



$$I(J^P) = \frac{1}{2}(\frac{1}{2}^+) \text{ Status: } ****$$

We have omitted some results that have been superseded by later experiments. See our earlier editions.

***n* MASS (atomic mass units *u*)**

The mass is known much more precisely in *u* (atomic mass units) than in MeV. The conversion from *u* to MeV, $1 \text{ u} = 931.494013 \pm 0.000037 \text{ MeV}/c^2$ (MOHR 99, the 1998 CODATA value), involves the relatively poorly known electronic charge.

<u>VALUE (<i>u</i>)</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
1.00866491578 ± 0.00000000055	MOHR	99	RVUE 1998 CODATA value
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
1.008665904 ± 0.000000014	COHEN	87	RVUE 1986 CODATA value

***n* MASS (MeV)**

The mass is known much more precisely in *u* (atomic mass units) than in MeV; see the previous data block. The conversion from *u* to MeV, $1 \text{ u} = 931.494013 \pm 0.000037 \text{ MeV}/c^2$ (MOHR 99, the 1998 CODATA value), involves the relatively poorly known electronic charge.

<u>VALUE (MeV)</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
939.565330 ± 0.000038	MOHR	99	RVUE 1998 CODATA value
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
939.565331 ± 0.000037	¹ KESSLER	99	SPEC $np \rightarrow d\gamma$
939.56565 ± 0.00028	^{2,3} DIFILIPPO	94	TRAP Penning trap
939.56563 ± 0.00028	COHEN	87	RVUE 1986 CODATA value
939.56564 ± 0.00028	^{3,4} GREENE	86	SPEC $np \rightarrow d\gamma$
939.5731 ± 0.0027	³ COHEN	73	RVUE 1973 CODATA value

¹We use the 1998 CODATA *u*-to-MeV conversion factor (see the heading above) to get this mass in MeV from the much more precisely measured KESSLER 99 value of $1.00866491637 \pm 0.00000000082 \text{ u}$.

²The mass is known much more precisely in *u*: $m = 1.0086649235 \pm 0.0000000023 \text{ u}$. We use the 1986 CODATA conversion factor to get the mass in MeV.

³These determinations are not independent of the $m_n - m_p$ measurements below.

⁴The mass is known much more precisely in *u*: $m = 1.008664919 \pm 0.000000014 \text{ u}$.

\bar{n} MASS

<u>VALUE (MeV)</u>	<u>EVTS</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
939.485 ± 0.051	59	⁵ CRESTI	86	HBC $\bar{p}p \rightarrow \bar{n}n$

⁵This is a corrected result (see the erratum). The error is statistical. The maximum systematic error is 0.029 MeV.

$$(m_n - m_{\bar{n}}) / m_n$$

A test of *CPT* invariance. Calculated from the n and \bar{n} masses, above.

VALUE _____ DOCUMENT ID _____
(9±5) × 10⁻⁵ OUR EVALUATION

$$m_n - m_p$$

<u>VALUE (MeV)</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
1.2933318 ± 0.0000005	⁶ MOHR	99	RVUE 1998 CODATA value
• • • We do not use the following data for averages, fits, limits, etc. • • •			
1.293318 ± 0.000009	⁷ COHEN	87	RVUE 1986 CODATA value
1.2933328 ± 0.0000072	GREENE	86	SPEC $np \rightarrow d\gamma$
1.293429 ± 0.000036	COHEN	73	RVUE 1973 CODATA value

⁶ Calculated by us from the MOHR 99 ratio $m_n/m_p = 1.00137841887 \pm 0.00000000058$.

In u, $m_n - m_p = (1.3884489 \pm 0.0000006) \times 10^{-3}$ u.

⁷ Calculated by us from the COHEN 87 ratio $m_n/m_p = 1.001378404 \pm 0.000000009$. In u, $m_n - m_p = 0.001388434 \pm 0.000000009$ u.

***n* MEAN LIFE**

We now compile only direct measurements of the lifetime, not those inferred from decay correlation measurements. For the average, we only use measurements with an error less than 10 s.

Limits on lifetimes for *bound* neutrons are given in the section "*p* PARTIAL MEAN LIVES."

For an early review, see EROZOLIMSKII 89 and papers that follow it in an issue of NIM devoted to the "Proceedings of the International Workshop on Fundamental Physics with Slow Neutrons" (Grenoble 1989). For later reviews and/or commentary, see FREEDMAN 90, SCHRECKENBACH 92, and PENDLEBURY 93.

<u>VALUE (s)</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
885.7 ± 0.8 OUR AVERAGE			
885.4 ± 0.9 ± 0.4	ARZUMANOV 00	CNTR	UCN double bottle
889.2 ± 3.0 ± 3.8	BYRNE	96	CNTR Penning trap
882.6 ± 2.7	⁸ MAMPE	93	CNTR Gravitational trap
888.4 ± 3.1 ± 1.1	NESVIZHEV...	92	CNTR Gravitational trap
887.6 ± 3.0	MAMPE	89	CNTR Gravitational trap
891 ± 9	SPIVAK	88	CNTR Beam
• • • We do not use the following data for averages, fits, limits, etc. • • •			
888.4 ± 2.9	ALFIMENKOV 90	CNTR	See NESVIZHEVSKII 92
893.6 ± 3.8 ± 3.7	BYRNE	90	CNTR See BYRNE 96
878 ± 27 ± 14	KOSSAKOW...	89	TPC Pulsed beam
877 ± 10	PAUL	89	CNTR Storage ring
876 ± 10 ± 19	LAST	88	SPEC Pulsed beam

903 ± 13	KOSVINTSEV 86	CNTR	Gravitational trap
937 ± 18	⁹ BYRNE 80	CNTR	
875 ± 95	KOSVINTSEV 80	CNTR	
881 ± 8	BONDAREN... 78	CNTR	See SPIVAK 88
918 ± 14	CHRISTENSEN72	CNTR	

⁸IGNATOVICH 95 calls into question some of the corrections and averaging procedures used by MAMPE 93. The response, BONDARENKO 96, denies the validity of the criticisms.

⁹This measurement has been withdrawn (J. Byrne, private communication, 1990).

n MAGNETIC MOMENT

See the "Note on Baryon Magnetic Moments" in the Λ Listings.

