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PARITY VIOLATION IN NUCLEI: STUDIES OF THE WEAK NUCLEON-NUCLEON INTERACTION

Violation de parité dans les noyaux: études sur l'interaction faible nucléon-nucléon

A.B. McDONALD

Paper presented to the CAP Annual Congress,
Vancouver, B.C., 18-21 June 1979.

Chalk River Nuclear Laboratories   Laboratoires nucléaires de Chalk River

Chalk River, Ontario

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Violation de parité dans les noyaux: études sur l'interaction faible nucléon-nucléon*

par

A.B. McDonald

*Texte d'un exposé présenté sur invitation au congrès annuel de CAP tenu à Vancouver du 18 au 21 juin 1979

Résumé

Le modèle unifié de Weinberg-Salam des interactions faibles et électromagnétiques a permis d'expliquer clairement la violation de parité et les effets des courants neutres dans les interactions neutrino-nucléon, électron-nucléon et neutrino-électron. Diverses expériences de violation de parité en physique nucléaire sont actuellement en cours pour mesurer les effets de l'interaction faible nucléon-nucléon dans quelques systèmes de nucléon et dans certains noyaux plus lourds où l'on s'attend à des accroissements. L'état d'avancement de ces expérience sera passé en revue. On donnera des détails au sujet d'une expérience effectuée à Chalk River[1] pour déceler la violation de parité dans la photodésintégration du deutérium et on présentera le complément des mesures publiées précédemment[2] au sujet du mélange de parité dans ^{21}Ne. On fera des commentaires au sujet de l'interprétation des résultats en fonction des modèles de base de l'interaction faible.

1) A.B. McDonald, E.D. Earle, M.A. Lone and J.W. Knowles

2) K.A. Snover, R. Von Lintig, E.G. Adelberger, H.E. Swanson, T.A. Trainor, A.B. McDonald, E.D. Earle and C.A. Barnes, Phys. Rev. Lett. 41 (1978) 145.

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ABSTRACT

The Weinberg-Salam Unified Model of weak and electromagnetic interactions has been very successful in explaining parity violation and neutral current effects in neutrino-nucleon, electron-nucleon and neutrino-electron interactions. A wide variety of nuclear physics parity violation experiments are in progress to measure effects of the weak nucleon-nucleon interaction in few nucleon systems and certain heavier nuclei where enhancements are expected. The current status of these experiments will be reviewed, including details of an experiment at Chalk River[1)] to search for parity violation in the photo-disintegration of deuterium and an extension of our previous measurements[2)] of parity mixing in ^{21}Ne. The interpretation of results in terms of basic models of the weak interaction will be discussed.

[1)] A.B. McDonald, E.D. Earle, M.A. Lone and J.W. Knowles

[2)] K.A. Snover, R. Von Lintig, E.G. Adelberger, H.E. Swanson, T.A. Trainor, A.B. McDonald, E.D. Earle and C.A. Barnes, Phys. Rev. Lett. 41 (1978) 145.

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1. INTRODUCTION

There is no evidence to date for parity violation in any interaction other than the weak interaction. Measurements of parity violation in nuclei may therefore be regarded as probes of the weak nucleon-nucleon interaction in the presence of the much stronger electromagnetic and strong interactions. The current interest in models of the weak interaction which unify it with the electromagnetic interaction make such measurements particularly significant at this time.

This paper primarily discusses parity violation measurements in low energy nuclear physics, with illustrations from experiments in progress at Chalk River. Section 2 describes the success of the Weinberg-Salam Unified Model[1)] of the weak and electromagnetic interactions for leptonic and semi-leptonic interactions. Section 3 deals with the implications of this model for strangeness conserving hardronic weak interactions such as those occurring in nuclei. Parity violation measurements at Chalk River are discussed in Section 4 and the final section describes the information which has been obtained to date for parity violation experiments in nuclear physics.

2. LEPTONIC AND SEMILEPTONIC WEAK INTERACTIONS

During the last few years, considerable progress has been made in understanding the properties of the basic weak interaction. The Weinberg-Salam[1)] unified model of the weak and electromagnetic interactions is in excellent agreement[2)] with the results of a variety of experiments designed to test the new feature of the theory: the existence of weak neutral currents arising from the exchange of a neutral vector boson.

The model contains only one parameter, the so-called Weinberg angle θ_W which relates weak and electromagnetic coupling constants:

$$g \sin \theta_W = e$$

and predicts the masses of charged and neutral weak bosons $W^{\pm}$, Z^{o} in terms of known constants, e.g.

$$M_{W\pm} = \sqrt{\frac{1}{4\sqrt{2}} \; \frac{1}{\alpha} \; \frac{h^3}{cG_F}} \cdot \frac{1}{\sin\theta_W}$$

$$= \frac{37 \text{ GeV}}{\sin\theta_W} \quad \text{and} \quad M_{Z^o} = \frac{M_{W\pm}}{\cos\theta_W}$$

The experiments which have been performed to confirm the existence of parity-violating neutral weak currents have included neutrino scattering measurements for a wide variety of targets and beams and a very beautiful recent measurement[3)] of parity violation in the inelastic scattering at $\sim$19 GeV of polarized electrons from deuterium and hydrogen. These experiments can all be parameterized in terms of the Weinberg-Salam model and the Weinberg angle θ_W. Figure 1 (reproduced from the review paper by Baltay[2)]) indicates the extensive agreement among the experiments performed to date on neutral currents in leptonic and semileptonic interactions. It appears as though the Weinberg-Salam (W-S) Unified Model works very well for lepton-quark (nucleon) and lepton-lepton interactions.

3. *HADRONIC WEAK INTERACTIONS*

Because of the confinement of quarks, information about the weak quark-quark interaction must be obtained from interactions of composite particles such as nucleons. The W-S model predicts the existence of parity-violating neutral current interactions between quarks. Much of the following discussion will be concerned with the influence of such interactions on the weak nucleon-nucleon (NN) interaction.

The strong NN interaction, particularly at low energies, is usually thought to arise from diagrams of the type shown in Figure 2(a) in which a strong nucleon-nucleon-meson (NNM) interaction occurs at each vertex. For the weak NN interaction one of the NNM vertices is weak and in a quark model would arise from terms of the type illustrated in Figure 2(c) where the weak interaction occurs between two of the constituent quarks.

Since one is interested in weak NNM vertices of this type it is interesting to ask if sufficient information can be obtained from strangeness changing ($\Delta S=1$) nonleptonic hadron decays which unambiguously arise from weak vertices of this type. In fact, for charged currents, these ($\Delta S=1$) decay lifetimes provide an excellent test of weak interaction theory. For example, Desplanques et al.[4] are able to obtain an excellent fit to seven nonleptonic hadron decay lifetimes using a quark model with three adjustable parameters to take account of strong renormalization effects.

However, no $\Delta S=1$ decays arising from neutral current interactions have ever been observed. It was this fact which led Glashow, Iliopoulos and Maiani[5] to propose the so-called GIM mechanism wherein the existence of a fourth (charmed) quark creates an additional symmetry and $\Delta S=1$ neutral current decays are suppressed. Therefore, neutral weak currents only contribute to $\Delta S=0$ interactions and one must resort to parity violation as a means of distinguishing these from the strong interaction.

Experiments to dete t parity violation are of two general types:

1. The observation of parity forbidden transitions between eigenstates of the strong interaction with definite parity. An example is the parity forbidden decays of nuclear energy levels.

