SPIN OBSERVABLES IN HIGH ENERGY ELECTRON SCATTERING*

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The electromagnetic structure of the nucleon is of fundamental importance to our understanding of models of the nucleon and of nuclei. Experiments which extract information on spin degrees of freedom can enhance knowledge of small components of the nucleon and nuclar wave functions. This review summarizes the results of recent experiments which exploit measurements of spin observables.

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1. Introduction

The electromagnetic probe has long been an important tool for studying nucleon and nuclear structure and dynamics. High energy electron scattering can probe distances of less than 1 fm where quark degrees of freedom are expected to play an observable role. A new generation of medium energy accelerators, operating CW with energies of 0.5–6 GeV, has recently come into operation. These enhanced capabilities, particularly the 100% duty factor and kinematic reach, will dramatically improve our ability to carry out coincidence studies. Storage ring facilities at MIT-Bates and NIKHEF make possible unique studies with thin polarized and unpolarized internal nuclear targets at relatively high luminosity.

A greatly enhanced physics scope involving the measurement of electromagnetic spin observables on the nucleon and few-body systems has become possible with the availability of intense polarized electron beams and polarized nuclear targets. Such data is necessary to provide a complete understanding of the structure of the nucleus. Experiments which

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extract information on spin degrees-of- freedom can enhance our knowledge of small components of the nucleon and nuclear wave functions. Important small amplitudes often become accessible to measurement if they enter the spin observables through their interference with larger, and in general, much better known amplitudes. In many cases, the experiments involve asymmetry measurements where systematic errors can be kept under much tighter control.

In this review, we summarize the status and results of some recent experiments which exploit the measurement of spin observables to study nucleon and nuclear structure. The use of polarized beams, polarized targets, recoil polarimetry and coincidence measurements of reaction products out-of-the scattering plane allows us to take full advantage of the capabilities of electron scattering.

2. Neutron form factors

The electromagnetic structure of the nucleon is of fundamental importance to our understanding of models of the nucleon and of nuclei. The neutron electric form factor, G_E^n, is the least well known of the four nucleon electromagnetic form factors.

The elastic scattering of unpolarized electrons from unpolarized nucleons $(I = \frac{1}{2})$, at a momentum transfer Q, involves a measurement of the cross section

$$\frac{d\sigma}{d\Omega} = \sigma_M \; f_{\rm rec}^{-1} \; [(G_E^N)^2 \; + \; \tau (G_M^N)^2 \; \{1 \; + \; 2(1+\tau) \tan^2 \frac{\theta}{2}\}]$$

where $\tau = -Q^2/4M_N^2$ and $f_{\rm rec}^{-1}$ is a kinematic recoil factor. A Rosenbluth separation of the electric and magnetic form factors, G_E^N (Q^2) and G_M^N (Q^2), allows for reasonable accuracy only when the two amplitudes are comparable. In the nucleon case the magnetic form factor dominates over the electric one at high momentum transfers. As a result, only the magnetic form factor is relatively well known over an extended range in momentum transfer. For the proton, reasonable knowledge of G_E^p exists only up to ~ 4 GeV^2. For the neutron, which is charge neutral, G_E^n is very small and as a result is very poorly known for all momentum transfers.

At present, much of our information on G_E^n comes from measurements of $A(Q^2)$ from electron-deuteron elastic and quasi-elastic scattering. The neutron electric form factor has recently been extracted from some precise new measurements [1] on $A(Q^2)$. The results for G_E^n are dependent upon the potential model which is used to describe the deuteron. The resulting systematic dependences are as large as $\sim$50%.

Spin observables now allow us to make more accurate measurements of G_E^n. For the nucleon case, experiments with both polarized beams and targets (or alternatively recoil polarimetry) are required. The differential cross section for inclusive scattering of longitudinally polarized electrons from a spin $\frac{1}{2}$ target may be written [2] as

$$\frac{d\sigma}{d\Omega d\omega} = \Sigma \pm \Delta(\theta^*, \phi^*)$$

where ω is the energy transfer and the angles θ^* and ϕ^* define the target spin direction relative to Q and the scattering plane as shown in Fig. 1. The plus (minus) sign corresponds to positive (negative) helicity of the incident electrons. The spin-independent cross section Σ has the usual Rosenbluth form

