experiment is repeated (taken from ref. Bev69). All these probabilities lie between 0.21 and 0.95, which is acceptable.

The values for $-P/(v/c)$ obtained with arrangement I and the 120 $\mu g/cm^2$ source are: 1.12 ± 0.14 at 15.8 keV; 1.08 ± 0.14 at 14.1 keV; 1.02 ± 0.15 at 12.1 keV and 1.10 ± 0.25 at 10.1 keV. Within error limits the results obtained with arrangements I and II are consistent, but the errors with arrangement I are much larger.

7.3. Comparison with theory and with other polarization results

For comparison with theory we only use the three polarization values obtained with the 23 $\mu g/cm^2$ source and arrangement II at the highest energy settings (see table 7.1). For these results the depolarization correction is small and sufficiently accurate. At lower energies it becomes large and less accurate. Besides, spurious electrons may interfere at lower energies, as discussed in sect. 5.3 and subsect. 6.3.3. Therefore, we give as our final result for the longitudinal polarization of β-particles emitted in the decay of tritium the weighted average of the values at the three highest energies only:

$$P(^3H) = -(1.005 \pm 0.026)\ v/c, \qquad (7.11)$$

at a mean energy of 15.2 keV and a corresponding mean velocity of 0.24 c. The given error is one standard deviation and includes all known sources of error (see table 7.1): counting statistics (1.4%) and errors in the polarimeter efficiency S_{an} (1.4%), in the depolarization correction (1.6%) and in the energy calibration of the apparatus (0.7%). The various errors were added quadratically.

The two-component neutrino theory discussed in subsect. 1.2.3 predicts for allowed transitions: $P = -v/c$ (for β^--particles), apart from corrections for higher-order transitions, finite nuclear size and screening by atomic electrons. These corrections can be completely neglected in our experiment (see sect. 2.2). Thus, our result 7.11, obtained with a calibrated polarimeter, with extensive checks on instrumental asymmetries and from measurements near the end point of the spectrum, agrees excellently with the theoretical prediction. In the next chapter we discuss the magnitude of the ratios C'_V/C_V and C'_A/C_A, using the result 7.11.

Most of the earlier measurements on other allowed and first-forbidden transitions yielded too low polarization values at intermediate velocities ($0.4 \lesssim v/c \lesssim 0.6$), as shown in the compilation of data of fig. 2.2. The intermediate-velocity data refer to the decays of ^{60}Co (E_o = 313 keV), ^{147}Pm (E_o = 225 keV) and ^{198}Au (E_o = 962 keV); details on energy settings can be found in this figure. Because our result 7.11 confirms the relation $P = -v/c$ at much lower velocities, we propose to ascribe these earlier deviations to instrumental effects rather than to fundamental shortcomings of the theory. The most obvious cause of the deviations may be an underestimate of the depolarization in the source material. However, several investigators (Eck64; Kli66) used thin sources in which depolarization can hardly be disastrous. Nevertheless, measurements close to the end-point energy and with preselection of energy are safer in view of scattering and straggling of unwanted higher-energy electrons in the source or in other parts of the arrangement. The use of calculated values for the polarimeter efficiency S_{an} may also cause too low polarization results at intermediate velocities because it can not be excluded that the theoretical Mott asymmetry functions S, from which the calculated S_{an}-values are derived, are too large at intermediate velocities: double-scattering experiments (Mik63; Kli65,66a; Boe71) at intermediate velocities yield lower S-values than expected theoretically, while at higher velocities theory and experiment agree.

We do not know how to explain the low polarization values of Eckardt et al. (Eck64). Their results have been obtained with one and the same polarimeter setting at 100 keV by changing the source potential. Their data were not corrected for depolarization in the source material, but we agree with the authors that the given source conditions do not suggest large corrections.

We also have no certain explanation for the previous Groningen results (Kli66) at intermediate velocities obtained with an absolutely calibrated polarimeter, but we remark that these lower values have a large error margin and that these results have not been checked with a precise source simulator. We note that a part of the deviations for the high-Z nuclei ^{147}Pm and ^{198}Au may be caused by an underestimate of the screening factor Λ (see sect. 2.2).

Bienlein et al. (Bie59) were among the first investigators who obtained precise results at higher energies. They proposed to ascribe a deviation of 16% at 120 keV for ^{60}Co to the influence of screening on their calculated S_{an}-value. However, the calculations of Lin (Lin64) and Bühring (Büh68) showed that this effect is less than 3% and offers no explanation.

