SPIN EFFECTS IN THE WEAK INTERACTION

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SPIN EFFECTS IN THE WEAK INTERACTION [1]

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Résumé - Les expériences modernes sur la désintegration béta du neutron ainsi que des noyaux légers fournissent des contraintes importantes sur la theorie de l'interaction faible. Ces expériences produisent des valeurs plus précises des constantes de couplage permis et induit de l'interaction faible, et permettent de contraindre les extensions possibles au "modèle standard" électro-faible.

Abstract - Modern experiments investigating the beta decay of the neutron and light nuclei are still provide important constraints on the theory of the weak interaction. Beta decay experiments are yielding more precise values for allowed and induced weak coupling constants and putting constraints on possible extensions to the standard electroweak model. Here we emphasize the implications of recent experiments to pin down the strengths of the weak vector and axial vector couplings of the nucleon.

1 - INTRODUCTION

Nuclear beta decay was the first observed manifestation of the weak interaction and its sixty year old theoretical description, invented by Fermi, eventually led us to the modern SU(2)XU(1) electroweak "Standard Model". In this, nuclear beta decay experiments provided crucial guidance, but this simple semileptonic decay is just one example of the multitude of processes described by the modern theory. A rich phenomenology involving leptons and exotic hadrons containing quarks from all three generations is now compiled in standard references, and it is probable that by next year LEP experimenters will add much more from studying the records of more than a million Z_0 decays. So it is ironic that nuclear beta decay experiments with only first generation quarks and leptons and low energies are still making important contributions. Yet refined nuclear experiments continue to determine critical parameters with the best precision and they provide unique tests of possible extensions to the Standard Model. The values of the parameters from nuclear experiments are also essential inputs to theories astrophysics and cosmology. Here we consider some issues that are presently being addressed. We will concentrate on experiments studying neutron beta decay and the beta decay of light nuclei. In particular we will emphasize recent work to determine the values of the allowed weak couplings of nucleons and of quarks. Modern nuclear beta decay experiments are characterized by a remarkable variety of cunning techniques, consistent with the theme of this conference many experiments exploit polarization phenomena associated with the weak interaction.

For the present purpose it is useful to adopt the so-called "elementary particle" view point and to regard a nuclear state as if it were an elementary particle characterized by its spin, isospin, and parity /1/. Many of the important questions are complicated by isospin breaking, and to estimate corrections one must often resort to microscopic nuclear models. We begin our discussion with neutron decay. This simple mirror decay between spin-1/2 fermions illustrates most of the important issues and there are no nuclear physics complications.

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2 - NEUTRON BETA DECAY

At energies much lower that the W-boson rest mass (M_W) semileptonic decays are described in a standard model approximation by an effective current-current hamiltonian similar to the form originally proposed by Fermi, $H_{eff}=(G_\beta/\sqrt{2})J^{\mu+}j_\mu$+hc. A consequence of the standard model is the correspondence, $G_\beta/\sqrt{2}=g^2/M_W^2$, which explains why the weak interaction is so feeble at low energies in the context of a unified model in which the coupling g is about as large as the electromagnetic coupling e. In the "Minimal Standard Model" the leptonic charged current matrix element is

$$\langle \bar{\nu} e | j_\mu | 0 \rangle = \bar{u}_e \gamma_\mu (1 + \gamma_5)\, u_{\bar{\nu}} \quad .$$

The weak current is designed so that the weak interaction couples to the left (right) handed helicity leptons (antileptons). This unexpected feature is supported by decades of experiments but it was missed in Fermi's original formulation. Although experiments are consistent with a purely left handed theory, the signal of even a small right handed impurity is being actively sought. In a particular class of theories that incorporate both left and right handed couplings the weak interaction would appear to be symmetric at high energies /2/. For many, this kind of theory is an attractively logical extension to the Standard Model.

The quark currents are thought to have the same form as the leptonic current but nucleons are composite objects and, in general, we would need a detailed theory of hadronic structure in order to relate hadronic currents to quark currents. The correct description of the strong interaction between quarks is believed to be a SU(3) (color) gauge theory (quantum chromodynamics (QCD)) but this theory has not been solved in the confined phase appropriate to hadronic matter. Nevertheless, in general, the matrix element of the nucleon charged current is given by the expression,

$$\langle n | J_\mu | p \rangle = \bar{u}_n \left[g_V \gamma_\mu + i \left(g_M / 2M \right) \sigma_{\mu\nu} q^\nu + \left(g_S / 2M \right) q_\mu \right] u_p$$

$$+ \bar{u}_n \left[g_A \gamma_\mu \gamma_5 - i \left(g_T / 2M \right) \sigma_{\mu\nu} q^\nu \gamma_5 - \left(g_P / 2M \right) q_\mu \gamma_5 \right] u_p \quad .$$

In principle the g's are functions of the square of the momentum transfer but they can be well approximated as constants for low energy beta decay. Although we cannot yet calculate these coupling constants from first principles there are several important aspects of the theory that can be tested by determining their values.