<u>VALUE (μ_N)</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
-1.91304272 ± 0.00000045	MOHR	99	RVUE 1998 CODATA value
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
-1.91304275 ± 0.00000045	COHEN	87	RVUE 1986 CODATA value
-1.91304277 ± 0.00000048	¹⁰ GREENE	82	MRS

¹⁰GREENE 82 measures the moment to be $(1.04187564 \pm 0.00000026) \times 10^{-3}$ Bohr magnetons. The value above is obtained by multiplying this by $m_p/m_e = 1836.152701 \pm 0.000037$ (the 1986 CODATA value from COHEN 87).

n ELECTRIC DIPOLE MOMENT

A nonzero value is forbidden by both T invariance and P invariance.

A number of early results have been omitted. See RAMSEY 90 and GOLUB 94 for reviews.

<u>VALUE (10^{-25} e cm)</u>	<u>CL%</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
< 0.63	90	¹¹ HARRIS	99	MRS $d = (-0.1 \pm 0.36) \times 10^{-25}$
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
< 0.97	90	ALTAREV	96	MRS $(+0.26 \pm 0.40 \pm 0.16) \times 10^{-25}$
< 1.1	95	ALTAREV	92	MRS See ALTAREV 96
< 1.2	95	SMITH	90	MRS See HARRIS 99
< 2.6	95	ALTAREV	86	MRS $d = (-1.4 \pm 0.6) \times 10^{-25}$
0.3 ± 4.8		PENDLEBURY	84	MRS Ultracold neutrons
< 6	90	ALTAREV	81	MRS $d = (2.1 \pm 2.4) \times 10^{-25}$
< 16	90	ALTAREV	79	MRS $d = (4.0 \pm 7.5) \times 10^{-25}$

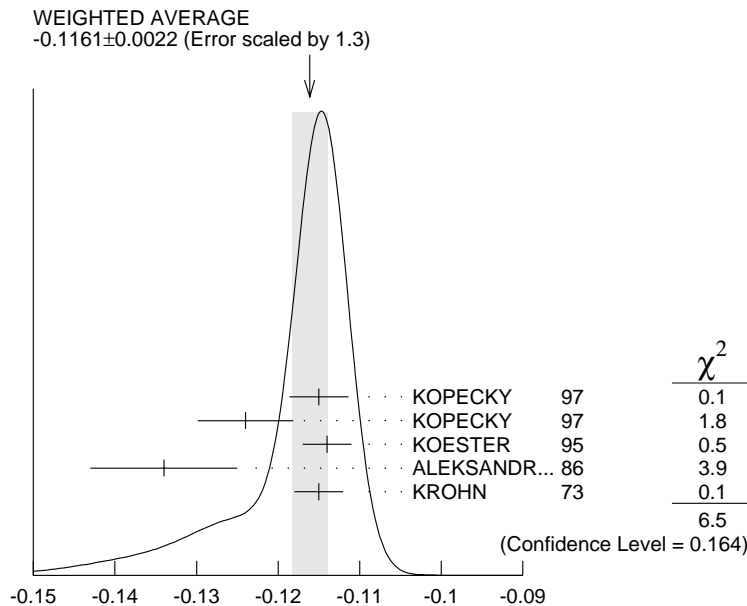
¹¹This HARRIS 99 result includes the result of SMITH 90. However, the averaging of the results of these two experiments has been criticized by LAMOREAUX 00.

n MEAN-SQUARE CHARGE RADIUS

The mean-square charge radius of the neutron, $\langle r_n^2 \rangle$, is related to the neutron-electron scattering length b_{ne} by $\langle r_n^2 \rangle = 3(m_e a_0 / m_n) b_{ne}$, where m_e and m_n are the masses of the electron and neutron, and a_0 is the Bohr radius. Numerically, $\langle r_n^2 \rangle = 86.34 b_{ne}$, if we use a_0 for a nucleus with infinite mass.

VALUE (fm ²)	DOCUMENT ID	COMMENT
-0.1161 ± 0.0022 OUR AVERAGE		Error includes scale factor of 1.3. See the ideogram below.
-0.115 ± 0.002 ± 0.003	KOPECKY 97	ne scattering (Pb)
-0.124 ± 0.003 ± 0.005	KOPECKY 97	ne scattering (Bi)
-0.114 ± 0.003	KOESTER 95	ne scattering (Pb, Bi)
-0.134 ± 0.009	ALEKSANDR...86	ne scattering (Bi)
-0.115 ± 0.003	¹² KROHN 73	ne scattering (Ne, Ar, Kr, Xe)
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●		
-0.113 ± 0.003 ± 0.004	KOPECKY 95	ne scattering (Pb)
-0.114 ± 0.003	KOESTER 86	ne scattering (Pb, Bi)
-0.118 ± 0.002	KOESTER 76	ne scattering (Pb)
-0.120 ± 0.002	KOESTER 76	ne scattering (Bi)
-0.116 ± 0.003	KROHN 66	ne scattering (Ne, Ar, Kr, Xe)

¹²This value is as corrected by KOESTER 76.



n mean-square charge radius

n ELECTRIC POLARIZABILITY α_n

Following is the electric polarizability α_n defined in terms of the induced electric dipole moment by $\mathbf{D} = 4\pi\epsilon_0\alpha_n\mathbf{E}$. For a review, see SCHMIED-MAYER 89.

VALUE (10^{-4} fm^3)	DOCUMENT ID	TECN	COMMENT
$9.8^{+1.9}_{-2.3}$ OUR AVERAGE	Error includes scale factor of 1.1.		
0.0 ± 5.0	¹³ KOESTER	95 CNTR	n Pb, n Bi transmission
$12.0 \pm 1.5 \pm 2.0$	SCHMIEDM...	91 CNTR	n Pb transmission
$10.7^{+3.3}_{-10.7}$	ROSE	90B CNTR	$\gamma d \rightarrow \gamma np$
8 ± 10	KOESTER	88 CNTR	n Pb, n Bi transmission
12 ± 10	SCHMIEDM...	88 CNTR	n Pb, n C transmission
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
13.6	¹⁴ KOLB	00 CNTR	$\gamma d \rightarrow \gamma np$
$11.7^{+4.3}_{-11.7}$	ROSE	90 CNTR	See ROSE 90B

¹³ KOESTER 95 uses natural Pb and the isotopes 208, 207, and 206. See this paper for a discussion of methods used by various groups to extract α_n from data.