2. The detection of pseudoscalar observables such as $\vec{\sigma} \cdot \vec{p}$. The two most common measurements are the detection of a net helicity in particles emitted from an unpolarized initial state (e.g. circularly polarized gamma rays) or the detection of an asymmetry relative to an initial direction of polarization as was observed in the original measurements of parity violation in β decay.

Experiments of this nature can be performed in low energy nuclear physics or in particle physics. Fischbach[6] has discussed the size of effects expected in several types of particle physics experiments. These include the dependence on the helicity of the incoming proton of cross sections for inclusive reactions such as $\vec{p} + p \to \pi^+ + X$ for high transverse momenta (dominated by quark-quark scattering). Another possible measurement would be the longitudinal polarization of protons emitted in the decay of mesons such as $J/\psi \to p + \vec{p}$. Parity-violating effects in these cases are predicted to be as large as 10^{-3}, but sufficient statistical accuracy does not appear possible yet.

Low energy nuclear physics experiments are of two general types. In few nucleon systems, the nuclear theory is well defined and even though effects are inherently small ($\lesssim 10^{-6}$), very well controlled, high counting rate experiments can be performed and systematic uncertainties well below 10^{-7} have been reported[7,8]. For multi-nucleon systems, the nuclear theory is more complex, but a number of special cases exist where competing parity-conserving transitions are inhibited, greatly increasing the sensitivity for detection of the parity-violating transition strength.

In studies of semileptonic interactions, experiments can be performed which are sensitive only to neutral weak currents. However, for $\Delta S=0$ hadronic weak interactions, both neutral and charged currents can contribute, and the presence of neutral currents must be inferred from results which differ from the predictions with charged currents alone.

The difference between the predictions of models with no neutral currents, such as the Cabibbo model, and the predictions of the Weinberg-Salam model is expected to be largest for the $NN\pi$ vertex. This vertex only contributes to matrix elements $\langle|H^W(\Delta I=1)|\rangle$ wherein the isospin changes by one unit, such as those which induce parity mixing between nuclear states differing in isospin by one unit. The pion weak vertex $N\pi^- p$, usually referred to as N_0^-, has been discussed in terms of an approximate sum rule relating it to the known $\Delta S=1$ hadronic decays:

$$N_0^- = \frac{2A}{\sqrt{3}} (2\Lambda^o - \Xi^-)$$

where A is a model-dependent constant of the order of 0.2 for the Cabibbo model and 5 for the Weinberg-Salam model. Strong interaction renormalization uncertainties make this sum rule only approximate, but upper limits can be set for the strength of this vertex in the Cabibbo model so that any larger strength observed could be attributed to the presence of neutral currents in quark-quark interactions. Alternatively one can say that $\Delta I=1$, parity-violating, nucleon-nucleon interactions may be enhanced by a factor as large as 25 by the presence of neutral currents.

The $NN\rho$ and $NN\omega$ vertices, on the other hand, cannot be related to known $\Delta S=1$ decays and must be calculated from first principles using, for example[4], a quark model with renormalization. The strengths of these vertices are found to be similar for Cabibbo or W-S models. These interactions are inherently short range and can contribute to $\Delta I=0$, 1 or 2 transition matrix elements.

It is therefore important to define the isospin structure of the weak nucleon-nucleon interaction if one is to determine the properties of the underlying weak quark-quark interaction. A variety of nuclear physics experiments are currently being performed for cases with varying isospin structure.

4. PARITY-VIOLATION EXPERIMENTS IN NUCLEAR PHYSICS

The three main types of parity-violation measurement may be illustrated by experiments in progress at Chalk River. These are

A. Parity-Forbidden Decay: Decay of the 3562 keV level of ^{6}Li (A.B. McDonald, E.D. Earle, W.G. Davies, G.C. Ball (AECL), R.G.H. Robertson and P. Dyer (Michigan State University) and T. Bowles (Argonne National Laboratory and LAMPF).

B. Few-Nucleon Systems: Parity Violation in the Photodisintegration of Deuterium with Circularly Polarized Gamma Rays (A.B. McDonald, E.D. Earle and J.W. Knowles, AECL).

C. Multi-Nucleon Systems: Parity Mixing in ^{21}Ne (A.B. McDonald, E.D. Earle, (AECL), K.A. Snover, E.G. Adelberger, R. Von Lintig, T.A. Trainor, H.E. Swanson (University of Washington, Seattle) and C.A. Barnes (Cal Tech, Pasadena)).

4A. *Parity-Forbidden Decay: Decay of the 3562 keV Level of ^{6}Li*

The 3562 keV, $J^\pi = 0^+$, T=1 level of ^{6}Li is forbidden both by parity and isospin to decay to ^{4}He $(0^+,T=0)$ + ^{2}H$(1^+,T=0)$. Therefore the decay can only proceed via opposite parity components in the initial or final states which arise from matrix elements of the form $\langle|H^W(\Delta I=1)|\rangle$. These matrix elements are expected to be enhanced if neutral currents contribute to nucleon-nucleon interactions and so predictions for the parity-forbidden decay width are quite different for the Weinberg-Salam or the Cabibbo model (no neutral currents).

The experiment consists of a search for a narrow, parity-forbidden resonance in the $^{2}D(^{4}He,^{6}Li)$ reaction. This measurement has been pursued for a number of years by groups at the University of Montreal[9)], University of Milan[10)] and Michigan State University[11)] and the present measurement at Chalk River is a collaboration with the Michigan State group using the MP tandem accelerator for a high intensity, high resolution ^{4}He beam and the QDDD magnetic spectrometer as a 0^{o} detector of ^{6}Li.

The measurements to date have merely set an upper limit on the parity-forbidden decay width of the 3562 keV level ($\Gamma_{\alpha} < 2.9 \times 10^{-4}$ eV, ref. 11). With the present experiment we hope to obtain a significantly better statistical accuracy ($\Gamma_{\alpha} \lesssim 4 \times 10^{-7}$ eV). The theoretical calculations are unsophisticated as yet, but estimates of $\Gamma_{\alpha} \approx 5 \times 10^{-8}$ eV for the Weinberg-Salam model and $\Gamma_{\alpha} \approx 5 \times 10^{-10}$ eV for the Cabibbo model have been made[11)]. These calculations illustrate the strong sensitivity to the neutral current enhancement factor in this case of parity-forbidden decay ($\Gamma_{\alpha} \propto |\langle|H^{W}|\rangle|^{2}$) but suggest that the experimental sensitivity may still only be sufficient to set an upper limit on the width.

4B. Few-Nucleon Systems: Parity Violation in the Photodisintegration of Deuterium

There are three parity-violation measurements which have been undertaken to detect parity mixing in the simplest nuclear system - two nucleons. First, parity violation has been observed as a helicity dependence in the total cross section for scattering of longitudinally polarized 15 MeV protons from hydrogen. The parity mixing in this case is primarily due to the short range ρ and ω exchange and is not very sensitive to the presence of neutral currents. The recent experimental result[12] $A(\vec{p} + p \rightarrow p + p) = (-1.7 \pm 0.85) \times 10^{-7}$ is in reasonable agreement with theoretical predictions for either the Weinberg-Salam or Cabibbo model: $A \simeq -1.3 \times 10^{-7}$ (ref. 4).