Except for radiative corrections the nucleon and the quark vector coupling constants are identical in the Standard Model. The principle insuring this correspondence, weak vector current conservation (CVC) /3/, is a natural consequence of the model. Current conservation also applies to complicated nuclei, so the vector coupling strength should be universal. The strength of the vector interaction, $G_V=G_\beta\, g_V$ is related (with additional radiative corrections) to the coupling strength for purely leptonic muon beta decay by $G_V/G_\mu=\cos\theta_C$, where θ_C is the Cabbibo angle. In the more general six quark model this ratio is just the first element of the "Kobayashi-Maskawa matrix". Measurements of the vector strength combined with measurements of strange particle decay and B-meson decay are now being used in attempts to verify that the K-M matrix is unitary /4/.

In contrast to the vector current, the axial vector current is not conserved and it is necessary to determine the nucleon axial vector strength, $G_A=G_\beta\, g_A$ directly from neutron beta decay. In the naive (nonrelativistic) quark model $g_A/g_V=\Delta u-\Delta d= -5/3$, where Δu and Δd are the average value of the up and down quark spin along the nucleon spin. As we shall see the experiment value is closer to -5/4. The difference has important implication for the spin structure of the nucleon and various QCD-inspired models of the nucleon.

The remaining four coupling constants are coefficients in the terms proportional to momentum transfer (recoil order terms) in the matrix element of the current. Two of these terms are expected to be zero because of symmetry principles. Vector current conservation directly implies that the "induced scalar", g_S, is zero. Another important symmetry constraint is obtained by noting that the strong interaction (QCD) is invariant under both charge conjugation and, to the extent that m_u and m_d are equal, isospin rotation. As a consequence, the weak vector and axial vector currents (including the terms induced by the strong interaction between the quarks) must each transform consistently under the product transformation (G-parity). The implication is that $g_S=0$, and that the "induced tensor", g_T, is zero as well. The search for these "second class" terms has been the goal of precision nuclear beta decay experiments during the past two decades /5/.

A simple relationship between the "weak magnetism" coupling constant and the magnetic moments of the neutron and proton ($g_M=\mu_p-\mu_n-1$) is a direct consequence of electroweak unification in the Standard Model and isospin symmetry. This prediction predates the Standard Model since it is a consequence of the strong form of the CVC hypothesis which postulates that the weak vector current and the isovector part of the electromagnetic current come from a single isospin multiplet of conserved currents. There are similar implications for the isodoublet and triplet mirror nuclei. Indeed, the classic test of this principle comes from precise measurements spectral shape corrections in the isotriplet mass 12 system. However, the extreme difficulty of these measurements has led to controversy /6/. Better tests of weak magnetism and the absence of second class couplings come from elegant angular correlation measurements that have been perfected during the last 15 years /5/. The status of these experiments, particularly those involving the angular correlations of betas from aligned nuclei, was discussed during the last Polarization Conference /7/.

The "induced pseudoscalar" coupling constant, g_P should be finite but its effect is strongly suppressed by the kinematics of low energy beta decay. Reasonably accurate values of g_P are inferred from muon capture experiments in which the momentum transfer is larger. A specific relationship of g_P to g_A is one consequence of the hypothesis (PCAC) that the axial-vector current is nearly conserved and its small divergence is related to the pion /5/.

If time reversal invariance is enforced then all the couplings are relatively real. There is little theoretical guidance for experimenters who search for the consequences of time symmetry failure in low energy beta decay. The simplest phenomenology based on universality in the Minimal Standard Model indicates that the effects will be hopelessly small, but the discovery of a larger effect could be revolutionary. Few new experiments have been attempted in recent years but some are planned in hopes of discovering even a small clue to the origin of the puzzling CP violation observed in neutral kaon decay /8/.

At present, experiments support all the Standard Model expectations for the sizes of the induced couplings at the 10% to 20% level and better experiments are being developed. However, there are important questions which can be settled by knowing the values of the less exotic allowed couplings, G_A and G_V and we concentrate on these issues below.

3 - THE NEUTRON LIFETIME

Neutron beta decay experiments are finally providing consistent results. The neutron lifetime dependence on the weak coupling constants is displayed by the relation

$$f\tau = \frac{2\pi^3\hbar^7}{m_e^5c^4}\,\frac{1}{G_V^2(1 + 3\,\lambda^2)}$$

with

$$\lambda = |G_A/G_V|$$

The statistical rate function f is the usual phase space integral corrected for the final state coulomb interaction. The induced couplings expected from CVC make a negligible correction to this relationship but radiative corrections must be included /9/.

Before 1986, the neutron lifetime values obtained from different experiments were very inconsistent and fig. 1 displays an ideogram of these older results. All of the experiments utilized thermal neutron beams from reactors. A 15% variation of the results, despite much smaller reported errors, reflects the experimental difficulties of making absolute measurements of neutron decay rates and neutron fluxes.