$$\Sigma = 4\pi\sigma_M[v_{\rm L}R_{\rm L}(q,\omega) \; + \; v_T R_T(q,\omega)],$$

where q is the momentum transfer, $v_{\rm L}$ and v_T are kinematic factors, $R_{\rm L}$ and R_T are the longitudinal and transverse response functions. These response functions are dependent on bilinear combinations of the nucleon electromagnetic form factors. The spin-dependent cross section Δ involves two other response functions:

$$\Delta = -4\pi\sigma_M \; [v_{T'}R_{T'} \; (q,\omega)\cos\theta^* + 2v_{TL'}R_{TL'}(q,\omega)\sin\theta^*\cos\phi^*],$$

where $v_{T'}$ and $v_{TL'}$ are kinematic factors independent of nuclear structure.

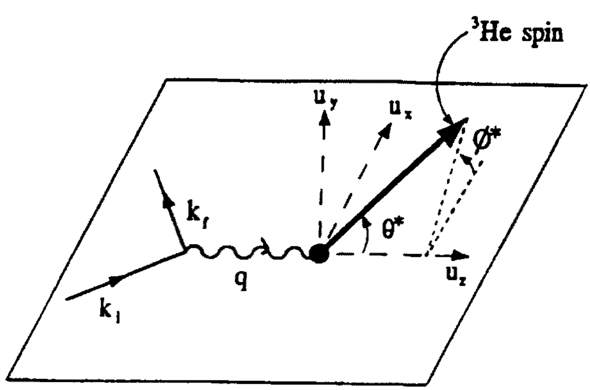

Fig. 1. Kinematic variables for electron scattering from polarized targets. The vector μ_z is along the direction of momentum transfer $\vec{q}$. The vector μ_y is normal to the electron scattering plane and $\mu_x = \mu_y x \mu_z$ lies in the scattering plane. The target polarization direction is defined by the angles (θ^*, ϕ^*) as shown.

Experiments measure the asymmetry in the cross section under reversal of electron helicity: $A = \Delta/\Sigma$. The experimental asymmetry A_{exp} is related to A by $A_{exp} = P_e P_T A$, where P_e and P_T are the electron beam and target polarizations, respectively. The electron polarization $P_e = 0.40$ typically.

In the case of a polarized neutron target, the asymmetry may be expressed in terms of the electric and magnetic form factors as

$$A = \frac{-2\tau v_{T'}(G_M^n)^2 \cos\theta^* - 2\sqrt{2\tau(1+\tau)}\, v_{TL'} G_M^n G_E^n \sin\theta^* \cos\phi^*}{(1+\tau)v_L(G_E^n)^2 + 2\tau V_T(G_M^n)^2}$$

A measurement of the asymmetry for $\theta^* = \pi/2$ involves the interference term $G_M^n\, G_E^n$ which is directly sensitive to the small electric form factor and the relative sign.

Several experiments have been designed to exploit this interference term and provide precise new information on G_E^n. These include quasi-elastic scattering from the deuteron and from polarized ^{3}He.

2.1. $^2\mathrm{H}(\vec{e}, e'\vec{n})p$

In this experiment the electric form factor of the neutron, G_E^n, is determined by scattering longitudinally polarized electrons from deuterium quasi- elastically and measuring the transverse polarization component, P_x, of the recoiling neutron. In the impulse approximation, it has been shown [3] that the neutron polarization components are given by:

$$P_x = -2\sqrt{\tau(1+\tau)}\, G_M^n\, G_E^n / I_o,$$
$$P_z = \frac{E+E'}{M}\sqrt{\tau(1+\tau)}\,(G_M^n)^2 \tan^2\frac{\theta}{2}/I_o,$$

where $\tau = Q^2/4M^2$ and the unpolarized cross section

$$I_o = (G_E^n)^2 + \tau(G_M^n)^2\,[1 + 2(1+\tau)\tan^2\theta/2].$$

The neutron polarization component, P_x, in the scattering plane normal to the neutron momentum is seen to be directly proportional to G_E^n.

In the Bates experiment [4], a longitudinally polarized electron beam, at an energy of 868 MeV, was incident on a liquid deuterium target (0.845g/cm^3). The scattered electrons were momentum-analyzed in a magnetic spectrometer. The recoil neutrons were detected in coincidence with the scattered electrons, and their transverse polarization measured. The experiment operated at a luminosity of 3×10^{36} cm^{-2} s^{-1}, using a pulsed beam with a duty factor of 1%. Fig. 2 displays the measured value of G_E^n. It is in agreement with the Galster parameterization.