Parity violation may be also observed in two different measurements of electromagnetic transitions in deuterium. First, the asymmetry of gamma ray emission relative to the spin orientation of polarized neutrons captured in hydrogen may be measured. This asymmetry is primarily sensitive to $\Delta I=1$ parity mixing and hence may be enhanced by the presence of neutral currents. Theoretical calculations[13] predict $A \simeq 1 \times 10^{-7}$ for the Weinberg-Salam model, and $A \simeq 1 \times 10^{-8}$ for the Cabibbo model, but as yet the experimental upper limit[8] $(A = (0.6 \pm 2.0) \times 10^{-7})$ is larger than both numbers.

Finally, a measurement of the circular polarization of 2223 keV gamma rays following the capture of unpolarized thermal neutrons in hydrogen is sensitive to $\Delta I = 0,2$ parity mixing and hence primarily ρ,ω exchange diagrams. A definite result for this measurement $P = (-1.3 \pm 0.45) \times 10^{-6}$ was published in 1972[14] but none of the many theoretical papers written on this topic have been able to come close to this large result without including unreasonably large $\Delta I=2$ mixing matrix elements. Theoretical calculations[13)] of ρ,ω exchange with renormalization predict $P_\gamma \sim 3 \times 10^{-8}$ for either the Weinberg-Salam or Cabibbo models.

At Chalk River we are undertaking a measurement of the time reversal of the $n+p \rightarrow d+\vec{\gamma}$ case. We will attempt to observe a difference in the cross section for photodisintegration of deuterium near threshold with right and left circularly polarized incident photons. The recent development at Stanford of an intense source of polarized electrons and at Chalk River of a high intensity, low energy CW electron linac will be combined to produce circularly polarized bremsstrahlung at about 3 MeV for this measurement.

Figure 3 illustrates schematically the main elements in the $n + p \rightarrow d + \gamma$ measurement[14)]. Thermal neutrons from a pool reactor were captured in an H_2O sample shielded from the intense background of gammas from the core by lead and bismuth. The circular polarization of the capture gamma rays was measured by observing the variation of transmission through magnetized iron as the magnetic field is reversed. The Compton scattering cross section for circularly polarized photons is dependent on the relative spin of the photons and electrons. For the magnet used the sensitivity to circular polarization was $\approx$ 5% and the switching rate was limited to 0.5 Hz. The ratio of the currents from the gamma detector and a monitor detector was used to drive a very large Q pendulum tuned to the magnet reversal frequency. Difficulties in this measurement were presented by the large background of partly ($\sim 10^{-3}$) circularly polarized gammas from the β-bremstrahlung in the reactor core which had to be shielded from scattering in the sample; by the fundamentally low (5%) sensitivity of the gamma ray circular polarimeter and by the slow (0.5 Hz) flipping rate which limited the accuracy because of reactor flux variations at this frequency.

Figure 4 illustrates schematically the proposed Chalk River experiment which presents some experimental advantages and will certainly involve different systematic uncertainties from the $n + p \rightarrow d + \vec{\gamma}$ experiment. Polarized electrons from a GaAs photoemission source of the type developed at Stanford[3] will be accelerated in the Chalk River Electron Test Accelerator[15] and will strike a tungsten radiator producing bremsstrahlung at energies up to 1 MeV above the threshold (2.223 MeV) for photodisintegration of deuterium. For the photons above threshold, the circular polarization will be > 90% of the longitudinal polarization of the incident electrons ($\gtrsim$ 35% for the Stanford source). The D_2O target will be surrounded by a ^{10}B lined, gamma compensated neutron detector. Lock-in amplifier techniques will be used to search for a variation in detector current synchronous with the reversal of the electron polarization ($\sim$ 100 Hz). This reversal rate is limited by the thermalization times of neutrons in the D_2O, but is high enough that the noise contribution from beam current fluctuations should be negligible. In addition, the relatively large polarization of the incident photons, compared to the 5% polarization sensitivity in the $n + p \rightarrow d + \vec{\gamma}$ measurement[14], results in an increased sensitivity in the present measurement, enabling greater statistical accuracy for equivalent counting times if the neutron and photon fluxes are comparable.

Parity violation in the photodisintegration of deuterium has been studied theoretically by H.C. Lee[16] who concludes that for photodisintegration at energies less than 1 MeV above threshold, the parity violation is dominated by the same matrix elements as the thermal neutron capture case. The pseudoscalar observables are predicted to be the same size in both cases, so that the present measurement is effectively a remeasurement of the $n+p \rightarrow d+\vec{\gamma}$ case with very different systematic uncertainties.

To date at Chalk River, neutron and gamma ray fluxes have been measured with an unpolarized electron beam; a prototype, gamma-compensated, ^{10}B neutron detector has been tested and a full scale model is being designed. Milliampere currents of electrons have been obtained at low voltages from GaAs photocathodes.

4C. *Multi-Nucleon Systems*

A number of favourable cases exist in heavier nuclei ($A \gtrsim 16$) where a gamma ray transition is strongly inhibited thus enhancing the size of pseudoscalar observables arising from interference with opposite parity admixtures. In a number of the heavier nuclei[17)] (^{41}K, ^{175}Lu, ^{181}W) parity violation has been firmly established for a number of years. However, the nuclear structure calculations in these cases are very complicated and analysis has necessarily been restricted to extracting an effective one-body, proton-nucleus, parity-violating interaction. This interaction is found to be of the order of magnitude expected for the basic weak interaction but the presence or absence of neutral currents cannot be determined.

Recently, measurements have been made for a set of closely spaced parity doublets in neighbouring light nuclei. The three cases in ^{18}F, ^{19}F and ^{21}Ne are illustrated in Fig.5 and exhibit a number of similar and useful features. First, in all cases the energy separation to the next level of the same spin is more than a factor of ten larger than the separation of the doublet so that parity mixing with other levels can be ignored. Secondly, in all cases there is a significant enhancement of a pseudoscalar observable due to an inhibition of a gamma ray transition rate. For example, in ^{21}Ne, the circular polarization of the 2789 keV gamma ray from the $1/2^-$ level to the ground state can be written[18)]:

$$P_\gamma = \frac{2<1/2^+ |H^w| 1/2^->}{\Delta E} \times \frac{<M1>}{<E1>} \times f$$

where ΔE is the energy separation of the levels (6.9 ± 0.7 keV)[19)], <M1> is the M1 strength of the $1/2^+ \rightarrow$ ground state transition[20)] ($(7.9 \pm 1.0) \times 10^{-15}$ s)$^{-1/2}$ or 0.14 Weisskopf units (W.U.) <E1> is the E1 strength[18,19)] of the $1/2^- \rightarrow$ ground state transition ($(6.9 \pm 0.5) \times 10^{-10}$s)$^{-1/2}$ or 8.5×10^{-8} W.U., f = 0.97 is a function of the mixing ratios of these transitions and $<1/2^+|H^w|1/2^->$ is the matrix element of the parity-violating weak Hamiltonian which mixes the levels. The small energy separation and the strong inhibition of the $1/2^-$ to ground state transition results in an excellent sensitivity to parity mixing, in this case $P_\gamma = 9.5 \times 10^{-2}$ eV^{-1} $<1/2^+ |H^w| 1/2^->$.

We have measured an upper limit for this circular polarization at Seattle[21)] and preparations are in progress to extend this measurement with significantly higher sensitivity at Chalk River. An upper limit for the circular polarization[22)] of γ's from the 1082 keV level of ^{18}F and the asymmetry[23)] of gamma ray emission from the polarized 110 keV $1/2^-$ level of ^{19}F have recently been measured. These measurements and the corresponding parity-mixing matrix elements are shown in Figure 5.

