ELSEVIER

Nuclear Instruments and Methods in Physics Research A 402 (1998) 383–385

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH
Section A

Polarized ^{3}He and neutron form factors

S. Ishikawa*

Department of Physics, Hosei University, Fujimi 2-17-1, Chiyoda, Tokyo 102, Japan

Abstract

The transverse–longitudinal response function $R_{TL'}$ of ^{3}He is studied with full inclusion of final state interaction. Contributions from each nucleon form factor are calculated. Possible relativistic effect is examined in extracting neutron charge form factor from associated spin-dependent asymmetry in inclusive scattering of polarized electrons from polarized ^{3}He.

PACS: 21.45. + v; 25.30.Fj; 24.70. + s; 13.40.Gp
Keywords: Polarized ^{3}He; Inclusive electron scattering; Three-nucleon systems; Final-state interaction; Neutron form factors

Due to dominance of spin-singlet state of proton-pair in ^{3}He nucleus, polarized ^{3}He is regarded as an effective neutron target or beam. In particular, the scattering of polarized electron from polarized ^{3}He at quasielastic kinematics is considered to be a useful tool to study the electromagnetic structure (form factors) of the neutron.

The cross section of inclusive scattering of the longitudinally polarized electron with helicity $h(=\pm 1)$ from the polarized ^{3}He target, $^3\vec{\mathrm{He}}(\vec{\mathrm{e}}, \mathrm{e}')$, is given by the following expression:

$$\frac{\mathrm{d}^2\sigma}{\mathrm{d}\Omega'_e\,\mathrm{d}E'_e} = \sigma_{\mathrm{Mott}}\,\{v_L R_L + v_T R_T - h\,(\cos\theta^*\, v_{T'} R_{T'} + 2\sin\theta^*\cos\phi^*\, v_{TL'} R_{TL'})\}, \quad (1)$$

where R_L, R_T, $R_{T'}$ and $R_{TL'}$ are the response functions of the target nucleus; v_L, v_T, $v_{T'}$ and $v_{TL'}$ are electron kinematical factors; θ^* and ϕ^* are the polar and azimuthal angles of the target spin with respect to the 3-momentum transfer $\boldsymbol{Q}$ and the electron scattering plane. In the naive picture, where the ^{3}He target is essentially the neutron target, $R_{T'}$ and $R_{TL'}$ on top of the quasielastic peak are related with the neutron magnetic (G_M^n) and electric (G_E^n) form factors as

$$R_{T'} \propto (G_M^n)^2, \quad R_{TL'} \propto G_M^n \cdot G_E^n. \quad (2)$$

Recently, experimental information of these response functions [1–3] has been obtained by measuring the spin-dependent asymmetry with respect to electron helicity in $^3\vec{\mathrm{He}}(\vec{\mathrm{e}}, \mathrm{e}')$ reaction:

$$A = \frac{\sigma(h=+1)-\sigma(h=-1)}{\sigma(h=+1)+\sigma(h=-1)} = \cos\theta^*\, A_{T'} + \sin\theta^*\cos\phi^*\, A_{TL'}. \quad (3)$$

Here, the transverse asymmetry $A_{T'}$ and the transverse–longitudinal asymmetry $A_{TL'}$ are related with

* E-mail: ishikawa@fujimi.hosei.ac.jp.

PII S0168-9002(97)00867-X

the response functions as

$$A_{\mathrm{T}'} = -\frac{v_{\mathrm{T}'} R_{\mathrm{T}'}}{v_{\mathrm{L}} R_{\mathrm{L}} + v_{\mathrm{T}} R_{\mathrm{T}}}, \quad A_{\mathrm{TL}'} = -\frac{2 v_{\mathrm{TL}'} R_{\mathrm{TL}'}}{v_{\mathrm{L}} R_{\mathrm{L}} + v_{\mathrm{T}} R_{\mathrm{T}}}. \tag{4}$$

The measured asymmetries are dominated by $A_{\mathrm{T}'}$ [1] or $A_{\mathrm{TL}'}$ [2,3] depending on the experimental conditions: $\theta^* \sim 0°$ [1] or $\theta^* \sim 90°$ [2,3].