The experimental situation changed dramatically in the last five years and fig. 2 is the corresponding ideogram of the seven consistent neutron lifetimes reported since 1986. Except for the result of Spivak which is a re-analysis of an earlier experiment all of these measurements were made with cold neutron beams or with ultracold neutrons confined in material

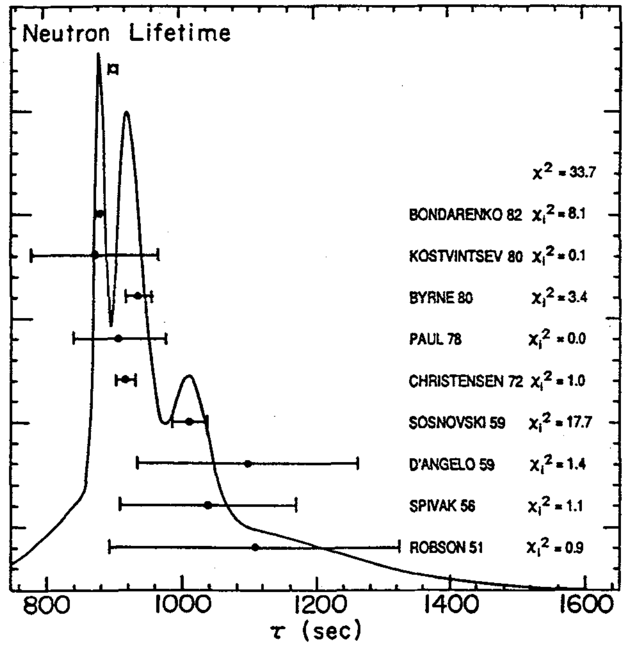

Fig. 1 - Ideogram of neutron lifetime results before 1986 /8/. Each result is represented by a gaussian curve of unit area and a width given from the reported error.

"bottles" or in magnetic storage rings. The experiments with stored neutrons hold the promise of even more precise determinations since they are based on relative rather than absolute measurements.

The experiment with the smallest reported error is the work of Mampe et al. /10/ who measured the lifetime of neutrons contained in a material bottle. Very slow neutrons have wavelengths long compared to the spacing of atoms in solids and thus their propagation is dominated by coherent forward scattering like the propagation of light. It turns out that the effective index of refraction for neutrons in many solids is less than one, decreasing with increasing wavelengths. For neutrons with velocities below about 7 m/sec the index of refraction in many materials is imaginary and indicating total neutron reflection at all incident angles. The walls of the glass box used by Mampe et al was covered with a fluorinated oil (Fomblin) having remarkably few impurities which could inelastically scatter of absorb neutrons. The oil also provides an easily renewable and reproducible surface. The box was filled with ultracold neutrons from a newly installed rotating turbine neutron cooler at the Institute Laue Langevin reactor (ILL). After a specified time the number of neutrons remaining in the box was counted with a ^{3}He-detector. The lifetime in the box was inferred from measurements with different sitting times. The size of the box could be changed and to evaluated the small but inevitable loss of neutrons from incoherent interactions with the walls, measurements were made for different volumes and thus for different surface to volume ratios. After corrections, the final result is τ=887.6±3 sec.

The most recent lifetime is from an in-beam experiment by Byrne et al. /11/ carried out at a cold neutron beam position at the ILL. They measured the neutron decay rate in a well defined volume of a Penning trap which collected the residue protons from beta decay. The trapped protons where subsequently accelerated and detected in a silicon detector. The neutron flux was measured by detecting alpha particles from the ^{10}B(n,α)^{7}Li reaction. The target was an accurately calibrated foil containing boron. The neutron and β-decay detection methods both have efficiencies proportional to 1/v and thus the neutron velocity distribution cancels. Despite the difficulties of making two absolute measurements, Byrne et al. obtain τ=893.6±5.3 sec, in agreement with the result of Mampe et al.

Taking the weighted average of the lifetimes reported since 1986 we have τ=888.8±2.4 sec /12/. The new experiments are consistent and we can have some confidence that we finally know the neutron lifetime to better than one percent.

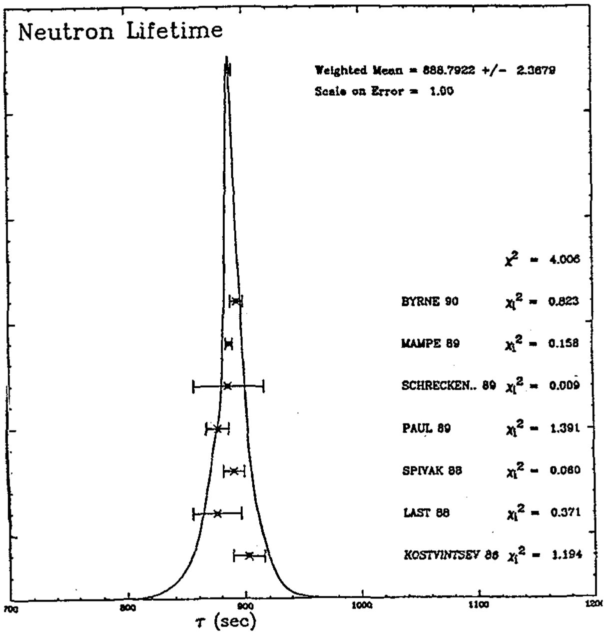

Fig. 2 - Ideogram of neutron lifetime results since 1986 /12/.