The expressions for P_x and P_z can be used to calculate the ratio P_x/P_z:

$$\frac{P_x}{P_z} = -\left[\frac{2M}{E+E'}\right]\frac{G_E^n}{G_M^n}\tan^{-1}\theta/2\,.$$

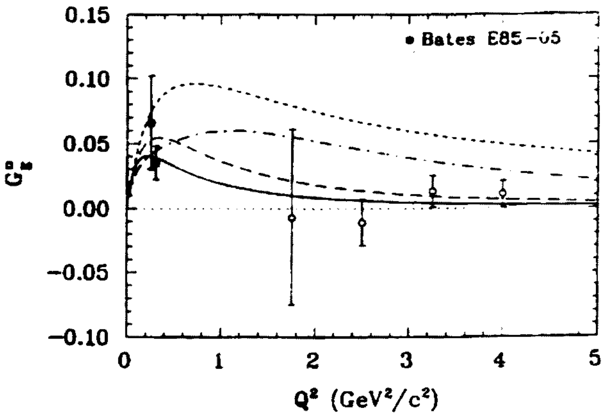

Fig. 2. Recently reported values of G_E^n: quasielastic $^2\mathrm{H}(\vec{e}, e'\vec{n})$ reaction (shaded circle), exclusive $^3\vec{\mathrm{He}}(\vec{e}, e'n)$ by Meyerhoff *et al.* [27] (shaded square), and the inclusive quasielastic $^2\mathrm{H}(e, e')$ results of Lung *et al.* [28] (open circles). The parameterizations are from the work of Galster *et al.* [29] $G_E^n = -\tau\mu_n(1 + 5.6\tau)^{-1}$ (long dashes), Platchkov *et al.* [1] where the Paris potential fit is shown (solid), the Gari-Krümpelmann VMD-PQCD model 3 (dash-dot) and the parameterization $G_E^n = -\tau G_M^n$ (short dashes) where $F_{1n} = 0$.

A measurement of this ratio would be largely insensitive to both the electron polarization and polarimeter analyzing power. The longitudinal polarization can be measured with the same polarimeter after precessing the neutron spin by $\pi/2$ with a dipole magnet.

Further experiments are planned at Bates at higher Q^2 using extracted CW beams from the South Hall Ring. Similar experiments have been carried out at MAINZ and are also planned for CEBAF at high Q^2.

2.2. $^3\vec{\mathrm{He}}(\vec{e}, e')$

^{3}He is a very interesting nucleus for electromagnetic studies. It can be polarized and one expects that spin-dependent scattering from ^{3}He would be sensitive to neutron electromagnetic form factors. To a good approximation, the two protons in the ground-state are in a singlet configuration.

For the case of ^{3}He, $(I = \frac{1}{2})$, in analogy with the nucleon case, the asymmetry is given by

$$A = -\frac{v_{T'}R_{T'}\ \cos\theta^* + 2v_{TL'}\ R_{TL'}\ \sin\theta^*\cos\phi^*}{v_L R_L + v_T R_T}$$

By choosing the target spin to be along $\vec{q}(\theta^* = 0°)$ or normal to $\vec{q}(\theta^* = 90°)$, one can select the asymmetry to be proportional to $R_{T'}$ *or* $R_{TL'}$, respectively.

All calculations show that the spin-dependent asymmetry for $\vec{q}$ parallel to the target spin is proportional to $(G_M^n)^2$. In comparison to a target of polarized neutrons, ^{3}He dilutes the asymmetry since proton scattering contributes to the unpolarized cross section. In addition, small amplitudes in the ^{3}He wave function which are due to polarized protons also contribute to the asymmetry.

Similarly, the spin-dependent asymmetry for $\vec{q}$ perpendicular to the target spin is sensitive to the neutron electric form factor. The calculations of Blankleider and Woloshyn [5] showed that the neutron contribution dominated allowing a direct measurement of G_M^n and G_E^n. The more recent calculations [6,7,8] for the response function $R_{TL'}$ show a substantial proton contribution which significantly reduces the sensitivity to G_E^n.