Lazarus and Greenberg (Laz70) are the only investigators who report $P \approx -v/c$ at intermediate velocities (fig. 2.2). However, their data contain an unexplained discrepancy between the (large) intensity of back-scattered and consequently depolarized electrons and the (small) correction for depolarization by the source backing, given by the authors. We remark that their polarimeter was equipped with two polarization sensitive detectors at $\theta = 70^{\circ}$. Instrumental asymmetries were measured using unpolarized conversion electrons. In our experience the sensitivity to instrumental asymmetries is much larger at forward angles than at backward angles: for decreasing scattering angles the magnitude of instrumental asymmetries increases as ctg $\frac{\theta}{2}$ (Kli65,66a), while polarization asymmetries become relatively small (especially at lower energies) since the polarimeter efficiency S_{an} decreases. For an accurate determination of instrumental asymmetries we prefer two extra detectors placed at $\theta \approx 45^{\circ}$ combined with the use of a precise source simulator.

8.1. Introduction

As discussed in sect. 1.2 the experimental features of β-decay are consistent with lepton conservation, time-reversal invariance, V,A-interaction and two-component neutrino theory with left-handed neutrinos. The latter implies that the parity-conserving and the parity-violating coupling constants in the interaction hamiltonian are equal: $C_i = C_i'$, with i = V (vector) or A (axial vector).

Information about the ratios C_i'/C_i can be obtained from experimental results for the degree of longitudinal polarization of β-particles or neutrinos and for the β-γ circular polarization correlation. The observables due to parity violation contain C_i'/C_i in a form

$$x_i = 2C_iC_i'/(C_i^2 + C_i'^2) \tag{8.1}$$

($-1 \leq x_i \leq +1$). For $C_i' \approx C_i$, this "parity factor" x_i is insensitive to the value of C_i'/C_i (see fig. 8.1). Therefore, a high precision is needed to set even modest limits on possible deviations of C_i'/C_i from unity. For pure Fermi or Gamow-Teller transitions these limits are independent of assumptions on the magnitude of the nuclear matrix elements.

In a survey study published in 1965 Steffen and Frauenfelder (Ste65) suggested the limits:

$$0.4 < C_V'/C_V < 2.5 \quad \text{and} \quad 0.85 < C_A'/C_A < 1.15 \,. \tag{8.2}$$

The limits for C_V'/C_V came from positron polarization measurements on pure Fermi transitions, while the limits for C_A'/C_A were derived from β-γ circular polarization correlation data. We have to remark that the statistical interpretation of these limits is not clear. For instance, the range for C_A'/C_A was based on β-γ circular polarization correlation experiments for ^{60}Co which yielded x_A = 1.020 ± 0.030 and for ^{22}Na yielding x_A = 1.038 ± 0.054. Since the

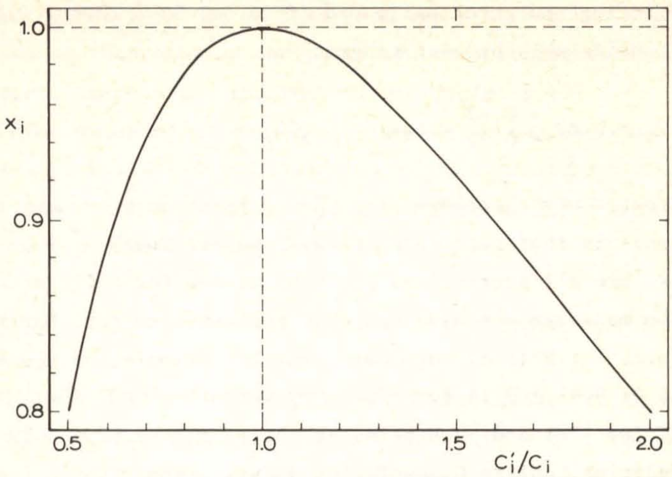

Fig. 8.1. Dependence of $x_i = 2C_iC'_i/(C_i^2 + C_i'^2)$ *on the ratio* C'_i/C_i $(i = V,A)$ *around* $C'_i/C_i = 1$.

theoretical value of x_A cannot be larger than !, the C'_A/C_A-range was obtained from the lower limit for x_A of about 0.99. The range given is only indicative, since it is strongly determined by the "lucky circumstance" that the experimental x_A-values lie rather far above the extreme value 1. A more accurate experimental result $x_A = 0.99 \pm 0.02$, for instance, would give a considerably broader range for C'_A/C_A. In the following section we give a somewhat more detailed account on confidence levels for error limits of coupling-constant ratios.