4 - CORRELATIONS IN NEUTRON DECAY

The pioneering experiment to measure the correlations of particles from neutron decay was completed in 1960 by Burgy et al. at Argonne. In terms of the experimental observables so far utilized the decay angular correlation in neutron decay is given by the expression /13/

$$dW = dW(p_e)\, d\Omega_e d\Omega_\nu \left[1 + a \frac{\vec{p}_e}{E_e} \bullet \frac{\vec{p}_\nu}{E_\nu} + \frac{\vec{J}}{\langle J \rangle} \bullet \left[A \frac{\vec{p}_e}{E_e} + B \frac{\vec{p}_\nu}{E_\nu} + D \frac{\vec{p}_e \times \vec{p}_\nu}{E_e \quad E_\nu}\right]\right]$$

where $\vec{J}$ is the neutron spin and $\vec{p}_e$ and $\vec{p}_\nu$ are the electron and neutrino momentum.

The correlation coefficients are expressible as functions of the coupling coupling constants. A non-zero D coefficient that could not be explained by final state interactions (expected to give $D \approx 2X10^{-5}$) would indicate a failure of time reversal symmetry. Experimental searches for a non-zero D were all made more than 15 years ago, providing upper limits at the 10^{-3} level /18/. With modern techniques the sensitivity can be improved significantly and new experiments are being planned. The weak magnetism give a small energy dependence to the correlation coefficients. The corresponding effects have been seen in nuclear systems, but not yet for the neutron. In general induced currents effects are small corrections to the "allowed approximation" which considers only the effects of the real constants G_A and G_V. In the allowed approximation induced couplings are neglected and the correlation coefficients have the form:

$$a = \frac{1 - \lambda^2}{1 + 3\lambda^2}$$

$$A = -\frac{2\lambda(\lambda - 1)}{1 + 3\lambda^2}$$

$$B = \frac{2\lambda(\lambda + 1)}{1 + 3\lambda^2}$$

Measurements of these correlation coefficients can be used to determine the ratio of the coupling constants directly.

The best experimental determination of λ comes from recent measurements of the beta asymmetry parameter by a collaboration between Argonne, the University of Heidelberg, and ILL who used the PERKEO neutron decay spectrometer and a cold neutron beam at the ILL reactor /14/. The experimental apparatus is shown in fig. 3. A key feature of the experiment is a very efficient supermirror polarizer which produces intense neutron beam with P>97%. Neutrons polarized along their direction of motion enter the spectrometer along the axis of a 1.7m long superconduction solenoid having a 15 Kgauss internal field. Electrons from neutron decay move in helical trajectories with diameters less that 3mm. Trim coils at the ends of the apparatus distort the field and electrons are guided to plastic scintillator counters outside of the region of the neutron beam. Backscattered electrons are trapped between the scintillators and eventually deposit all their energy in the counters. Timing information is used to identify the counter struck first.

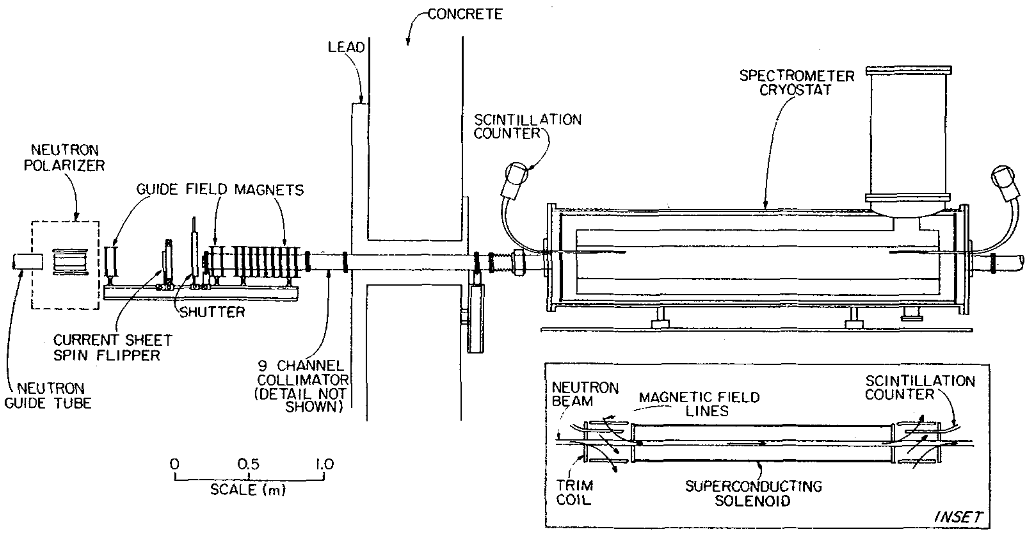

Fig. 3 - Arrangement of the PERKEO experiment at the ILL reactor. The inset shows the inner region of the superconducting solenoid.

The beta asymmetry as a function of electron kinetic energy is measured by observing the count rate asymmetry for two opposite polarizations of the neutron beam. Figure 4 shows the experimental data for the asymmetry as a function of electron energy. The principal energy dependence is caused by the factor v/c which multiplies the nearby asymmetry parameter. The data is fit to a function expected from v/c, induced terms (assuming CVC), radiative corrections, and the measured detector response. The asymmetry corresponding to the allowed approximation is extracted directly after corrections for the measured polarization of the beam and the magnetic mirror effect of the spectrometer on the decay electrons. The PERKEO spectrometer was also used for a recent in-beam measurement of the neutron lifetime using a pulsed neutron beam /15/.