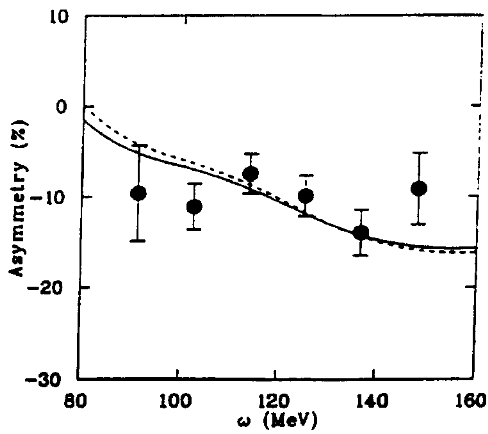

Fig. 3. The measured transverse asymmetry $A_{T'}$ as a function of energy loss ω. The dashed line is the calculation by Salmè *et al.* [7], and the solid line is the calculation by Schulze *et al.* [8].

The first measurements of spin-dependent inclusive electron scattering from a polarized ^{3}He target were carried out at Bates in 1990 [9,10]. A high-precision measurement [11] was performed at Bates in 1993 using the Caltech target. The beam energy was 370 MeV, and 25 μA beams at 37% polarization were typical. The target polarization was ~38%. Fig. 3 shows the measured asymmetry, $A_{T'}$, over the quasi-elastic peak. The neutron magnetic form factor, G_M^n, has been extracted from this asymmetry based on recent PWIA calculations using spin-dependent spectral functions. The result at $Q^2 = 0.19$ GeV^2 is in agreement with the dipole parameterization, $\mu_n\, G_D$, and the ratio is $(G_M^n/\mu_n\, G_D)^2 = 0.998 \pm 0.117 \pm 0.059 \pm 0.030$,

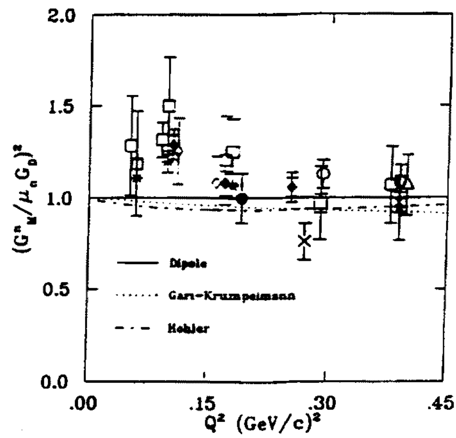

Fig. 4. The square of the neutron magnetic from factor $(G^n_M)^2$, in units of the standard dipole parameterization, $(\mu_n G_D)^2$, in the *low* $- Q^2$ region. The solid circle is from the data of Gao *et al.* [11]. The other data points are defined in Ref. [11].

where the errors are statistical, systematic, and model dependence, respectively. The result for G^n_M is shown in Fig. 4, together with other experimental data. This experiment is the first measurement for the neutron magnetic form factor using spin- dependent inclusive electron scattering.

The same measurement [26] also yielded results for the $A_{TL'}$ asymmetry. The experimental result is $A^{\rm exp}_{TL'} = 1.52 \pm 0.55 \pm 0.15\%$ and the theoretical prediction is , $A^{\rm thy}_{TL'} = 2.1 - 2.9\%$. The theoretical variation is due to uncertainties in the wavefunction of ^{3}He, nucleon form factors and off-shell prescriptions. Given the sizeable proton contribution, it is unlikely that this can be used to provide accurate information on G^n_E. There is some expectation that measurements at higher Q^2 could provide useful data for G^n_E.

Further inclusive measurements of quasi-elastic asymmetries at higher-Q^2 are planned at Bates and CEBAF. The MAINZ program on polarized ^{3}He emphasizes exclusive measurements.

3. Out-of-plane spectrometry

Exclusive measurements involving electron scattering have been used for many years to study excitations in the nuclear continuum and to provide information on momentum distributions and medium effects in nuclei. An out-of-plane electron scattering capability is essential to fully exploit the potential of coincidence experiments. It has been shown that such a capability would give access to new observables and thus permit the isolation of important and otherwise inaccessible small amplitudes.