¹⁴ KOLB 00 obtains this value with a lower limit of $7.6 \times 10^{-4} \text{ fm}^3$ but no upper limit from this experiment alone. Combined with results of ROSE 90, the $1\text{-}\sigma$ range is $(7.6\text{--}14.0) \times 10^{-4} \text{ fm}^3$.

n MAGNETIC POLARIZABILITY β_n

VALUE (10^{-4} fm^3)	DOCUMENT ID	TECN	COMMENT
1.6	¹⁵ KOLB	00 CNTR	$\gamma d \rightarrow \gamma np$

¹⁵ KOLB 00 obtains this value with an upper limit of $7.6 \times 10^{-4} \text{ fm}^3$ but no lower limit from this experiment alone. Combined with results of ROSE 90, the $1\text{-}\sigma$ range is $(1.2\text{--}7.6) \times 10^{-4} \text{ fm}^3$.

n CHARGE

See also " $|q_p + q_e|/e$ " in the proton Listings.

VALUE ($10^{-21} e$)	DOCUMENT ID	TECN	COMMENT
-0.4 ± 1.1	¹⁶ BAUMANN	88	Cold n deflection
-15 ± 22	¹⁷ GAEHLER	82 CNTR	Cold n deflection

¹⁶ The BAUMANN 88 error ± 1.1 gives the 68% CL limits about the the value -0.4 .
¹⁷ The GAEHLER 82 error ± 22 gives the 90% CL limits about the the value -15 .

LIMIT ON $n\bar{n}$ OSCILLATIONS

Mean Time for $n\bar{n}$ Transition in Vacuum

A test of $\Delta B=2$ baryon number nonconservation. MOHAPATRA 80 and MOHAPATRA 89 discuss the theoretical motivations for looking for $n\bar{n}$ oscillations. DOVER 83 and DOVER 85 give phenomenological analyses. The best limits come from looking for the decay of neutrons bound in nuclei. However, these analyses require model-dependent corrections for nuclear effects. See KABIR 83, DOVER 89, ALBERICO 91, and GAL 00 for discussions. Direct searches for $n \rightarrow \bar{n}$ transitions using reactor neutrons are cleaner but give somewhat poorer limits. We include limits for both free and bound neutrons in the Summary Table.

VALUE (s)	CL%	DOCUMENT ID	TECN	COMMENT
$>8.6 \times 10^7$	90	BALDO-...	94 CNTR	Reactor (free) neutrons
$>1.2 \times 10^8$	90	BERGER	90 FREJ	n bound in iron
$>1.2 \times 10^8$	90	TAKITA	86 CNTR	n bound in oxygen
• • • We do not use the following data for averages, fits, limits, etc. • • •				
$>1 \times 10^7$	90	BALDO-...	90 CNTR	See BALDO-CEOLIN 94
$>4.9 \times 10^5$	90	BRESSI	90 CNTR	Reactor neutrons
$>4.7 \times 10^5$	90	BRESSI	89 CNTR	See BRESSI 90
$>1 \times 10^6$	90	FIDECARO	85 CNTR	Reactor neutrons
$>8.8 \times 10^7$	90	PARK	85B CNTR	
$>3 \times 10^7$		BATTISTONI	84 NUSX	
$> 2.7 \times 10^7 - 1.1 \times 10^8$		JONES	84 CNTR	
$>2 \times 10^7$		CHERRY	83 CNTR	

n DECAY MODES

Mode	Fraction (Γ_i/Γ)	Confidence level
Γ_1 $p e^- \bar{\nu}_e$	100 %	
Γ_2 hydrogen-atom $\bar{\nu}_e$		
Charge conservation (Q) violating mode		
Γ_3 $p \nu_e \bar{\nu}_e$	$Q < 8 \times 10^{-27}$	68%

n BRANCHING RATIOS

$\Gamma(\text{hydrogen-atom } \bar{\nu}_e)/\Gamma_{\text{total}}$ Γ_2/Γ

VALUE	CL%	DOCUMENT ID	TECN
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• • • We do not use the following data for averages, fits, limits, etc. • • •

$<3 \times 10^{-2}$	95	¹⁸ GREEN	90 RVUE
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¹⁸ GREEN 90 infers that $\tau(\text{hydrogen-atom } \bar{\nu}_e) > 3 \times 10^4$ s by comparing neutron lifetime measurements made in storage experiments with those made in β -decay experiments. However, the result depends sensitively on the lifetime measurements, and does not of course take into account more recent measurements of same.

$\Gamma(\rho\nu_e\bar{\nu}_e)/\Gamma_{\text{total}}$					Γ_3/Γ
Forbidden by charge conservation.					
VALUE	CL%	DOCUMENT ID	TECN	COMMENT	
<8 × 10⁻²⁷	68	¹⁹ NORMAN	96	RVUE	⁷¹ Ga → ⁷¹ Ge neutrals
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<9.7 × 10 ⁻¹⁸	90	ROY	83	CNTR	¹¹³ Cd → ^{113m} In neut.
<7.9 × 10 ⁻²¹		VAIDYA	83	CNTR	⁸⁷ Rb → ^{87m} Sr neut.
<9 × 10 ⁻²⁴	90	BARABANOV	80	CNTR	⁷¹ Ga → ⁷¹ GeX
<3 × 10 ⁻¹⁹		NORMAN	79	CNTR	⁸⁷ Rb → ^{87m} Sr neut.
¹⁹ NORMAN 96 gets this limit by attributing SAGE and GALLEX counting rates to the charge-nonconserving transition ⁷¹ Ga → ⁷¹ Ge+neutrals rather than to solar-neutrino reactions.					

BARYON DECAY PARAMETERS

Written 1996 by E.D. Commins (University of California, Berkeley).

Baryon semileptonic decays

The typical spin-1/2 baryon semileptonic decay is described by a matrix element, the hadronic part of which may be written as:

$$\bar{B}_f [f_1(q^2)\gamma_\lambda + i f_2(q^2)\sigma_{\lambda\mu}q^\mu + g_1(q^2)\gamma_\lambda\gamma_5 + g_3(q^2)\gamma_5q_\lambda] B_i . \quad (1)$$

Here B_i and \bar{B}_f are spinors describing the initial and final baryons, and $q = p_i - p_f$, while the terms in f_1 , f_2 , g_1 , and g_3 account for vector, induced tensor (“weak magnetism”), axial vector, and induced pseudoscalar contributions [1]. Second-class current contributions are ignored here. In the limit of zero momentum transfer, f_1 reduces to the vector coupling constant g_V , and g_1 reduces to the axial-vector coupling constant g_A . The latter coefficients are related by Cabibbo’s theory [2], generalized to six quarks (and three mixing angles) by Kobayashi and Maskawa [3]. The g_3 term is negligible for transitions in which an e^\pm is emitted, and gives a very small correction, which can be estimated by PCAC [4], for μ^\pm modes. Recoil effects include

weak magnetism, and are taken into account adequately by considering terms of first order in

$$\delta = \frac{m_i - m_f}{m_i + m_f}, \quad (2)$$

where m_i and m_f are the masses of the initial and final baryons.