An ideogram of all neutron beta asymmetry measurements is shown in fig. 5 including the two most recent experiments with PERKEO. All the measurements are in good agreement and the weighted average asymmetry is A_0= -0.1147±0.0046, implying G_A/G_V= -1.262±0.004. This average is consistent with the corresponding average from all the measurements of the beta-neutrino correlation which gives G_A/G_V= -1.256±0.015. The measured neutrino-asymmetry coefficients do not constrain G_A/G_V very effectively.

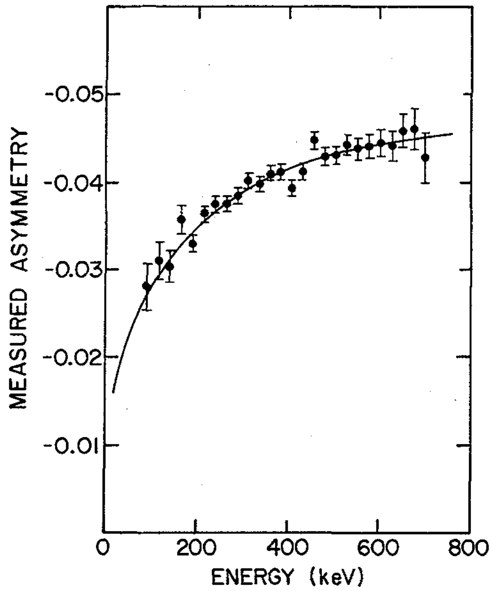

Fig. 4 - Beta-asymmetry vs energy from the PERKEO experiment /14/.

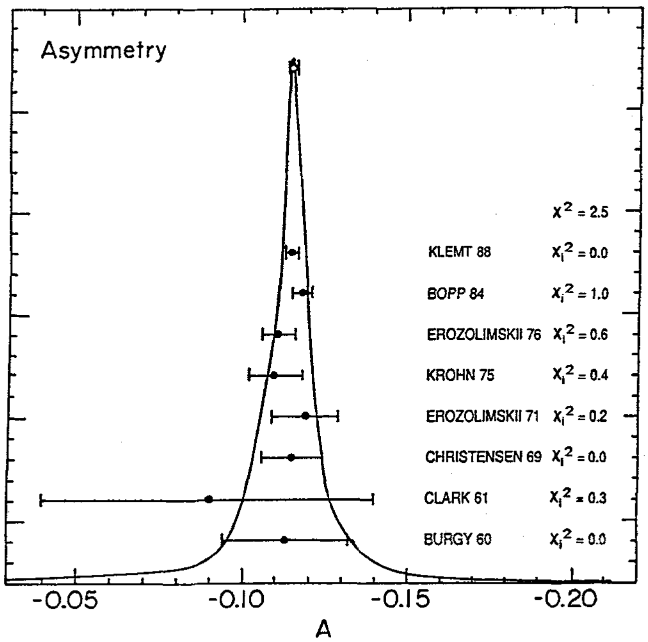

Fig. 5 - Ideogram of neutron asymmetry parameter measurements /8/ /15/.

5 - IMPLICATIONS OF NEUTRON DECAY TO ASTROPHYSICS AND COSMOLOGY

In the epoch after nucleon formation in the early stages of the Big Bang the magnitudes of the weak processes determined how closely the neutron to proton number ratio tracked thermal equilibrium as the universe continued to cool. Processes like neutrino or electron capture allow neutrons and protons to transform into each other. The allowed approximation matrix element for all these processes is precisely the matrix element for neutron decay and the corrections for induced effects can be neglected. In the standard model scenario big bang nucleosythesis the presently observed abundance of observable primordial helium and the ratio of baryons to photons is related by the neutron lifetime. The specific relationship also depends on the number of light types of light neutrinos because the number of light relativistic particles (with m_ν < 10-15 MeV) determine the expansion and cooling rate of the early universe. Recent work has put stringent limits on the hadron to photon ratio using observations of other primordial light element abundances so this cosmological relationship has the potential of predicting the number of light neutrino types as shown in fig. 6. For many years the uncertain neutron lifetime was of major concern in reliability of the predictions. With the new neutron lifetime determinations the prediction is, N_ν=2.6±0.3 /16/.