The $A(\vec{e}, e'\times)B$ cross section corresponding to the reaction depicted in Fig. 5 can be written in the one-photon exchange approximation as [12];

$$\frac{d\sigma}{d\Omega} = \Sigma(\theta^*, \phi^*) + h\ \Delta(\theta^*, \phi^*),$$

where

$$\Sigma = \sigma_M[v_L R_L + v_T R_T + v_{TL} R_{TL} \cos\phi^* + v_{TT} R_{TT}\ \cos 2\phi^*]$$

and

$$\Delta = \sigma_M\ v_{TL'}\ R_{TL'} \sin\phi^*.$$

The polar angles θ^* and ϕ^* define the direction of the decay product (*e.g.* a proton) relative to the direction of the momentum transfer and the scattering plane. The cross section is separated into helicity dependent and independent parts ($h = \pm 1$ is the electron helicity). In the usual case, where unpolarized targets are used and the polarization of the decay proton is not measured, the cross section depends on five nuclear response functions.

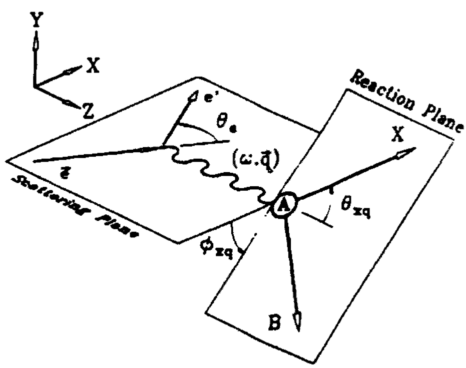

Fig. 5. Kinematic definitions for the $A(\vec{e}, e'X)$ B reaction.

These five response functions are bilinear combinations of the transverse and longitudinal components of the nuclear current with respect to the direction of the momentum transfer $\vec{q}$. The goal of any experiment is to effect an accurate isolation of each response. R_L *and* R_T are readily determined using a Rosenbluth separation. R_{TL} *and* R_{TT} can be separated by measurements at values of ϕ^* on a cone centered on $\vec{q}$. The "fifth" structure function, $R_{TL'}$ – a new observable, breaks the symmetry for decay particles scattering above and below the plane and can be measured if the incident electrons are longitudinally polarized and decay particles are observed out-of-plane.

Interference terms typically contribute at a level of (1-20)% to the total cross section. As a result, there are major experimental challenges in performing these measurements with high statistical and systematic precision. The most straightforward approach involves sequential measurements with a spectrometer positioned at different θ^* and ϕ^*.

At MIT-Bates, we are implementing a unique system of four small magnetic spectrometers (OOPS) which will allow for simultaneous measurements [13]. The basic idea is to arrange the spectrometers in a cone symmetrically about the momentum transfer $\vec{q}$. It is believed that the simultaneous measurement of several asymmetries will allow for the isolation of the interference structure functions with very high accuracy. The required control of kinematic variables and other experimental parameters is expected to be greatly reduced in comparison with the usual technique of sequential measurements. Large out-of-plane angles are readily accommodated. This is essentially impractical with typical large magnetic spectrometers. The Bates system will be fully operational in 1996.

3.1. $N \to \Delta$ transition

The electroexcitation of the $\Delta(1232)$ resonance is predominantly M1. In a naive quark model, the nucleon and delta are each made up of three 1-S quarks and the transition is a pure spin-isospin flip excitation. If the quark wavefunction has a non-vanishing D-state component, C2 and E2 transition amplitudes would also be allowed. Such admixtures can arise in bag models through bag deformation or through color magnetic effects from one-gluon exchange in a more fundamental QCD picture. The isolation of quadrupole amplitudes in the $N \to \Delta$ transition is of fundamental importance to our understanding of the nucleon.

The first nucleon resonance has been studied with photoproduction and with inclusive and coincidence electron scattering. Rosenbluth separations have been used to extract longitudinal and transverse cross-sections. Experimental values of E2/M1 (EMR) and C2/M1 (CMR) ratios can have contributions from "background" amplitudes such as Born terms and the tails of nearby resonances. There have been recent results from the LEGS collaboration for the $^1\mathrm{H}(\vec{\gamma},p)\pi^0$ reaction [14] and from Bonn [15]. A consistent model description of the LEGS data at $Q^2 = 0$ with pion photoproduction data has not yet been achieved for any EMR value. In the Bonn experiment, a surprisingly large C2/M1$= 13 \pm 2\%$ at the four-momentum transfer $Q^2 = 0.127\mathrm{GeV}^2$ was reported. Both experiments suggest the importance of background terms and reinforce the need to confirm these results.