The experimental quantities of interest are the total decay rate, the lepton-neutrino angular correlation, the asymmetry coefficients in the decay of a polarized initial baryon, and the polarization of the decay baryon in its own rest frame for an unpolarized initial baryon. Formulae for these quantities are derived by standard means [5] and are analogous to formulae for nuclear beta decay [6]. We use the notation of Ref. 6 in the Listings for neutron beta decay. For comparison with experiments at higher q^2 , it is necessary to modify the form factors at $q^2 = 0$ by a “dipole” q^2 dependence, and for high-precision comparisons to apply appropriate radiative corrections [7].

The ratio g_A/g_V may be written as

$$g_A/g_V = |g_A/g_V| e^{i\phi_{AV}}. \quad (3)$$

The presence of a “triple correlation” term in the transition probability, proportional to $\text{Im}(g_A/g_V)$ and of the form

$$\boldsymbol{\sigma}_i \cdot (\mathbf{p}_\ell \times \mathbf{p}_\nu) \quad (4)$$

for initial baryon polarization or

$$\boldsymbol{\sigma}_f \cdot (\mathbf{p}_\ell \times \mathbf{p}_\nu) \quad (5)$$

for final baryon polarization, would indicate failure of time-reversal invariance. The phase angle ϕ has been measured precisely only in neutron decay (and in ^{19}Ne nuclear beta decay), and the results are consistent with T invariance.

Hyperon nonleptonic decays

The amplitude for a spin-1/2 hyperon decaying into a spin-1/2 baryon and a spin-0 meson may be written in the form

$$M = G_F m_\pi^2 \cdot \bar{B}_f (A - B\gamma_5) B_i , \quad (6)$$

where A and B are constants [1]. The transition rate is proportional to

$$\begin{aligned} R = & 1 + \gamma \hat{\omega}_f \cdot \hat{\omega}_i + (1 - \gamma)(\hat{\omega}_f \cdot \hat{\mathbf{n}})(\hat{\omega}_i \cdot \hat{\mathbf{n}}) \\ & + \alpha(\hat{\omega}_f \cdot \hat{\mathbf{n}} + \hat{\omega}_i \cdot \hat{\mathbf{n}}) + \beta \hat{\mathbf{n}} \cdot (\hat{\omega}_f \times \hat{\omega}_i) , \end{aligned} \quad (7)$$

where $\hat{\mathbf{n}}$ is a unit vector in the direction of the final baryon momentum, and $\hat{\omega}_i$ and $\hat{\omega}_f$ are unit vectors in the directions of the initial and final baryon spins. (The sign of the last term in the above equation was incorrect in our 1988 and 1990 editions.)

The parameters α , β , and γ are defined as

$$\begin{aligned} \alpha &= 2 \operatorname{Re}(s^*p) / (|s|^2 + |p|^2) , \\ \beta &= 2 \operatorname{Im}(s^*p) / (|s|^2 + |p|^2) , \\ \gamma &= (|s|^2 - |p|^2) / (|s|^2 + |p|^2) , \end{aligned} \quad (8)$$

where $s = A$ and $p = |\mathbf{p}_f| B / (E_f + m_f)$; here E_f and \mathbf{p}_f are the energy and momentum of the final baryon. The parameters α , β , and γ satisfy

$$\alpha^2 + \beta^2 + \gamma^2 = 1 . \quad (9)$$

If the hyperon polarization is \mathbf{P}_Y , the polarization \mathbf{P}_B of the decay baryons is

$$\mathbf{P}_B = \frac{(\alpha + \mathbf{P}_Y \cdot \hat{\mathbf{n}})\hat{\mathbf{n}} + \beta(\mathbf{P}_Y \times \hat{\mathbf{n}}) + \gamma\hat{\mathbf{n}} \times (\mathbf{P}_Y \times \hat{\mathbf{n}})}{1 + \alpha\mathbf{P}_Y \cdot \hat{\mathbf{n}}} . \quad (10)$$

Here \mathbf{P}_B is defined in the rest system of the baryon, obtained by a Lorentz transformation along $\hat{\mathbf{n}}$ from the hyperon rest frame, in which $\hat{\mathbf{n}}$ and \mathbf{P}_Y are defined.

An additional useful parameter ϕ is defined by

$$\beta = (1 - \alpha^2)^{1/2} \sin\phi . \quad (11)$$

In the Listings, we compile α and ϕ for each decay, since these quantities are most closely related to experiment and are essentially uncorrelated. When necessary, we have changed the signs of reported values to agree with our sign conventions. In the Baryon Summary Table, we give α , ϕ , and Δ (defined below) with errors, and also give the value of γ without error.

Time-reversal invariance requires, in the absence of final-state interactions, that s and p be relatively real, and therefore that $\beta = 0$. However, for the decays discussed here, the final-state interaction is strong. Thus

$$s = |s| e^{i\delta_s} \text{ and } p = |p| e^{i\delta_p} , \quad (12)$$

where δ_s and δ_p are the pion-baryon s - and p -wave strong interaction phase shifts. We then have

$$\beta = \frac{-2|s||p|}{|s|^2 + |p|^2} \sin(\delta_s - \delta_p) . \quad (13)$$

One also defines $\Delta = -\tan^{-1}(\beta/\alpha)$. If T invariance holds, $\Delta = \delta_s - \delta_p$. For $\Lambda \rightarrow p\pi^-$ decay, the value of Δ may be compared with the s - and p -wave phase shifts in low-energy $\pi^- p$ scattering, and the results are consistent with T invariance.