Paul (Pau70) reported in 1970 from an extensive least-squares adjustment procedure to data from the literature:

$$C'_V/C_V = 0.82 \begin{array}{l} +\ 0.40 \\ -\ 0.13 \end{array} \quad \text{and} \quad C'_A/C_A = 1.10 \pm 0.06 . \qquad (8.3a)$$

The range for C'_A/C_A might give a suggestion that C'_A/C_A deviates from unity. However, as remarked already in subsect. 1.2.1, Paul's error limits are external errors which are about 2.4 times smaller than the internal ones. Later, Kropf and Paul (Kro74) felt it safer (as we do) to use the larger of the internal and external errors. Enlarging the error estimates of (8.3a) by a factor 2.4 gives the considerably broader ranges:

$$C'_V/C_V = 0.82 \begin{smallmatrix} +\,0.97 \\ -\,0.32 \end{smallmatrix} \quad \text{and} \quad C'_A/C_A = 1.10 \pm 0.15. \qquad (8.3b)$$

The reason why the ranges for C'_V/C_V are so much braoder than the C'_A/C_A-ones is that pure Fermi decays (superallowed $0^+ \to 0^+$ transitions) are all short-lived positron decays for which accurate polarization measurements have not been performed so far. Experimental results for $P/(v/c)$ were obtained, for example, by Deutsch et al. (Deu57: 0.95 ± 0.14 for ^{34}Cl), by Gerhart et al. (Ger59: 0.73 ± 0.17 for ^{14}O) and by Hopkins et al. (Hop61: 0.97 ± 0.19 for ^{14}O). In addition, unlike Gamow-Teller decays, Fermi transitions show no β-asymmetry and no β-γ circular polarization correlation.

In the next section we show that narrower limits for C'_V/C_V follow from our tritium β-polarization measurement.

8.2. Limits obtained from the present investigation

If lepton conservation, time-reversal invariance and V,A-interaction are assumed and if the influence of screening, finite nuclear size and higher-order transitions is neglected, the theoretical expression for the degree of longitudinal polarization of β^--particles emitted in an allowed transition is (rewriting eq. 1.36 and using eq. 8.1)

$$-P/(v/c) = 1 - \rho_m (C_V - C'_V)^2/(C_V^2 + C'^2_V) - (1-\rho_m)(C_A - C'_A)^2/(C_A^2 + C'^2_A)$$
$$= \rho_m x_V + (1-\rho_m) x_A . \qquad (8.4)$$

Here, the mixing parameter

$$\rho_m = (C_V^2 + C'^2_V)\,|M_F|^2 / \left[(C_V^2 + C'^2_V)\,|M_F|^2 + (C_A^2 + C'^2_A)\,|M_{GT}|^2 \right] \qquad (8.5)$$

is a measure for the relative strengths of the Fermi and the Gamow-Teller contributions to the transition under consideration: its value lies between 0 (pure Gamow-Teller transition) and 1 (pure

Fermi transition). It is seen from eq. 8.4 that for any set of values of the coupling constants the theoretical value of $-P/(v/c)$ is restricted to the interval $-1 \lesssim -P/(v/c) \lesssim 1$.

The value of ρ_m for the tritium decay can be found by substituting in eq. 8.5 values for $\lambda^2 = (C_A^2 + C_A'^2)/(C_V^2 + C_V'^2)$ (subsect. 1.2.2) and for $|M_F(^3H)|$ and $|M_{GT}(^3H)|$ (sect. 3.5). More directly, however, $\rho_m(^3H)$ is found from the expression

$$\rho_m(^3H) = ft(^3H)\ |M_F(^3H)|^2 \ / \left[ft(0^+ \rightarrow 0^+)\ |M_F(0^+ \rightarrow 0^+)|^2\right] \quad (8.6)$$

(see eq. 1.31). Using $|M_F(^3H)| = 1$ (sect. 3.5), $ft(^3H) = 1157 \pm 4$ sec (eq. 3.4), $|M_F(0^+ \rightarrow 0^+)|^2 = 2$ and $ft(0^+ \rightarrow 0^+) = 3085 \pm 5$ sec (subsect. 1.2.2) one obtains $\rho_m(^3H) = 0.1875 \pm 0.0007$.