Model calculations suggest that the R_{LT} response function is sensitive to CMR, while other observables appear to be more sensitive to background terms. An experiment has just been completed at Bates which measured the coincidence yields for the $^1H(e,e'p)\pi^0$ reaction at $Q^2 = 0.127 GeV^2$ at residual energies $W = 1170, 1232$ and 1280 MeV. A liquid H_2 target was used together with the MEPS and OHIPS spectrometers for electron and proton detection, respectively. OHIPS was also instrumented with a focal plane proton polarimeter which was used for these studies. Very careful attention was given to the optical charactersitics of the spectrometers, luminosities, and detector efficiencies. The data will allow an extraction of absolute cross-sections and the response functions R_T (all W values) and R_{LT} (W = 1170 and 1232), as well as the proton polarization P_n at $W = 1232$ MeV. The preliminary cross sections are within the range spanned by current models. P_n , which is believed to be mainly sensitive to background terms, shows a large preliminary value $P_n \sim -0.3$.

3.2. Fifth structure functions: ^2H,^{12}C

We have recently completed experiments involving the measurement of the "fifth" structure function in nuclei. They involved the out-of-plane coincident detection of protons, using longitudinally polarized electrons. The reactions studied were $^2H(\vec{e},e'p)$ and $^{12}C(\vec{e},e'p)$. The objective was to test model descriptions of these nuclei and, in particular, to isolate the contributions of background terms from the resonant ones.

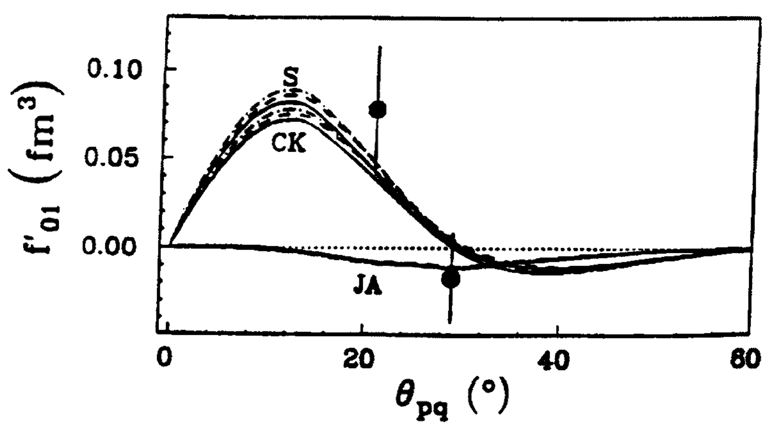

Fig. 6. The fifth structure function is compared to theoretical predictions in the impulse approximation for three optical potentials.

The measurements were carried out with a single OOPS module. Data were acquired at quasi-free kinematics at $Q^2 = 3.3\ fm^{-2}$. Results [16] for ^{12}C, dominated by counting statistics, are compared with theoretical calculations [17] in Fig. 6. They are in good agreement with the model calculations. When the OOPS system is fully operational, we expect to continue these measurements with much improved accuracy.

4. Proton recoil polarimetry

Recently, the first series of coincidence $(e, e'\vec{p})$ reactions with hydrogen and deuterium targets were carried out at Bates. The proton focal plane polarimeter (FPP) was constructed by a UVa, W&M and MIT collaboration [18] and is installed in the OHIPS spectrometer. Physics issues which will be addressed include the quadrupole amplitudes in the $N \to \Delta$ transition via the $^1\mathrm{H}(\vec{e}, e'\vec{p})\pi^0$ reaction, the electromagnetic structure of the deuteron and sensitive tests of nucleon-nulceus dynamics in complex nuclei.

The initial measurements were of the spin transfer coefficients in elastic scattering of polarized electrons from hydrogen and in quasielastic scattering from the deuteron at $q^2 = 0.38$ and $0.5\ \mathrm{GeV}^2$. Preliminary analysis indicates that, in quasifree kinematics, the spin transfer coefficients on deuterium are consistent with those on hydrogen at the level of a few percent. All three components of the proton polarization were measured in these experiments and appear to be consistent with modern two-body theories. Subsequent measurements will explore the deuteron away from quasifree kinematics where the influence of other amplitudes may be enhanced.