These three cases are of further interest because they display different sensitivities to parity mixing with a change of isospin of 0 or 1. The ^{18}F case involves mixing of an I=0 and an I=1 state. It therefore involves only mixing with ΔI=1 and is especially sensitive to the presence of neutral currents. The cases in ^{19}F and ^{21}Ne both arise from the mixing of two I=1/2 states but they contain different ΔI=0 and ΔI=1 contributions. Definitive results for both cases could determine the presence of an enhancement of the ΔI=1 contribution.

The experimental apparatus used in the ^{21}Ne measurement at Seattle is shown schematically in Figure 6. The 2789 keV, $J^{\pi} = 1/2^-$ level of ^{21}Ne was populated by the $^{21}Ne(p,p')^{21}Ne$ reaction at an incident energy of 4.08 MeV. This energy was chosen to enhance the population of the $1/2^-$ level relative to the $1/2^+$ level so that the numbers of 2789 keV and 2796 keV γ's were nearly equal. Since the 2796 keV transition is much less sensitive to parity mixing ($P_\gamma(2796) = 2.1 \times 10^{-7} eV^{-1} \langle 1/2^+|H^W|1/2^-\rangle$) NaI detectors were used to look at the unresolved sum of the 2796 and 2789 keV transitions. Any circular polarization observed must arise from the latter transition.

The circular polarization (P_γ) of the gamma rays was measured with a pair of magnetic transmission polarimeters, 8.28 cm thick, with a polarization sensitivity $\eta = (3.4 \pm 0.1) \times 10^{-2}$. The polarimeters were placed on either side of the ^{21}Ne gas target and the magnetizations were reversed every two seconds. NaI spectra were accumulated for each detector for the two states of magnetization (+ and -). A typical spectrum is shown in Figure 7. Peaks are observable corresponding to the unresolved doublet at 2.8 MeV, the 2.4 MeV transition to the 350 keV level and a 1.4 MeV transition from the 1.75 MeV level to the 350 keV level. The latter two peaks were used to determine relative gain and zero corrections between the spectra (generally less than 0.01 channels). The 2.4 MeV transition should exhibit no circular polarization and hence serves as an excellent null test.

Asymmetries calculated according to the formula

$$A = \frac{\sqrt{\frac{L^+}{R^+}\frac{R^-}{L^-}} - 1}{\sqrt{\frac{L^+}{R^+}\frac{R^-}{L^-}} + 1}$$

were evaluated for the 2.8 MeV doublet, 2.4 MeV peak and the background at higher energies. This quadruple ratio approach eliminates spurious asymmetries arising from effects such as: beam current fluctuations, unequal cycle times, analyzer dead times, unequal detector efficiencies or geometries. No statistically significant asymmetries were determined for the peaks or background after twenty days of counting at a beam current of about 14 microamperes. The circular polarization of the 2789 keV gamma ray was therefore determined to be

$$P_\gamma = \frac{A}{\eta f} = (+23 \pm 29) \times 10^{-4} \text{ where}$$

$A = (41 \pm 51) \times 10^{-6}$

$\eta = (3.4 \pm .1) \times 10^{-2}$

$f = 0.52$ is the fraction of the 2.8 MeV peak due to the 2789 keV transition.

The resulting parity-mixing matrix element is listed in Figure 5, along with the equivalent results for ^{18}F and ^{19}F.

A set of four polarimeters, using "5 x 6 in" NaI(Tℓ) detectors is under construction at Chalk River which will be used to remeasure this ^{21}Ne case at ten times the counting rate. With this apparatus it is hoped that the statistical uncertainties can be reduced at least a factor of three in the near future.

4D. Theory of Parity Violation in Nuclei

Figure 8 illustrates the main elements in the theory of parity violation in nuclear physics. The first element is the calculation of nucleon-nucleon weak vertices from basic gauge theories of the weak interaction and quark models of the nucleons. The inclusion of strong renormalization effects is a matter of substantial theoretical interest at the present time. These vertices can be used to define a weak internucleon potential, V_{12}^{weak} Results for few-nucleon measurements may be calculated directly from this potential whereas multi-nucleon cases require nuclear shell-model calculations to define the wave functions of the levels involved. For some cases in light nuclei the calculations have included the complete two-body interaction V_{12}^{weak} and short range correlations in the nuclear wave functions. For most of the heavier nuclei this is not possible, and an effective one-body nucleon-nucleus potential has been used to estimate the size of effect.

As yet the ^{21}Ne case has not been calculated with two-body matrix elements and short-range correlations. However, a detailed shell model calculation using an SU(3) basis has been performed[18)]. Electromagnetic transition rates calculated with these wave functions for the $1/2^+$ and $1/2^-$ levels are in excellent agreement with experiment. It is interesting to examine the predictions for parity mixing in ^{18}F, ^{19}F and ^{21}Ne which have been calculated with these wave functions and a parity-violating one-body effective interaction (V_{PV}) in order to examine the different isospin sensitivities in the three cases.

Mixing matrix elements are tabulated in Figure 5 for a one-body effective interaction of the form:

$$|V_{PV}| = \vec{\sigma}\cdot\vec{p}\ [1 + 0.3\ f\ \tau_3] \times 10^{-6}$$

as used by Millener[18)] where the strength constants for f=1 are taken from a study of parity mixing in ^{19}F and are appropriate for the Cabibbo model. The factor f multiplying the isovector term <u>may</u> be greater than one if neutral currents contribute to the weak interaction, as predicted by the Weinberg-Salam model.

For positive f, there is a cancellation of isovector and isoscalar terms in the ^{21}Ne case, which could explain the relatively small matrix element in this case. Recent calculations* by Desplanques et al.[4] imply $f \simeq +5$ for their "best values" of meson-nucleon-nucleon vertex strengths in the Weinberg-Salam model.

Calculations are in progress[24] for parity mixing in these three nuclei using the SU(3) basis nuclear shell model with two-body, parity-violating matrix elements and short-range correlations. The above analysis indicates that these cases are sensitive to the enhancement of isovector matrix elements even at the present level of experimental sensitivity. These new calculations, and improved measurements in ^{18}F and ^{21}Ne, may provide a clear determination of the isovector enhancement.

A number of authors have parameterized the available experimental results in terms of strengths of weak nucleon-nucleon matrix elements[25] or weak meson-nucleon-nucleon vertices[26]. This tests the various few- and multi-nucleon experiments for consistency and defines a set of basic parameters which can be compared with calculations based on various weak-interaction models and renormalization approaches.

At present there are a few inconsistencies in the comparison of theory and experiment, a noteworthy one being the $n + p \rightarrow d + \gamma$ measurement. The remainder of the experiments when analyzed[26] provide a reasonably consistent set of strengths for the weak nucleon-nucleon-meson vertices. However, the uncertainties in these parameters are large because of the scarcity

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* By calculating one-body effective potentials X^P and X^N for protons and neutrons using the Weinberg-Salam "Best values" in ref. 4, one finds a one-body isovector potential strength about +1.5 times the isoscalar strength.

of accurate experimental results. In addition, the calculations of Desplanques et al.[4] make it clear that renormalization effects also lead to uncertainties in the theoretical strengths of the weak nucleon-nucleon vertices. It is therefore impossible at present to deny or confirm the presence of neutral current effects in nucleon-nucleon weak interactions.