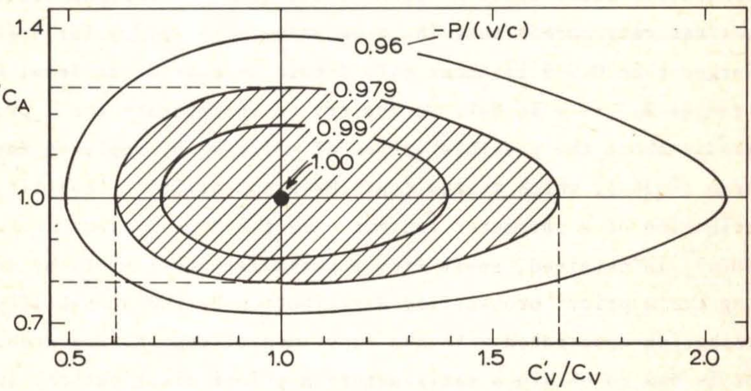

Fig. 8.2. Iso-polarization contours as calculated for various degrees of longitudinal polarization of β-particles from the tritium decay. The experimental P-value confines C_V'/C_V and C_A'/C_A to the shaded area.

In fig. 8.2 some iso-polarization contours for the tritium transition are presented which were calculated from eq. 8.4, using the above value of $\rho_m(^3H)$. In this figure we have shaded the area allowed for C_V'/C_V and C_A'/C_A if the tritium result $-P/(v/c) = 1.005 \pm 0.026$ (eq. 7.11) is interpreted as $-P/(v/c) \gtrsim 0.979$ (= 1.005 - 0.026). By taking the extremes of the contour for $-P/(v/c) = 0.979$ (see fig. 8.2) we obtained

$$0.61 < C'_V/C_V < 1.65 \quad \text{and} \quad 0.80 < C'_A/C_A < 1.26. \quad (8.7)$$

These limits do not depend sensitively on the value of ρ_m. Effectively C'_A/C_A has been considered as a free parameter for obtaining the limits for C'_V/C_V, and vice versa. The C'_V/C_V-range is much narrower than in eq. 8.2 and somewhat narrower than in eq. 8.3b. The range for C'_A/C_A is somewhat broader than the ranges given in these equations.

The statistical procedure leading to the limits 8.7 is essentially the same as was used for obtaining the limits 8.2 and is, as remarked, not unambiguous. Strictly speaking, the a priori knowledge that the "true" value of $-P/(v/c)$ must lie between −1 and +1 should be incorporated. When this a priori knowledge is ignored, our experimental result $-P/(v/c) = 1.005 \pm 0.026$ means that the probability (in "inverse probability" sense: see ref. Hud64) that the true value of $-P/(v/c)$ for tritium is larger than 0.979 is about 84%. Then, the confidence level for the ranges 8.7 is also 84%. We may try to incorporate the a priori knowledge about the possible values of $-P/(v/c)$ by applying Bayes theorem (Hud64), which states that the a posteriori probability distribution of a parameter [in our case the "true" value of $-P/(v/c)$] is obtained, apart from a normalization factor, by multiplying the a priori probability distribution by the probability distribution associated with the experimental result. The problematic point is how to obtain a satisfactory a priori distribution. In the spirit of Bayes we may define the a priori probability density of $-P/(v/c)$ as equal to one for $|P/(v/c)| \leq 1$ and as zero elsewhere. This means that each value of $-P/(v/c)$ between −1 and +1 is assumed to be equally probable a priori. Because the probability distribution associated with the experimental result is Gaussian (with a mean value of 1.005 and a standard deviation of 0.026) the a posteriori probability distribution becomes a Gaussian function truncated at $-P/(v/c) = 1$. It turns out that the a posteriori probability that the true value of $-P/(v/c)$ lies between 0.979 and 1.000 is 63%, while there is a chance of 37% that this parameter has a value below 0.979. This means that, in this approach, the confidence level of the ranges 8.7 is 63%. However, the choice of the a priori probability is rather arbitrary: if one assumes that C_i'/C_i has a constant a priori probability, a confidence level of about 80% for the ranges 8.7 is found. In conclusion, we assume a confidence level for the ranges 8.7 of about 70%.

The possibility to obtain limits for C_V'/C_V from a polarization measurement on a mixed transition remains restricted to decays between mirror nuclei. The reason is that all other mixed transitions are isospin forbidden ($\Delta T \neq 0$), so that the Fermi matrix element is small (Sch66, Ram75). As discussed in sect. 3.2, all transitions between mirror nuclei are β^+-transitions, apart from the neutron and the tritium decay. The accuracy of positron polarization measurements is poor: the most accurate result was obtained using Bhabha scattering and has a claimed accuracy of 9% (Ul161). Longitudinal polarization measurements for the decay of the free neutron have not been attempted so far, and will be hardly feasible. Thus, the tritium decay remains as the only suitable mixed transition for obtaining limits on C_V'/C_V.