The polarimeter was also used in some initial $N \to \Delta$ studies. A measurement was made of R^n_{LT} with unpolarized beams at $Q^2 = 0.127\mathrm{GeV}^2$ to complement the measurements of R_T and R_{LT} at the same Q^2. These data are now being analyzed.

A measurement was also carried out on a complex system, where the impulse approximation is not expected to hold. An unpolarized electron beam was scattered from ^{12}C. In the absence of any spin transfer, the only polarization observable is the induced polarization p_n, which arises from final state interactions between the recoiling proton and the residual nuclear system. Measurements were made for both the p- and s-shell spin orbit partners. Our data are consistent with calculations based on a p - ^{12}C optical potential.

5. Electroweak physics

Experiments designed to probe the structure of the neutral currents continue to be of great interest to atomic, nuclear and particle physicists. All of the data are in impressive agreement with the Standard Model [19] of Glashow, Weinberg, and Salam. The best value for the weak mixing angle, a free parameter in the theory, is $\sin^2\theta_w = 0.233 \pm 0.002$ [20] as determined from measurements of the Z-boson mass.

The neutral currents are known to be parity violating and this aspect of their structure may be studied using polarized electrons. The parity violating asymmetry may be defined as

$$A = (\sigma_{\rm R} - \sigma_{\rm L})/(\sigma_{\rm R} + \sigma_{\rm L}),$$

where $\sigma_{\rm R}(\sigma_{\rm L})$ is the differential cross section for the scattering of electrons with right (left) helicity. Parity violating asymmetries were first observed in the scattering of polarized electrons from deuterons at SLAC [21] and in the spectra of heavy atoms [22] at low energies.

The first Bates parity experiment involved elastic scattering from ^{12}C. In the case of a spinless and isoscalar nucleus the electromagnetic scattering is described by a single form factor and the asymmetry, A, may be written at the tree-level [23] as

$$A = \bar{\gamma}\frac{3}{2}G_F Q^2(\sqrt{2}\,\pi\,\alpha)^{-1}\,,$$

where G_F is the Fermi coupling constant, α is the fine structure constant, Q is the momentum transfer, and $\bar{\gamma}$ is the parity violating constant for an axial vector coupling to the hadronic matter. The asymmetry is completely independent of the electromagnetic form factor. It is a direct consequence of our assumption that the weak and electromagnetic currents couple to exactly the same operators. The cancellation is Q^2 independent and a precision test could be sensitive to possible extensions of the SM.

The ^{12}C experiment was carried out at $Q = 150$ MeV/c. A value of $\bar{\gamma}$ $= 0.136 \pm 0.032 \pm 0.009$ was measured [24] which is consistent with the prediction of the SM where, $\bar{\gamma}_{SM} = 0.155 \pm 0.002$.

Recently, there has been a lot of experimental and theoretical interest in strange quark contributions to hadronic matrix elements. New experiments using parity violating electron scattering as a neutral current probe of hadronic structure are underway at MIT-Bates and are also planned for MAINZ and CEBAF. They are designed to measure the neutral weak form factors G_E^z, G_M^z and G_A^z of the proton to provide an unambiguous signature for the presence of strange quarks in the nucleon.

The parity violating asymmetry for elastic scattering from a proton target can be written as a sum of three terms which reflect the interference between the electromagnetic and the neutral weak interactions:

$$A = \frac{G_F Q^2}{\pi\alpha\sqrt{2}} \frac{[\epsilon G_E^p\, G_E^z \;+\; \tau G_M^p G_E^z \;-\; \frac{1}{2}(1-4\sin^2\theta_w)\;\epsilon' G_M^p G_A^z]}{\epsilon(G_E^p)^2 \;+\; \tau(G_M^p)^2},$$

where $\tau = Q^2/4m_p^2$, $\epsilon = [1+2(1+\tau)\tan^2\theta/2]^{-1}$ and $\epsilon' = \sqrt{(1-\epsilon^2)\tau(1+\tau)}$.

The first two terms dominate at forward angles and the latter two terms contribute at backward angles. The term including the axial vector form factor, G_A^z is suppressed by the factor $(1 - 4\sin^2\theta_w)$.

The form factors $G_{E,M}^z$ contain contributions from strange quarks, $G_{E,M}^s$. The SAMPLE [25] experiment at MIT-Bates is designed to measure G_M^z and extract the contribution of strange quarks to the static anomalous magnetic moment of the proton.