However, as discussed above, there are a number of experiments and improved nuclear structure calculations in progress for cases with sensitivity to isovector mixing. These results could permit the accurate definition of the strength of the pion-nucleon-nucleon weak vertex. Any substantial enhancement of this strength over the charged current value would confirm the presence of neutral currents as predicted by the Weinberg-Salam model for quark-quark interaction.

In general, the definition of the strengths of meson-nucleon-nucleon weak vertices will provide a unique set of data to test current models of the basic quark-quark weak interactions, quark models of the nucleons and renormalization calculations.

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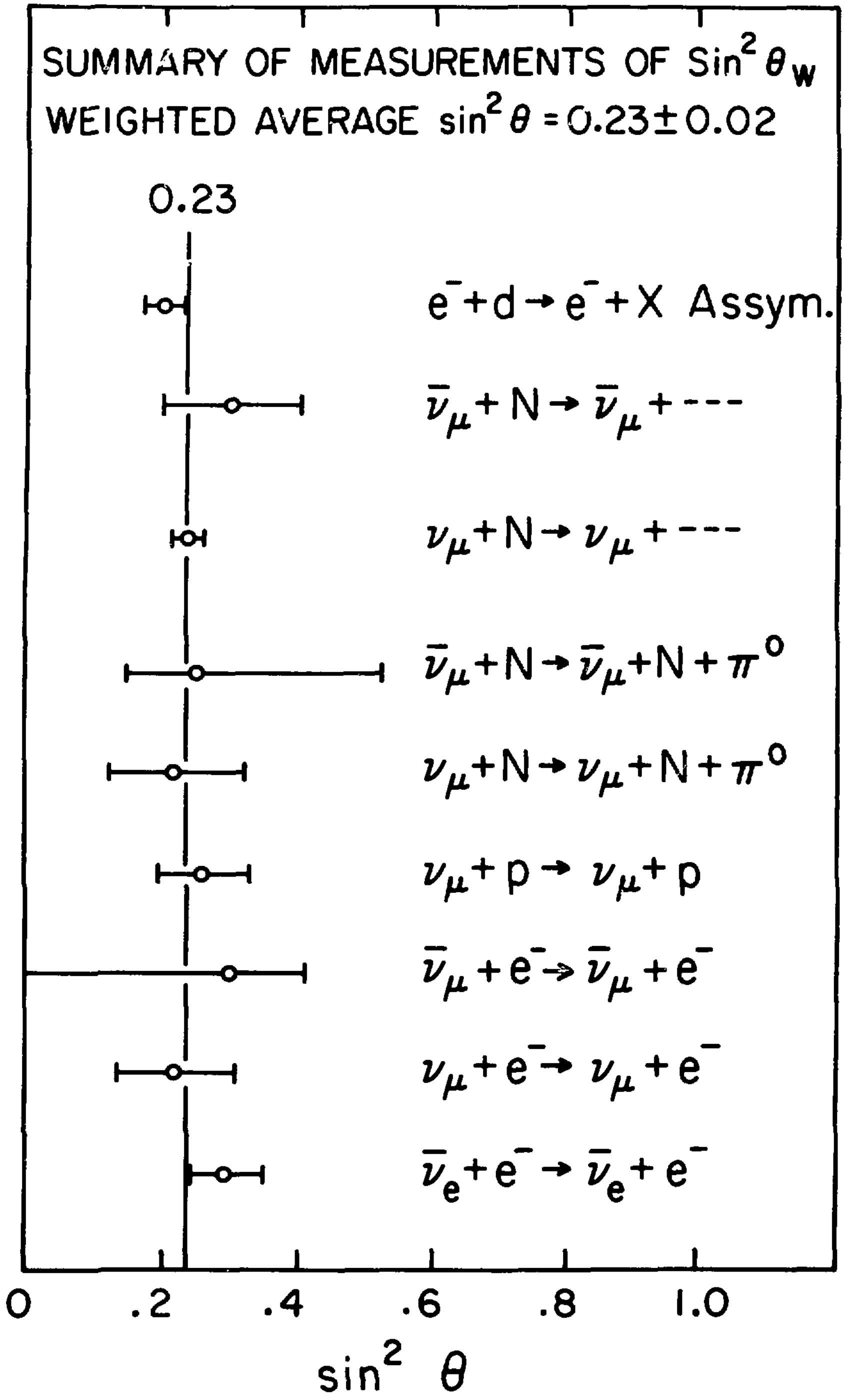


Figure 1 Results of neutral-current measurements parameterized in terms of the Weinberg angle θ_W.

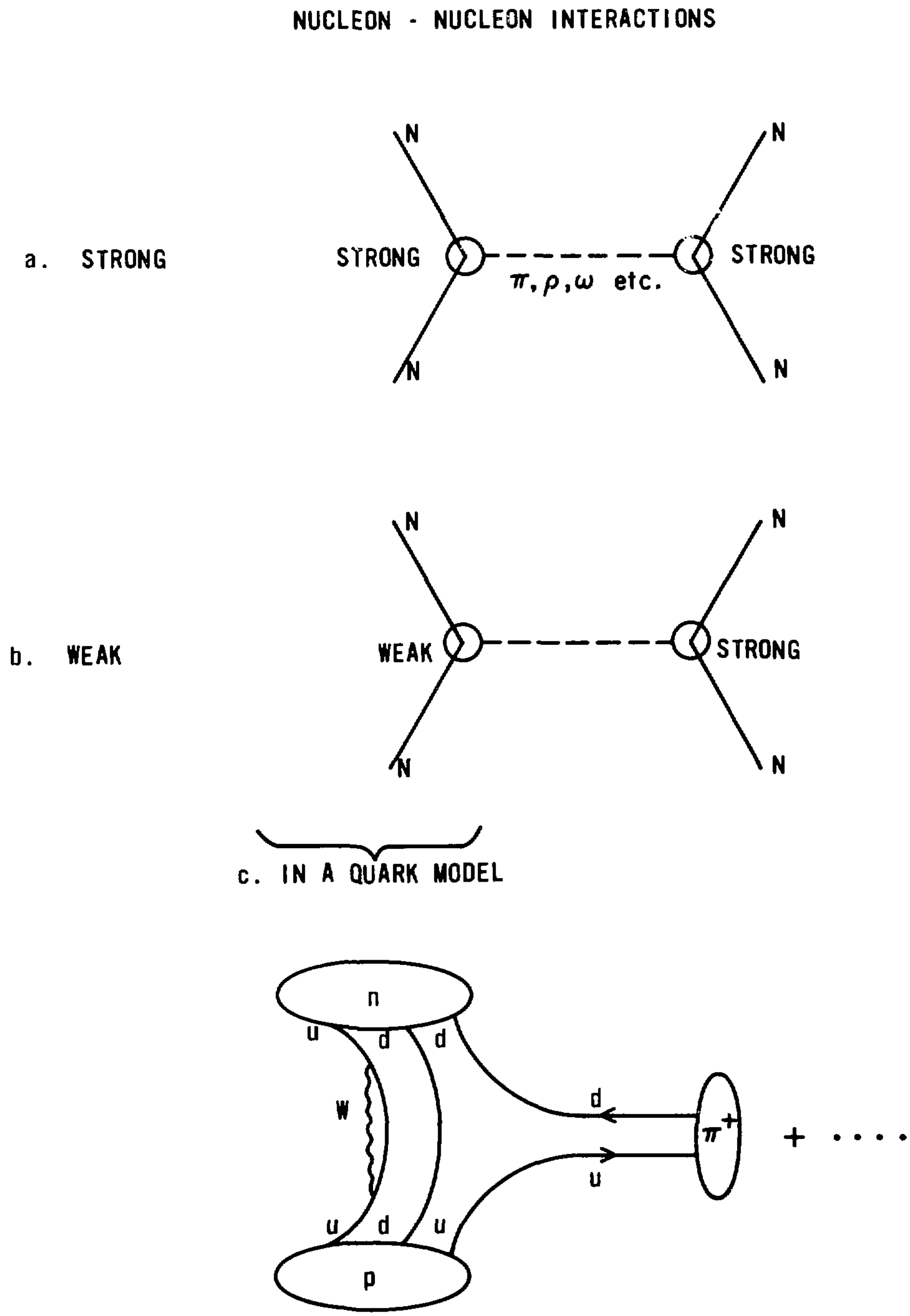


Figure 2 Strong (a) and weak (b) nucleon-nucleon interactions. The weak meson-nucleon-nucleon vertex in (b) can be calculated as a sum of terms of the type illustrated in (c).