Radiative hyperon decays

For the radiative decay of a polarized spin-1/2 hyperon, $B_i \rightarrow B_f\gamma$, the angular distribution of the direction \hat{p} of the final spin-1/2 baryon in the hyperon rest frame is

$$\frac{d\Gamma_\gamma}{d\Omega} = \frac{\Gamma_\gamma}{4\pi} (1 + \alpha_\gamma \hat{p} \cdot \mathbf{P}_i) , \quad (14)$$

where \mathbf{P}_i is the hyperon polarization and the asymmetry parameter α_γ is

$$\alpha_\gamma = \frac{2\text{Re} [g'_1(0)f_M^*(0)]}{|g'_1(0)|^2 + |f_M(0)|^2} . \quad (15)$$

Here $f_M = \frac{(m_i - m_f)}{(m_i + m_f)} [(m_i + m_f)f'_2 - f'_1]$, where $f'_1(q^2)$, $f'_2(q^2)$, and $g'_1(q^2)$ are the $\Delta Q = 0$ analogs of the $|\Delta Q| = 1$ form factors defined above.

References

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$n \rightarrow pe^- \bar{\nu}_e$ DECAY PARAMETERS

See the above "Note on Baryon Decay Parameters." For discussions of recent results, see the references cited at the beginning of the section on the neutron mean life. For discussions of the values of the weak coupling constants g_A and g_V obtained using the neutron lifetime and asymmetry parameter A , comparisons with other methods of obtaining these constants, and implications for particle physics and for astrophysics, see DUBBERS 91 and WOOLCOCK 91. For tests of the $V-A$ theory of neutron decay, see EROZOLIMSKII 91B and MOSTOVOI 96.

$$\lambda \equiv g_A / g_V$$

<u>VALUE</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
-1.2670 ± 0.0030 OUR AVERAGE	Error includes scale factor of 1.6. See the ideogram below.		
-1.2686 ± 0.0046 ± 0.007	²⁰ MOSTOVOI	01 CNTR	A and $B \times$ polarizations
-1.274 ± 0.003	ABELE	97D SPEC	Cold n , polarized, A
-1.266 ± 0.004	LIAUD	97 TPC	Cold n , polarized, A
-1.2594 ± 0.0038	²¹ YEROZLIM...	97 CNTR	Cold n , polarized, A
-1.262 ± 0.005	BOPP	86 SPEC	Cold n , polarized, A
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
-1.266 ± 0.004	SCHRECK...	95 TPC	See LIAUD 97
-1.2544 ± 0.0036	EROZOLIM...	91 CNTR	See YEROZOLIM-SKY 97
-1.226 ± 0.042	MOSTOVOY	83 RVUE	
-1.261 ± 0.012	EROZOLIM...	79 CNTR	Cold n , polarized, A
-1.259 ± 0.017	²² STRATOWA	78 CNTR	p recoil spectrum, a
-1.263 ± 0.015	EROZOLIM...	77 CNTR	See EROZOLIMSKII 79
-1.250 ± 0.036	²² DOBROZE...	75 CNTR	See STRATOWA 78
-1.258 ± 0.015	²³ KROHN	75 CNTR	Cold n , polarized, A
-1.263 ± 0.016	²⁴ KROPF	74 RVUE	n decay alone
-1.250 ± 0.009	²⁴ KROPF	74 RVUE	n decay + nuclear ft

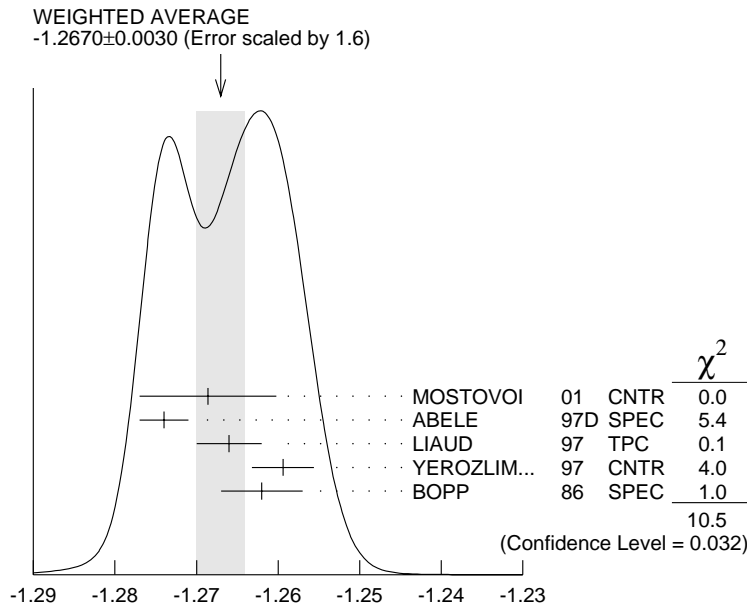
²⁰ MOSTOVOI 01 measures the two P -odd correlations A and B , or rather SA and SB , where S is the n polarization, in free neutron decay.

²¹ YEROZOLIMSKY 97 makes a correction to the EROZOLIMSKII 91 value.

²² These experiments measure the absolute value of g_A/g_V only.

²³ KROHN 75 includes events of CHRISTENSEN 70.

²⁴ KROPF 74 reviews all data through 1972.



$$\lambda \equiv g_A / g_V$$

β ASYMMETRY PARAMETER A

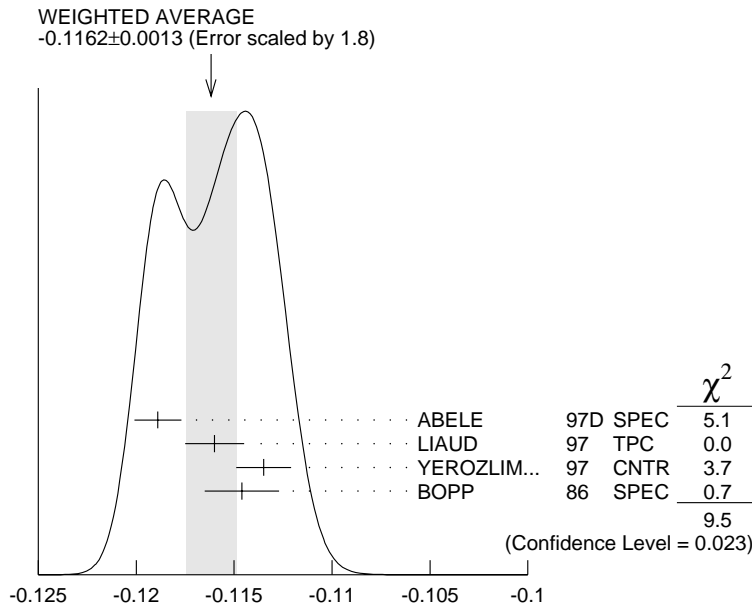
This is the neutron-spin electron-momentum correlation coefficient. Unless otherwise noted, the values are corrected for radiative effects and weak magnetism.