Theoretically, the three-nucleon systems have an advantage that calculations of the bound- and continuum states are available for realistic nucleon–nucleon interactions with reliable accuracy, which means that we can fully take account of effects from small components of ^{3}He in which the proton-pair is not in the spin-singlet state, neutron motion in the target ^{3}He and interaction between knocked out nucleon by the virtual photon and the rest nucleons, namely, final state interaction (FSI). In Ref. [4], we have developed a formalism to calculate the $3N$ longitudinal response functions with full inclusion of FSI, and found that the FSI effects are significant and lead to a satisfactory agreement with the experimental data. This formalism was extended to the $3N$ transverse response function [5], and interference responses between longitudinal and transverse terms, which are observed in polarization experiments [6,7].

In this contribution, we will report on analysis of $A_{\mathrm{TL}'}$-dominated asymmetry [2,3], which is expected to work as a source of information on $G_{\mathrm{E}}^{\mathrm{n}}$. Analysis of $A_{\mathrm{T}'}$-dominated asymmetry measurement [1] concerned with $G_{\mathrm{M}}^{\mathrm{n}}$ is reported elsewhere in this workshop [8].

Since the transverse-longitudinal response function $R_{\mathrm{TL}'}$ originates from an interference between transverse current and charge density, in general, it can be separated into four terms:

$$R_{\mathrm{TL}'} = R_{G_{\mathrm{M}}^{\mathrm{n}} G_{\mathrm{E}}^{\mathrm{n}}} + R_{G_{\mathrm{M}}^{\mathrm{p}} G_{\mathrm{E}}^{\mathrm{p}}} + R_{G_{\mathrm{M}}^{\mathrm{n}} G_{\mathrm{E}}^{\mathrm{p}}} + R_{G_{\mathrm{M}}^{\mathrm{p}} G_{\mathrm{E}}^{\mathrm{n}}}, \tag{5}$$

where $R_{g1\,g2}$ denotes a term which is proportional to a product of nucleon form factors, $g1$ and $g2$. In PWIA, only $R_{G_{\mathrm{M}}^{\mathrm{n}} G_{\mathrm{E}}^{\mathrm{n}}}$ and $R_{G_{\mathrm{M}}^{\mathrm{p}} G_{\mathrm{E}}^{\mathrm{p}}}$ terms appear because of non-interference character of PWIA with respect to proton and neutron contributions. In Fig. 1, $R_{\mathrm{TL}'}$ for the kinematical condition of Refs. [2,3], and each component in Eq. (5) are plotted as a function of energy transfer ω. The calculations are performed with the Paris potential [9] for realistic NN interaction, and with the model of Galster et al. [10] for nucleon from factors. Fig. 1 shows that the contribution from $R_{G_{\mathrm{M}}^{\mathrm{n}} G_{\mathrm{E}}^{\mathrm{n}}}$, which is important in extracting $G_{\mathrm{E}}^{\mathrm{n}}$, is not so large, and there exists a large contribution from protons, $R_{G_{\mathrm{M}}^{\mathrm{p}} G_{\mathrm{E}}^{\mathrm{p}}}$. Also, it is remarkable that there appears a large contribution from interference term, $R_{G_{\mathrm{M}}^{\mathrm{n}} G_{\mathrm{E}}^{\mathrm{p}}}$, which shows a significant effect of FSI.

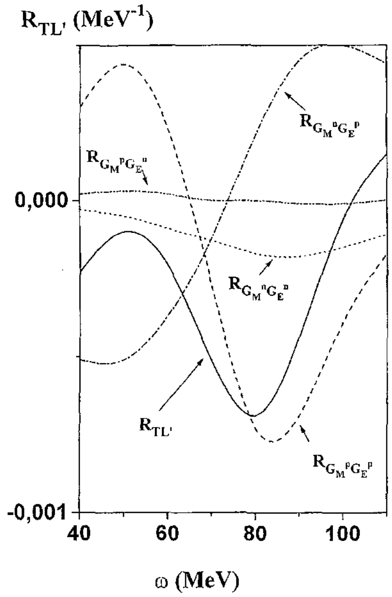

Fig. 1.