3659-F

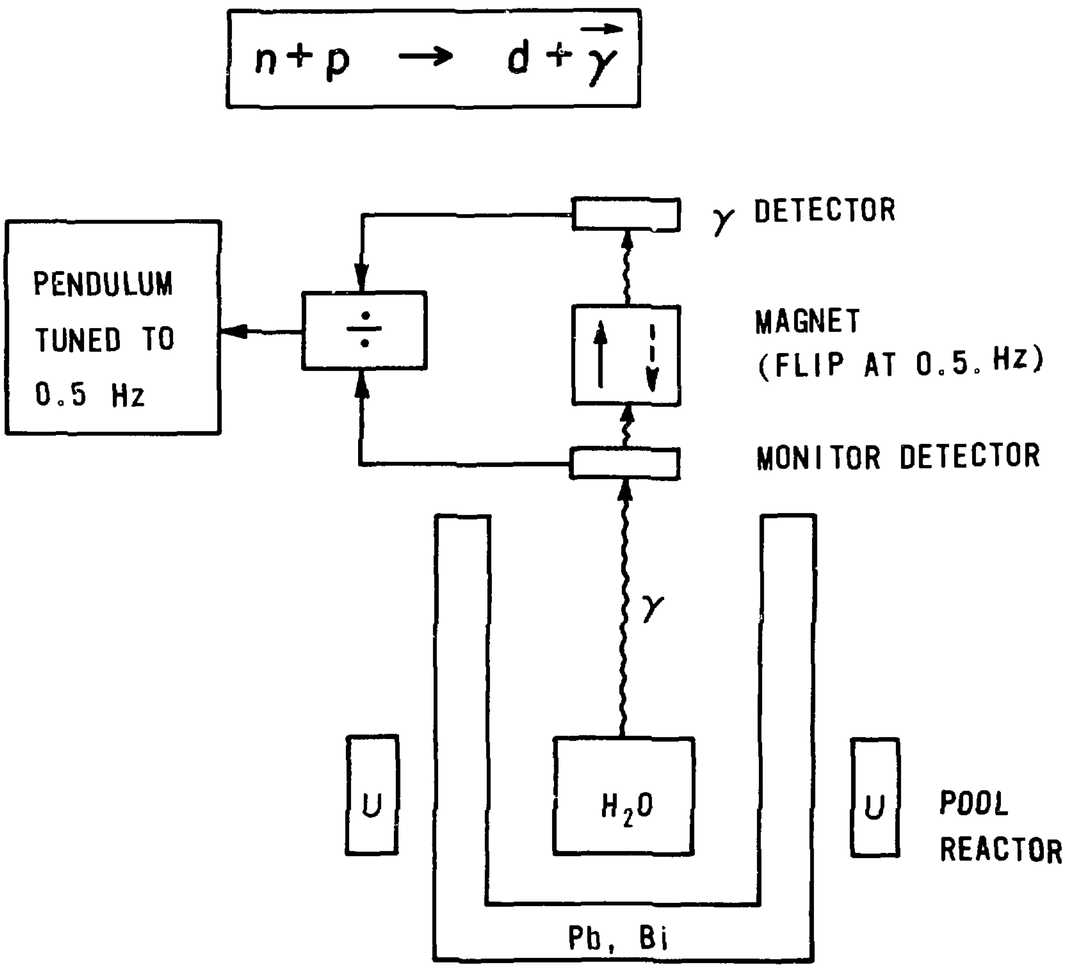


Figure 3 Schematic illustration of the $n + p \rightarrow d + \vec{\gamma}$ experiment of ref. 14.

3659-G

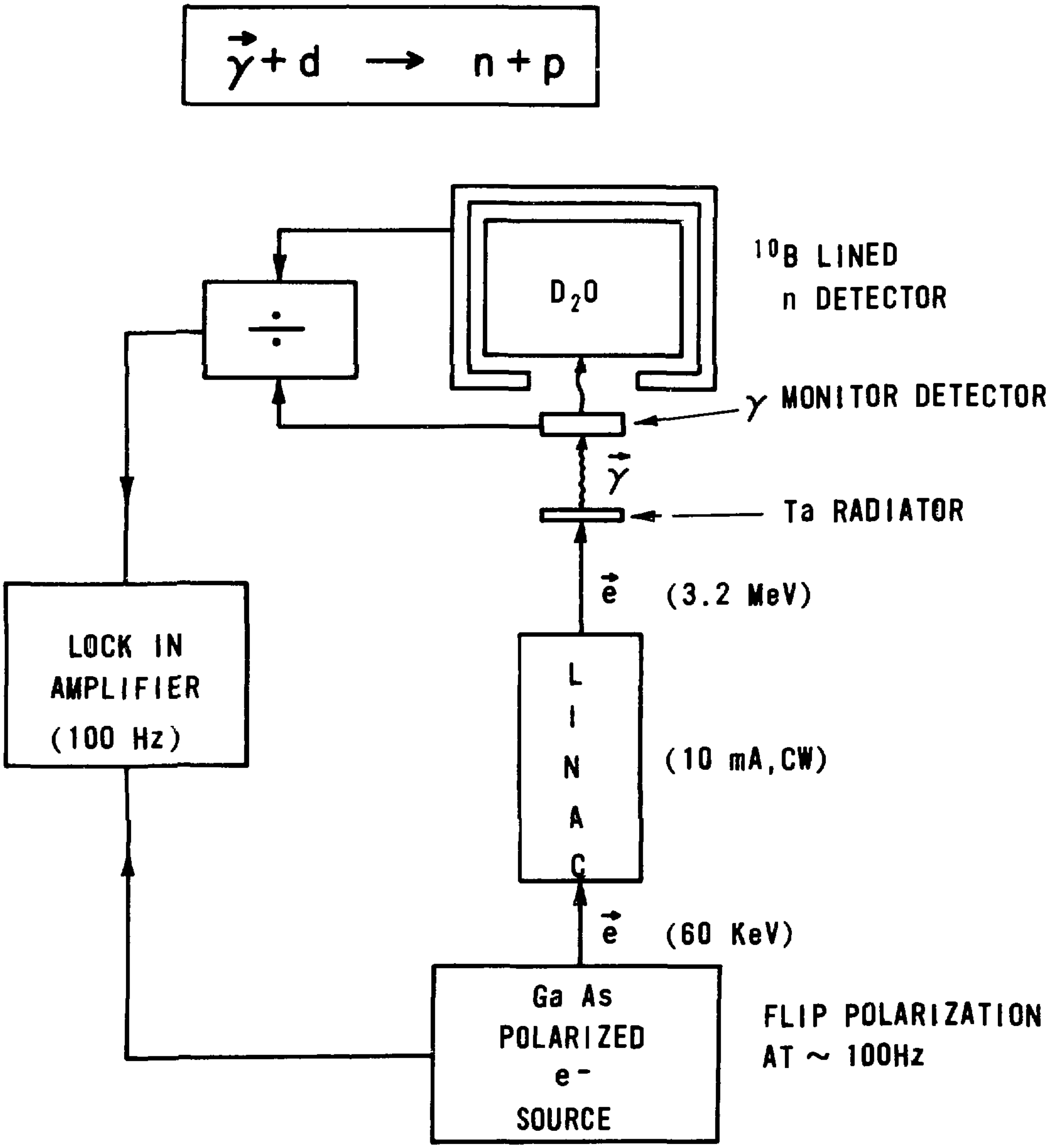
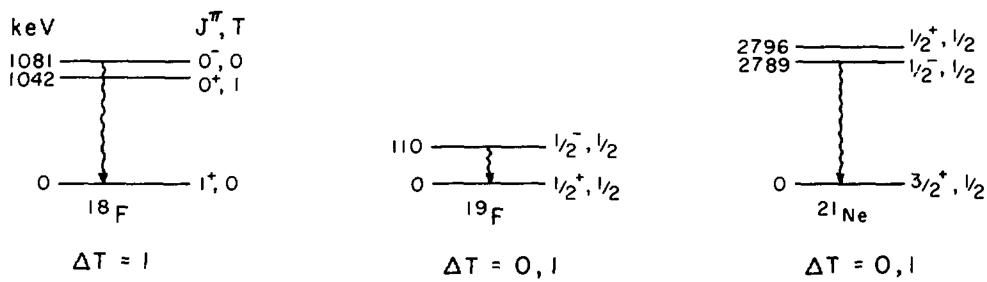