SAMPLE will measure backward angle scattering ($\bar{\theta} \sim 150°$) at E=200 MeV and $Q^2 = 0.1$ GeV^2. A large solid angle (2 sr) air Čerenkov detector (10 mirrors) will be used to detect the scattered electrons from a 40 cm long liquid hydrogen target and $40\mu A$ of polarized beam ($P_e = 40\%$).

The predicted asymmetry is $\sim 8 \times 10^{-6}$. The contribution of the axial vector term to the asymmetry is $\sim 20\%$ and the weak radiative corrections to this term are about $20-30\%$ with large uncertainty. The goal is to measure the asymmetry to a statistical accuracy of 5%. We expect to achieve an overall error in G_M^s of $\Delta G_M^s = 0.22$. Theoretical predictions fall in the range $-1 < G_M^s(0) < 0$. Data taking for this experiment is currently underway. Initial results show parity a violating asymmetry at about the expected level.

It would also be useful to have a direct measurement of the axial vector term. In quasi-elastic electron- deuteron scattering, at the same kinematics, the strange quark contributions to the proton and neutron add incoherently and approximately cancel in the asymmetry. However, the axial vector term and the uncertainty in the corresponding hadronic radiative correction contribute the same fraction to the asymmetry. Combining the two measurements puts constraints on the radiative corrections and improves the determination of the strange magnetic form factor. It is planned to do the deuterium measurements following those on the proton.

6. Internal target physics

The Bates South Hall Ring was designed and constructed to provide high duty factor extracted beams and an internal target capability for nuclear research. In the internal target mode, beam energies of $(0.3-1.0)$ GeV and circulating currents of 80 mA are available with very long storage times. Windowless storage cell targets of polarized ^1H, ^2H and ^3He can be used with densities of $10^{14} - 10^{16}$ atoms/cm^2. Luminosities up to $10^{33}cm^{-2}s^{-1}$ will be possible.

The proposed physics program will emphasize spin- dependent electron scattering. A major component will be neutron electromagnetic form factor measurements on ^2H and ^3He in both inclusive and exclusive channels over the range $Q^2 = 0.1 - 0.8$ GeV^2. Other measurements are designed to measure small amplitudes in the structure of ^3He and to study the $N \to \Delta$ transition. These experiments would complement efforts with extracted beams.

The Bates Large Acceptance Spectrometer Toroid (BLAST) project is an initiative to develop and construct a large acceptance detector optimized for internal target physics with the SHR. BLAST is a non-focussing magnetic spectrometer with eight copper coils arranged in a toroidal configuration. Two opposing sectors would be instrumented with wire chambers, scintillation counters, neutron detectors, and Čerenkov counters for tracking, time-of- flight, and particle identification.

At NIKHEF, an internal target experiment has recently been completed involving electron scattering from a tensor polarized deuterium target. The target was a long storage cell fed by an atomic beam source. The beam energy was 565 MeV and the stored current was 60 mA for an effective luminosity of $\approx 10^{31}cm^{-2}s^{-1}$. Scattered electrons were detected in a Cerenkov counter and recoil nucleons in a large hadron array. An accurate measurement was made of t_{20} at $Q = 1.7fm^{-1}$. The tensor asymmetry for the $^2\vec{H}(e, e'p)$ reaction was also measured for target polarizations perpendicular and parallel to $\vec{q}$. These initial results show that the internal target technique has a lot of potential for some very interesting physics.

7. Summary

The recent experiments at MIT-Bates and MAINZ, exploiting the use of polarized electrons and the measurement of spin observables, point to the importance of such studies in understanding nucleon and nuclear structure. In many instances we find both increased sensitivity and new observables which allow the accurate determination of small amplitudes. A major component of the future programs at MIT-Bates, NIKHEF, MAINZ and CEBAF, will involve the use of polarized beams, polarized targets and recoil polarimetry.

Modern electron accelerators, operating at 100% duty factor, will provide the ultimate capability for coincidence experiments. The stretcher/ storage ring facilities at MIT- Bates and NIKHEF were designed to operate with internal targets. Internal target experiments with polarized beams and polarized targets at high luminosities represents an important new capability for nuclear research.

The next decade promises to be a very exciting one for electronuclear physics. For the first time the full power of the electron probe can be applied in the broadest sense to study nucleons and nuclei.

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