<u>VALUE</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
-0.1162 ± 0.0013 OUR AVERAGE	Error includes scale factor of 1.8. See the ideogram below.		
-0.1189 ± 0.0012	ABELE	97D SPEC	Cold n , polarized
$-0.1160 \pm 0.0009 \pm 0.0012$	LIAUD	97 TPC	Cold n , polarized
-0.1135 ± 0.0014	²⁵ YEROZLIM...	97 CNTR	Cold n , polarized
-0.1146 ± 0.0019	BOPP	86 SPEC	Cold n , polarized
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
-0.1168 ± 0.0017	²⁶ MOSTOVOI	01 CNTR	Inferred
$-0.1160 \pm 0.0009 \pm 0.0011$	SCHRECK...	95 TPC	See LIAUD 97
-0.1116 ± 0.0014	EROZOLIM...	91 CNTR	See YEROZOLIM-SKY 97
-0.114 ± 0.005	²⁷ EROZOLIM...	79 CNTR	Cold n , polarized
-0.113 ± 0.006	²⁷ KROHN	75 CNTR	Cold n , polarized

²⁵ YEROZOLIMSKY 97 makes a correction to the EROZOLIMSKII 91 value.

²⁶ MOSTOVOI 01 calculates this from its measurement of $\lambda = g_A / g_V$ above.

²⁷ These results are not corrected for radiative effects and weak magnetism, but the corrections are small compared to the errors.



β asymmetry parameter A

$\bar{\nu}_e$ ASYMMETRY PARAMETER B

This is the neutron-spin antineutrino-momentum correlation coefficient.

VALUE	DOCUMENT ID	TECN	COMMENT
0.983 ± 0.004 OUR AVERAGE			
0.9801 ± 0.0046	SEREBROV 98	CNTR	Cold n , polarized
0.9894 ± 0.0083	KUZNETSOV 95	CNTR	Cold n , polarized
0.995 ± 0.034	CHRISTENSEN70	CNTR	Cold n , polarized
1.00 ± 0.05	EROZOLIM...	70C CNTR	Cold n , polarized
••• We do not use the following data for averages, fits, limits, etc. •••			
0.9876 ± 0.0004	²⁸ MOSTOVOI 01	CNTR	Inferred

²⁸MOSTOVOI 01 calculates this from its measurement of $\lambda = g_A/g_V$ above.

$e\bar{\nu}_e$ ANGULAR CORRELATION COEFFICIENT a

VALUE	DOCUMENT ID	TECN	COMMENT
-0.102 ± 0.005 OUR AVERAGE			
-0.1017 ± 0.0051	STRATOWA 78	CNTR	Proton recoil spectrum
-0.091 ± 0.039	GRIGOREV 68	SPEC	Proton recoil spectrum
••• We do not use the following data for averages, fits, limits, etc. •••			
-0.1045 ± 0.0014	²⁹ MOSTOVOI 01	CNTR	Inferred

²⁹MOSTOVOI 01 calculates this from its measurement of $\lambda = g_A/g_V$ above.

ϕ_{AV} , PHASE OF g_A RELATIVE TO g_V

Time reversal invariance requires this to be 0 or 180°. This is related to D given in the next data block and $\lambda \equiv g_A/g_V$ by $\sin(\phi_{AV}) = D(1+3\lambda^2)/2\lambda$.

VALUE (°)	DOCUMENT ID	TECN	COMMENT
180.08±0.10 OUR AVERAGE			
180.08±0.13	LISING	00	CNTR Polarized >93%
179.71±0.39	EROZOLIM...	78	CNTR Cold n , polarized
180.35±0.43	EROZOLIM...	74	CNTR Cold n , polarized
180.14±0.22	STEINBERG	74	CNTR Cold n , polarized

• • • We do not use the following data for averages, fits, limits, etc. • • •

181.1 ±1.3 ³⁰ KROPF 74 RVUE n decay

³⁰ KROPF 74 reviews all data through 1972.

TRIPLE CORRELATION COEFFICIENT D

These are measurements of the component of n spin perpendicular to the decay plane in β decay. Should be zero if T invariance is not violated.

VALUE	DOCUMENT ID	TECN	COMMENT
(-0.6 ±1.0) × 10⁻³ OUR AVERAGE			
- 0.0006±0.0012±0.0005	LISING	00	CNTR Polarized >93%
+ 0.0022±0.0030	EROZOLIM...	78	CNTR Cold n , polarized
- 0.0027±0.0050	³¹ EROZOLIM...	74	CNTR Cold n , polarized
- 0.0011±0.0017	STEINBERG	74	CNTR Cold n , polarized

³¹ EROZOLIMSKII 78 says asymmetric proton losses and nonuniform beam polarization may give a systematic error up to 0.003, thus increasing the EROZOLIMSKII 74 error to 0.005. STEINBERG 74 and STEINBERG 76 estimate these systematic errors to be insignificant in their experiment.

n REFERENCES

We have omitted some papers that have been superseded by later experiments. See our earlier editions.