Figure 4 Schematic illustration of the d + $\vec{\gamma}$ → n + p experiment in preparation at Chalk River.

3663-D



EXPERIMENT:

$P_\gamma = (-7 \pm 20) \times 10^{-4}$	$A_\gamma = (-60 \pm 33) \times 10^{-6}$	$P_\gamma = (23 \pm 29) \times 10^{-4}$
$\lvert\langle H_w \rangle\rvert = 0.14 \pm 0.41$ eV	$\langle H_w \rangle = -0.33 \pm 0.18$ eV	$\lvert\langle H^w \rangle\rvert = 0.023 \pm 0.029$ eV

THEORY:

USING: $|V_{PV}| = \vec{\sigma} \cdot \vec{p}\ [1 + 0.3 f\ \tau_3] \times 10^{-6}$

$\lvert\langle H_w \rangle\rvert = 0.07 f$ eV	$\lvert\langle H_w \rangle\rvert = 0.23 + 0.06 f$ eV	$\lvert\langle H^w \rangle\rvert = 0.13 - 0.015 f$ eV
$\lvert f \rvert \lesssim 8$	$-12 \lesssim f \lesssim 5$	$5 \lesssim f \lesssim 12$

Figure 5 Parity doublets in ^{18}F, ^{19}F and ^{21}Ne.

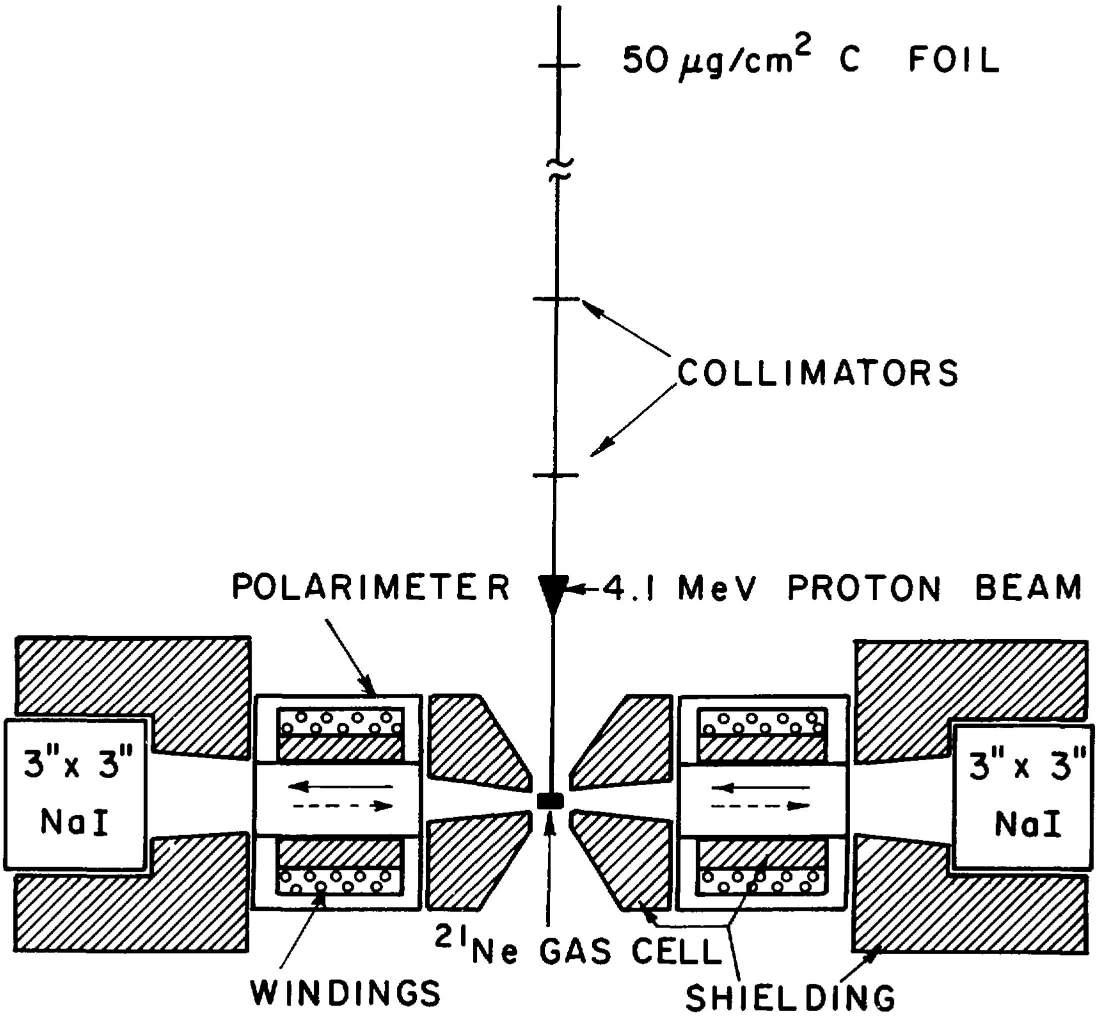


Figure 6 Schematic diagram of the apparatus used in the measurement of parity mixing in ^{21}Ne. The 50 μg/cm^2 carbon foil was used to diffuse the beam and prolong the lifetime of the molybdenum foil on the ^{21}Ne gas cell.