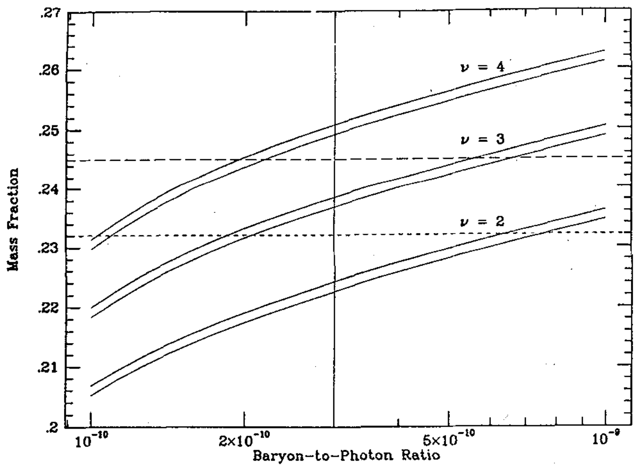

Fig. 6 - Helium mass fraction vs the baryon to photon ratio. The vertical line is the best value of the baryon to photon ratio from light element abundances. The dashed lines are best fit and 3σ upper bounds from observations of primordial helium. (See ref. /16/ and references therein.)

In the standard solar model /17/ (not to be confused with the two other "standard models" we have considered so far) the dominant energy producing process is the reaction $p+p=D+e^++\nu$. For the appropriately low solar proton energies, the reaction proceeds from a singlet-spin pp initial state, and the relevant matrix element is the Gamow-Teller matrix element from neutron decay. Except for small (≈2%) meson exchange corrections we have $\sigma \propto G_A^2$. Uncertainties in neutron decay parameters are no longer responsible for a significant uncertainty in the expectation for the solar neutrino flux from the standard solar model.

6 - G_V FROM NUCLEAR BETA DECAY

The realization that nuclear Fermi decays seems to have the identical strengths originally motivated the CVC hypothesis. Later, precise experiments became tests of the conjecture. Nuclear beta decay now provides useful tool for determining G_V. On the other hand, the axial current is not conserved and there is experimental evidence that effective G_A is reduced in nuclear systems, though the mechanism is poorly understood. As noted before, the magnitude of the nucleon G_A is itself reduced from the prediction of the quark model. Historically, the most precise values of G_V come from experiments which studies particular examples of $0^+ \rightarrow 0^+$ decays superallowed beta decay transitions within unit-isospin multiplets. Sixteen cases from ^{10}C to ^{54}Co have been investigated, and the small experimental errors associated with eight of these, ^{14}O, ^{26m}Al, ^{34}Cl, ^{38m}K, ^{42}Sc, ^{46}V, ^{50}Mn, and ^{54}Co, allow the corresponding ft-values to be computed to an interesting precision /18/. Modern research aims to better than a 0.1%

determination of G_V and high order radiative corrections and the effects of nuclear isospin breaking must account for to this level. It is customary to define a "corrected" ft-value, normally represented by the following expression:

$$Ft = ft\ (1 + \delta_R)\ (1 - \delta_C) = K/2G_V^2 \quad .$$

Traditionally t represents the half-life when discussing nuclear beta-decay. As usual the statistical f-function accounts for phase space and the Coulomb interaction of the final state lepton. The symbol, δ_R represents additional radiative corrections. Sophisticated calculational techniques are employed in estimating the leading "outer" radiative correction, terms of order α, $Z\alpha^2$, and $Z^2\alpha^3$ in the expansion for δ_R /19/. Additional "inner" corrections are necessary when relating G_V the muon vector coupling /20/. It has recently been noted that the precision is at the point where the simple separation into inner and outer corrections will soon be inappropriate /21/. Radiative corrections are difficult for high Z systems but they seem to be well under control at the present level of precision.

The corrections for nuclear isospin breaking, incorporated into δ_C, are more problematic. Nuclear isospin breaking modifies the value of the Fermi matrix element which is normally equal to $\sqrt{2}$ for these transitions. The dominant effect is due to wave function distortion from Coulomb repulsion of the extra proton in the initial state; this reduces the Fermi matrix element. There are currently two sets of detailed calculations of δ_C for the eight well measured cases. With the uncertainties assigned by the proponents, the resulting average Ft based on the two different corrections disagree by nearly three times the final error: Ft = 3077.3(19) /22/ and Ft = 3071.5(16) /23/. Figure 7 shows the values of G_V and G_A that are consistent with measurements of neutron beta-decay and from these two interpretations of the measurements of G_V from superallowed nuclear beta-decay. Neutron beta decay favors the smaller of the two Ft values and the correspondingly larger G_V.

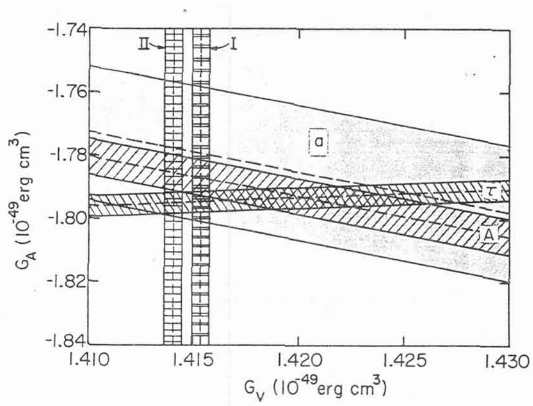

Fig. 7 - Restrictions on G_A and G_V from the neutron lifetime (t), the neutron beta asymmetry (A), the neutron electron-neutrino correlation (a), and two interpretations of superallowed pure Fermi beta-decay (I from ref. /23/ and II from ref. /22/).