MOSTOVOI	01	PAN 64 1955	Yu.A. Mostovoi <i>et al.</i>	
		Translated from YAF 64 2040.		
ARZUMANOV	00	PL B483 15	S. Arzumanov <i>et al.</i>	
GAL	00	PR C61 028201	A. Gal	
KOLB	00	PRL 85 1388	N.R. Kolb <i>et al.</i>	
LAMOREAUX	00	PR D61 051301R	S.K. Lamoreaux, R. Golub	
LISING	00	PR C62 055501	L.J. Lising <i>et al.</i>	(NIST emiT Collab.)
HARRIS	99	PRL 82 904	P.G. Harris <i>et al.</i>	
KESSLER	99	PL A255 221	E.G. Kessler Jr <i>et al.</i>	
MOHR	99	JPCRD 28 1713	P.J. Mohr, B.N. Taylor	(NIST)
Also	00	RMP 72 351	P.J. Mohr, B.N. Taylor	(NIST)
SEREBROV	98	JETP 86 1074	A.P. Serebrov <i>et al.</i>	
		Translated from ZETF 113 1963.		
ABELE	97D	PL B407 212	H. Abele <i>et al.</i>	(HEIDP, ILLG)
KOPECKY	97	PR C56 2229	S. Kopecky <i>et al.</i>	
LIAUD	97	NP A612 53	P. Liaud <i>et al.</i>	(ILLG, LAPP)
YEROZLIM...	97	PL B412 240	B.G. Erokolimsky <i>et al.</i>	(HARV, PNPI, KIAE)
ALTAREV	96	PAN 59 1152	I.S. Altarev <i>et al.</i>	(PNPI)
		Translated from YAF 59 1204.		
BONDAREN...	96	JETPL 64 416	L.N. Bondarenko <i>et al.</i>	(KIAE)
		Translated from ZETFP 64 382.		
BYRNE	96	EPL 33 187	J. Byrne <i>et al.</i>	(SUSS, ILLG)
MOSTOVOI	96	PAN 59 968	Y.A. Mostovoy	(KIAE)
		Translated from YAF 59 1013.		
NORMAN	96	PR D53 4086	E.B. Norman, J.N. Bahcall, M. Goldhaber	(LBL+)
IGNATOVICH	95	JETPL 62 1	V.K. Ignatovich	(JINR)
		Translated from ZETFP 62 3.		

KOESTER	95	PR C51 3363	L. Koester <i>et al.</i>	(+)
KOPECKY	95	PRL 74 2427	S. Kopecky <i>et al.</i>	
KUZNETSOV	95	PRL 75 794	I.A. Kuznetsov <i>et al.</i>	(PNPI, KIAE, HARV+)
SCHRECK...	95	PL B349 427	K. Schreckenbach <i>et al.</i>	(MUNT, ILLG, LAPP)
BALDO-...	94	ZPHY C63 409	M. Baldo-Ceolin <i>et al.</i>	(HEID, ILLG, PADO+)
DIFILIPPO	94	PRL 73 1481	F. DiFilippo <i>et al.</i>	(MIT)
Also	93	PRL 71 1998	V. Natarajan <i>et al.</i>	(MIT)
GOLUB	94	PRPL 237C 1	R. Golub, K. Lamoreaux	(HAHN, WASH)
MAMPE	93	JETPL 57 82	B. Mampe <i>et al.</i>	(KIAE)
PENDLEBURY	93	ARNPS 43 687	J.M. Pendlebury	(ILLG)
ALTAREV	92	PL B276 242	I.S. Altarev <i>et al.</i>	(PNPI)
NEVIZHEV...	92	JETP 75 405	V.V. Nesvizhevsky <i>et al.</i>	(PNPI, JINR)
SCHRECK...	92	JPG 18 1	K. Schreckenbach, W. Mampe	(ILLG)
ALBERICO	91	NP A523 488	W.M. Alberico, A. de Pace, M. Pignone	(TORI)
DUBBERS	91	NP A527 239c	D. Dubbers	(ILLG)
Also	90	EPL 11 195	D. Dubbers, W. Mampe, J. Dohner	(ILLG, HEID)
EROZOLIM...	91	PL B263 33	B.G. Erozolimsky <i>et al.</i>	(PNPI, KIAE)
Also	90	SJNP 52 999	B.G. Erozolimsky <i>et al.</i>	(PNPI, KIAE)
EROZOLIM...	91B	SJNP 53 260	B.G. Erozolimsky, Y.A. Mostovoy	(KIAE)
SCHMIEDM...	91	PRL 66 1015	J. Schmiedmayer <i>et al.</i>	(TUW, ORNL)
WOOLCOCK	91	MPL A6 2579	W.S. Woolcock	(CANB)
ALFIMENKOV	90	JETPL 52 373	V.P. Alfimenkov <i>et al.</i>	(PNPI, JINR)
BALDO-...	90	PL B236 95	M. Baldo-Ceolin <i>et al.</i>	(PADO, PAVI, HEIDP+)
BERGER	90	PL B240 237	C. Berger <i>et al.</i>	(FREJUS Collab.)
BRESSI	90	NC 103A 731	G. Bressi <i>et al.</i>	(PAVI, ROMA, MILA)
BYRNE	90	PRL 65 289	J. Byrne <i>et al.</i>	(SUSS, NBS, SCOT, CBNM)
FREEDMAN	90	CNPP A19 209	S.J. Freedman	(ANL)
GREEN	90	JPG 16 L75	K. Green, D. Thompson	(RAL)
RAMSEY	90	ARNPS 40 1	N.F. Ramsey	(HARV)
ROSE	90	PL B234 460	K.W. Rose <i>et al.</i>	(GOET, MPCM, MANZ)
ROSE	90B	NP A514 621	K.W. Rose <i>et al.</i>	(GOET, MPCM)
SMITH	90	PL B234 191	K.F. Smith <i>et al.</i>	(SUSS, RAL, HARV+)
BRESSI	89	ZPHY C43 175	G. Bressi <i>et al.</i>	(INFN, MILA, PAVI, ROMA)
DOVER	89	NIM A284 13	C.B. Dover, A. Gal, J.M. Richard	(BNL, HEBR+)
EROZOLIM...	89	NIM A284 89	B.G. Erozolimsky	(PNPI)
KOSSAKOW...	89	NP A503 473	R. Kossakowski <i>et al.</i>	(LAPP, SAVO, ISNG+)
MAMPE	89	PRL 63 593	W. Mampe <i>et al.</i>	(ILLG, RISL, SUSS, URI)
MOHAPATRA	89	NIM A284 1	R.N. Mohapatra	(UMD)
PAUL	89	ZPHY C45 25	W. Paul <i>et al.</i>	(BONN, WUPP, MPIH, ILLG)
SCHMIEDM...	89	NIM A284 137	J. Schmiedmayer, H. Rauch, P. Riels	(WIEN)
BAUMANN	88	PR D37 3107	J. Baumann <i>et al.</i>	(BAYR, MUNI, ILLG)
KOESTER	88	ZPHY A329 229	L. Koester, W. Waschkowski, J. Meier	(MUNI, MUNT)
LAST	88	PRL 60 995	I. Last <i>et al.</i>	(HEIDP, ILLG, ANL)
SCHMIEDM...	88	PRL 61 1065	J. Schmiedmayer, H. Rauch, P. Riels	(TUW)
Also	88B	PRL 61 2509 erratum	J. Schmiedmayer, H. Rauch, P. Riels	(TUW)
SPIVAK	88	JETP 67 1735	P.E. Spivak	(KIAE)
COHEN	87	RMP 59 1121	E.R. Cohen, B.N. Taylor	(RISC, NBS)
ALEKSANDR...	86	SJNP 44 900	Yu.A. Aleksandrov <i>et al.</i>	
ALTAREV	86	JETPL 44 460	I.S. Altarev <i>et al.</i>	(PNPI)
BOPP	86	PRL 56 919	P. Bopp <i>et al.</i>	(HEIDP, ANL, ILLG)
Also	88	ZPHY C37 179	E. Klempt <i>et al.</i>	(HEIDP, ANL, ILLG)
CRESTI	86	PL B177 206	M. Cresti <i>et al.</i>	(PADO)
Also	88	PL B200 587 erratum	M. Cresti <i>et al.</i>	(PADO)
GREENE	86	PRL 56 819	G.L. Greene <i>et al.</i>	(NBS, ILLG)
KOESTER	86	PL 137B 282	L. Koester <i>et al.</i>	
KOSVINTSEV	86	JETPL 44 571	Y.Y. Kosvintsev, V.I. Morozov, G.I. Terekhov	(KIAE)
TAKITA	86	PR D34 902	M. Takita <i>et al.</i>	(KEK, TOKY+)
DOVER	85	PR C31 1423	C.B. Dover, A. Gal, J.M. Richard	(BNL)
FIDECARO	85	PL 156B 122	G. Fidecaro <i>et al.</i>	(CERN, ILLG, PADO+)
PARK	85B	NP B252 261	H.S. Park <i>et al.</i>	(IMB Collab.)
BATTISTONI	84	PL 133B 454	G. Battistoni <i>et al.</i>	(NUSEX Collab.)
JONES	84	PRL 52 720	T.W. Jones <i>et al.</i>	(IMB Collab.)
PENDLEBURY	84	PL 136B 327	J.M. Pendlebury <i>et al.</i>	(SUSS, HARV, RAL+)
CHERRY	83	PRL 50 1354	M.L. Cherry <i>et al.</i>	(PENN, BNL)