3634-J

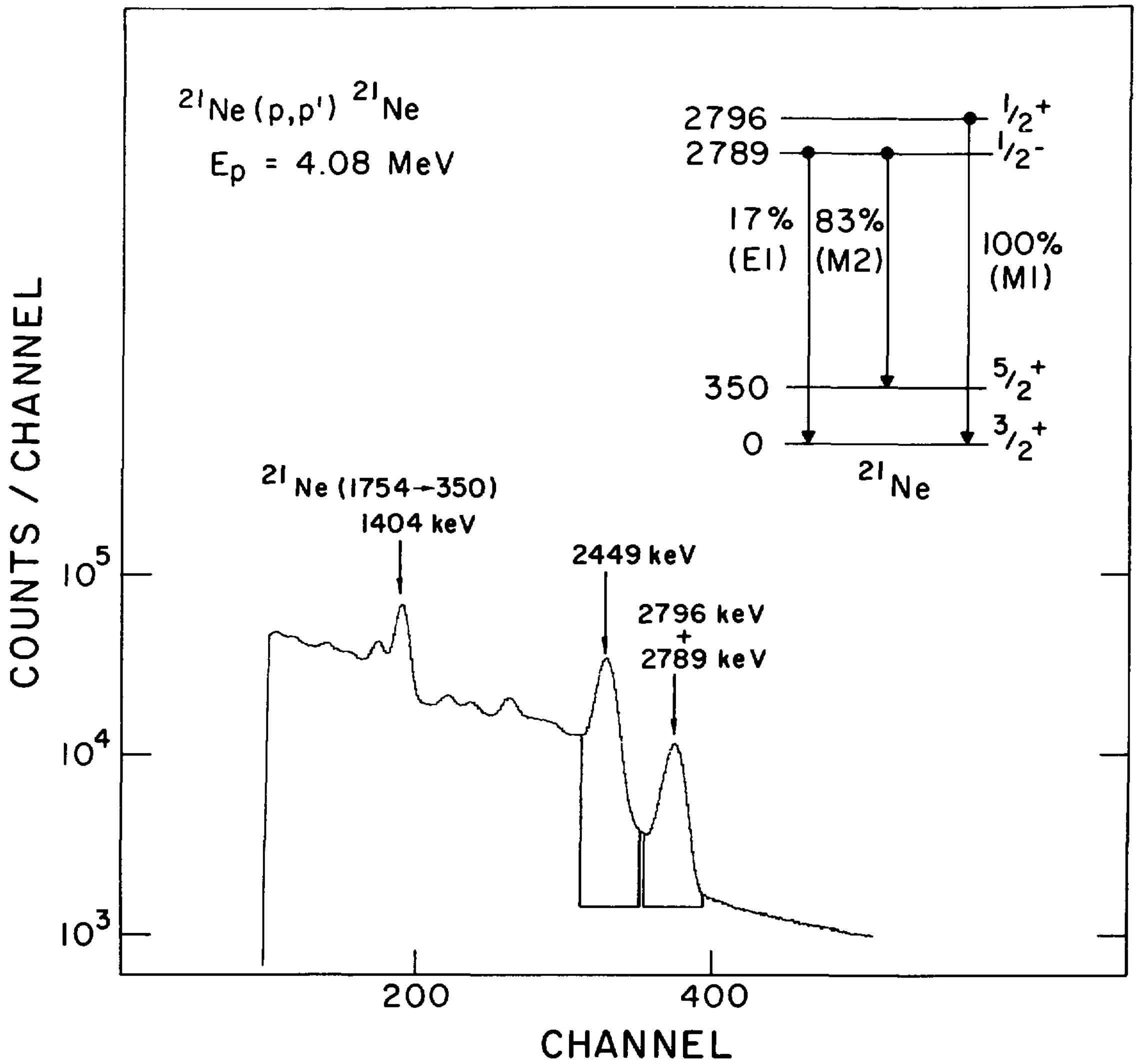


Figure 7 Spectrum of gamma rays from the $^{21}Ne(p,p')^{21}Ne$ reaction obtained from one of the NaI(Tℓ) detectors mounted behind the polarimeter. Windows used to determine total counts in the 2.4 and 2.9 MeV photopeaks are indicated.

3659-H

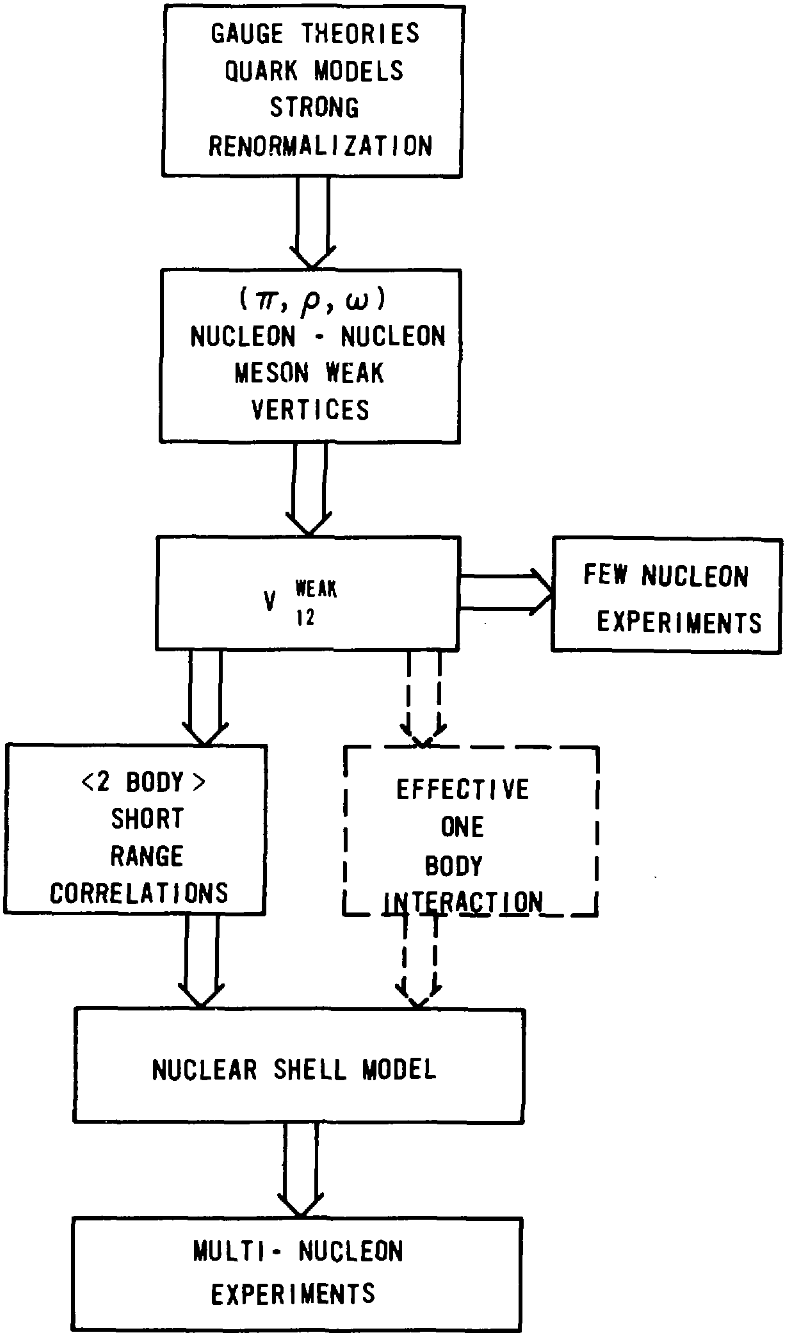


Figure 8 Schematic diagram of the main elements in calculations of parity violation in nuclear physics.

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