7 - THEORETICAL CONSTRAINTS ON G_V

The exact relationship of G_V to G_μ is not a prediction of the Standard Model but there are some important constraints. In the context of Cabbibo universality we have $|G_V| < |G_\mu|$. More specifically the strength of the strangeness conserving and strangeness violating charged current processes must satisfy a simple unitarity condition. These ideas are easily generalized to the presently accepted six quark model and a relationship between the charged current strengths follows from unitarity of the quark mixing matrix. In the usual notation in which the matrix elements are labeled by the relevant quarks we have, $\Sigma|V|^2 = |V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 1$. This is an important test of the Standard Model and a violation could indicated the existence of yet to be discovered generations of quarks. Our belief in only three generations, however, is supported by both cosmological arguments /16/ and by direct measurements of the total width of the Z_0. The matrix elements V_{us}, which corresponds to $\sin\theta c$ in the simpler Cabbibo model, is in K-meson and hyperon decay. The matrix element V_{ub}

is estimated to be from the decay of the B-meson. The two analysis of superallowed decay both give $\Sigma|V|^2 < 1$. In a recent interpretation in which very small theoretical errors are assigned, Jaus and Rasche /24/ obtain rather large discrepancies: $\Sigma|V|^2 = 0.9960(13)$ and $\Sigma|V|^2 = 0.9975(13)$ using the corrections of refs. /23/ and /18/ respectively.

The possibility of a failure of the unitarity condition hinted here is a serious matter and much effort is going into understanding the reason for the discrepancy. An obvious place to look is in the nuclear corrections, here one must rely on nuclear models and it is difficult to accurately assign the theoretical error. Indeed two different groups get moderately inconsistent corrections. Recently Wilkinson has speculated on the systematic differences in the nuclear corrections. The two sets of nuclear corrections are shown fig. 8 without theoretical errors. The calculations have similar fluctuations with Z but the corrections of Towner et al. /22/ are systematically larger that the corrections of Ormand and Brown /23/. The general trend led Wilkinson to speculate that there may be a part of the correction which varies smoothly with Z that has been missed by both groups. The cause may be related to the fact that of core polarization was neglected in both calculations. Based on this supposition two recent papers have introduced an additional correction obtaining better agreement with KM-unitarity. Reference /21/ obtains $\Sigma|V|^2 = 0.9989(12)$ with a quadratic form and ref. /25/ obtains $\Sigma|V|^2 = 0.9995(9)$ in an analysis with a linear form.

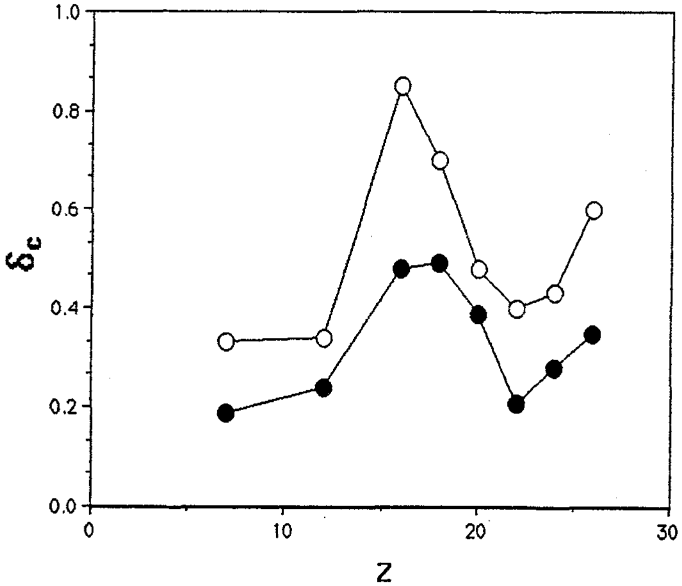

Fig. 8 - Nuclear corrections, δ_C (in percent), to super allowed Fermi decays. The open points are from Towner et al. /22/ and the solid points from Ormand and Brown /23/.

It would be of great interest to remeasure the ^{10}C super allowed decay which is presently poorly determined /26/. This system is the lowest Z example of a pure Fermi transition and the speculations about the nuclear corrections would be tested.

8 - DETERMINING G_V IN MIRROR BETA DECAY

Neutron beta decay and pion beta decay are especially attractive systems for determining G_V. Radiative corrections are small and nuclear corrections are unnecessary. On the other hand the experiment precision does not yet compete with nuclear experiments.

One need not be restricted to pure Fermi nuclear beta decay, however. Mixed allowed decays can also be used. As with the neutron it is necessary to measure something other than the lifetime to account for the effect of the Gamow-Teller contribution. In most cases, beta asymmetry measurements provide the additional information. In the technique pioneered by Commins and his collaborators to measure magnetic moments, polarization was achieved with radioactive noble gases using an atomic beams technique. This technique has been refined for beta-decay correlation measurements with ^{19}Ne /27/ and ^{35}Ar /28/. The radioactive gases are produced from targets containing Florine and Clorine, respectively and the noble gases are separated out with simple cryogenic filters. Figure 9 shows the layout of the ^{19}Ne asymmetry measurement /29/. The neon experiment provided a consistent value of G_V and the error is comparable to the less precisely determined pure Fermi measurements. This experiment also provided a sensitive test of the V-A nature of the charged current /30/. However, the ^{35}Ar measurements using the atomic beam technique provided an anomalous G_V. In fact the implied value was very close to G_μ leading to speculations that the Cabbibo angle might be zero for certain nuclei with non-zero spin /31/.