DOVER	83	PR D27 1090	C.B. Dover, A. Gal, J.M. Richard	(BNL)
KABIR	83	PRL 51 231	P.K. Kabir	(HARV)
MOSTOVOY	83	JETPL 37 196	Y.A. Mostovoy	(KIAE)
		Translated from ZETFP 37 162.		
ROY	83	PR D28 1770	A. Roy <i>et al.</i>	(TATA)
VAIDYA	83	PR D27 486	S.C. Vaidya <i>et al.</i>	(TATA)
GAEHLER	82	PR D25 2887	R. Gahler, J. Kalus, W. Mampe	(BAYR, ILLG)
GREENE	82	Metrologia 18 93	G.L. Greene <i>et al.</i>	(YALE, HARV, ILLG+)
ALTAREV	81	PL 102B 13	I.S. Altarev <i>et al.</i>	(PNPI)
BARABANOV	80	JETPL 32 359	I.R. Barabanov <i>et al.</i>	(PNPI)
		Translated from ZETFP 32 384.		
BYRNE	80	PL 92B 274	J. Byrne <i>et al.</i>	(SUSS, RL)
KOSVINTSEV	80	JETPL 31 236	Y.Y. Kosvintsev <i>et al.</i>	(JINR)
		Translated from ZETFP 31 257.		
MOHAPATRA	80	PRL 44 1316	R.N. Mohapatra, R.E. Marshak	(CUNY, VPI)
ALTAREV	79	JETPL 29 730	I.S. Altarev <i>et al.</i>	(PNPI)
		Translated from ZETFP 29 794.		
EROZOLIM...	79	SJNP 30 356	B.G. Erozolimsky <i>et al.</i>	(KIAE)
		Translated from YAF 30 692.		
NORMAN	79	PRL 43 1226	E.B. Norman, A.G. Seamster	(WASH)
BONDAREN...	78	JETPL 28 303	L.N. Bondarenko <i>et al.</i>	(KIAE)
		Translated from ZETFP 28 328.		
Also	82	Smolenice Conf.	P.G. Bondarenko	(KIAE)
EROZOLIM...	78	SJNP 28 48	B.G. Erozolimsky <i>et al.</i>	(KIAE)
		Translated from YAF 28 98.		
STRATOWA	78	PR D18 3970	C. Stratowa, R. Dobrozemsky, P. Weinzierl	(SEIB)
EROZOLIM...	77	JETPL 23 663	B.G. Erozolimsky <i>et al.</i>	(KIAE)
		Translated from ZETFP 23 720.		
KOESTER	76	PRL 36 1021	L. Koester <i>et al.</i>	
STEINBERG	76	PR D13 2469	R.I. Steinberg <i>et al.</i>	(YALE, ISNG)
DOBROZE...	75	PR D11 510	R. Dobrozemsky <i>et al.</i>	(SEIB)
KROHN	75	PL 55B 175	V.E. Krohn, G.R. Ringo	(ANL)
EROZOLIM...	74	JETPL 20 345	B.G. Erozolimsky <i>et al.</i>	
		Translated from ZETFP 20 745.		
KROPF	74	ZPHY 267 129	H. Kropf, E. Paul	(LINZ)
Also	70	NP A154 160	H. Paul	(VIEN)
STEINBERG	74	PRL 33 41	R.I. Steinberg <i>et al.</i>	(YALE, ISNG)
COHEN	73	JPCRD 2 664	E.R. Cohen, B.N. Taylor	(RISC, NBS)
KROHN	73	PR D8 1305	V.E. Krohn, G.R. Ringo	
CHRISTENSEN	72	PR D5 1628	C.J. Christensen <i>et al.</i>	(RISO)
CHRISTENSEN	70	PR C1 1693	C.J. Christensen, V.E. Krohn, G.R. Ringo	(ANL)
EROZOLIM...	70C	PL 33B 351	B.G. Erozolimsky <i>et al.</i>	(KIAE)
GRIGOREV	68	SJNP 6 239	V.K. Grigoriev <i>et al.</i>	(ITEP)
		Translated from YAF 6 329.		
KROHN	66	PR 148 1303	V.E. Krohn, G.R. Ringo	