Recently this measurement was redone using a different technique. A criticism of the atomic beams experiments is that the polarization of the decaying nucleus was not measured directly. Instead it was calculated using the geometric properties of state selection. In the new experiment of Garnett et al., the polarization is measured more directly /32/. In their experiment nuclear polarization is produced in a reaction using a polarized beam and the reaction $^{35}Cl(\vec{p},n)^{35}Ar$. The target is a mixture of CCl_4 and Helium. The decay scheme of ^{35}A is shown in Fig. 10 and the apparatus in Fig. 11. The method of polarization determination

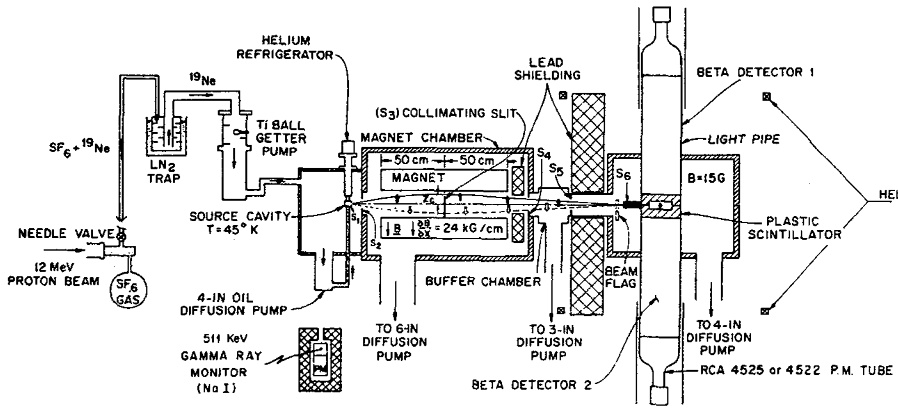

Fig. 9 - Experimental arrangement of the ^{19}Ne atomic beam apparatus used to measure the beta asymmetry /28/.

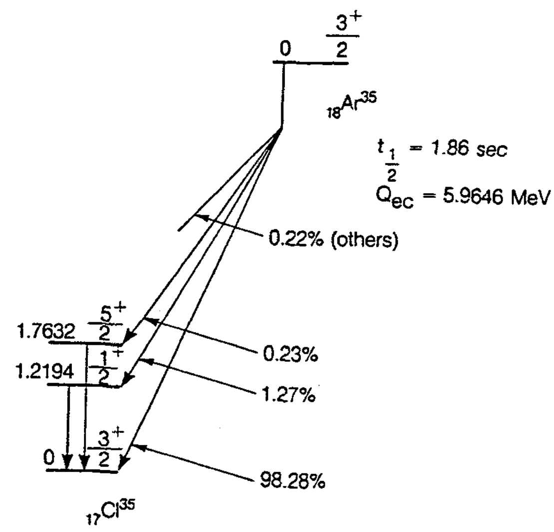

Fig. 10 - Decay scheme of ^{35}Ar.

was to monitor weak beta-decay branch to the first excited state of ^{35}Cl. Experimentally this is done by detecting the 1.2-MeV gamma-ray in coincidence. Since this decay is a pure Gamow-Teller decay the asymmetry depends only on the spins involved. The new experiment does not confirm the previous result and the measured asymmetry gives a consistent value of G_V resolving a long standing discrepancy.

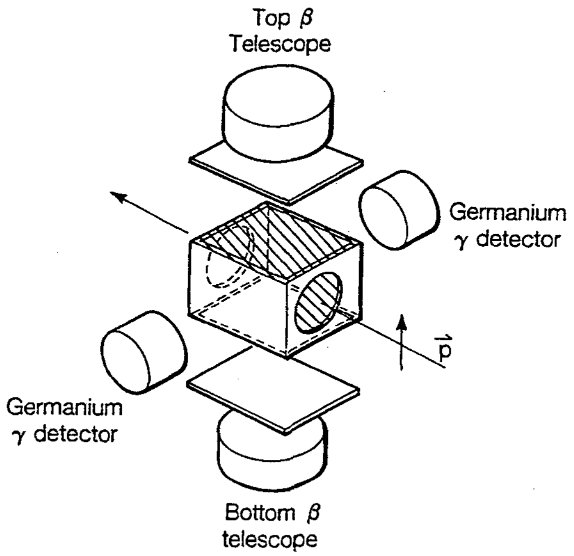

Fig. 11 - Arrangement of the experiment of Garnett et al. /32/ to measure the beta asymmetry of ^{35}Ar.

There have been other attempts to get G_V from mixed decays but the precision is not yet competitive with the measurements of pure Fermi decay /33/. Nevertheless, the issues involved are extremely important and it is important to continue to perfect these and other approaches and to improve our knowledge of the weak coupling constants.

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