The spin-dependent asymmetry calculated by $R_{\mathrm{TL}'}$ in Fig. 1 together with other response functions for higher-ω experiment around the quasi-elastic peak [2] is plotted by solid curve in Fig. 2. To know to what extent the neutron charge form factor $G_{\mathrm{E}}^{\mathrm{n}}$ contributes to the asymmetry, we calculate the symmetry by putting $G_{\mathrm{E}}^{\mathrm{n}} = 0$. The result is plotted by dashed curve in Fig. 2. The difference between the solid curve and the dashed curve is comparable with the error bars. Also, it is remarkable that the asymmetry with $G_{\mathrm{E}}^{\mathrm{n}} = 0$ turns to be closer to the experimental data than the asymmetry with the original $G_{\mathrm{E}}^{\mathrm{n}}$. Actually, χ^2 per datum with respect to the experimental data is 0.65 for the original $G_{\mathrm{E}}^{\mathrm{n}}$, while 0.49 for $G_{\mathrm{E}}^{\mathrm{n}} = 0$. When we calculate the asymmetry by multiplying a constant factor ($f_{\mathrm{E}}^{\mathrm{n}}$) on $G_{\mathrm{E}}^{\mathrm{n}}$, the resulting χ^2 has a minimum

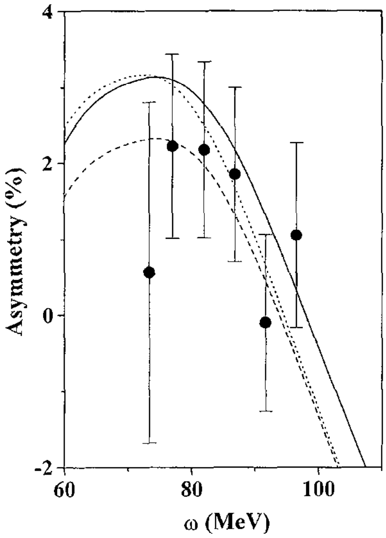

Fig. 2.

value at $f_E^n = 0.33$, which suggests a rather small value for G_E^n.

One possible reason for this might be the fact that our calculations are based on fully non-relativistic kinematics. Since a typical momentum transfer in the experimental condition, about 400 MeV/c, is rather large, relativistic effects on kinematics should play a non-negligible role. For example, it is reported that theoretical predictions for the position of the quasielastic peak of R_L and R_T calculated fully nonrelativistically differ significantly from experimental data [11]. For calculating the response functions, we should fix the center-of-mass energy (E) of the final three nucleons for given values of Q and ω. Nonrelativistically, this is given by:

$$E = \omega - \frac{1}{6M_N} Q^2 - B_3, \tag{6}$$

where M_N is the nucleon mass and B_3 is the binding energy of ^{3}He. Relativistically, we follow a prescription given in Ref. [11]. Let $\boldsymbol{k}_1$, $\boldsymbol{k}_2$ and $\boldsymbol{k}_3$ be momenta of final three nucleons in the laboratory system, which satisfy the momentum- and (relativistic) energy-conservation relations:

$$\begin{aligned} \boldsymbol{Q} &= \boldsymbol{k}_1 + \boldsymbol{k}_2 + \boldsymbol{k}_3, \\ \omega + M_T &= \sqrt{M_n^2 + k_1^2} + \sqrt{M_n^2 + k_2^2} + \sqrt{M_n^2 + k_3^2}, \end{aligned} \tag{7}$$

where M_T is the mass of the target ^{3}He. We evaluate k_i's for a specific condition in which a nucleon is knocked out directly parallel to $\boldsymbol{Q}$ leaving the remaining nucleons in a state without relative motion. In the three-body breakup channel, this is expected to be the dominant contribution. Using the Jacobi momenta defined as

$$\begin{aligned} \boldsymbol{p} &= \tfrac{1}{2}(\boldsymbol{k}_2 - \boldsymbol{k}_3), \\ \boldsymbol{q} &= \tfrac{2}{3}(\boldsymbol{k}_1 - \tfrac{1}{2}(\boldsymbol{k}_2 + \boldsymbol{k}_3)), \end{aligned} \tag{8}$$

E is calculated by

$$E = \frac{1}{M_N} p^2 + \frac{3}{4M_N} q^2. \tag{9}$$

The result for the original G_E^n is plotted by dotted curve in Fig. 2. In this case, χ^2 per datum is reduced to 0.62, and has a minimum value when the asymmetry is calculated with G_E^n multiplied by 0.84 (i.e. $f_E^n = 0.84$).

In summary, we have analyzed the transverse–longitudinal response function of ^{3}He related with the neutron charge form factor. A large contribution arising from protons is found. We need more accurate data for extraction of neutron charge form factor. Also, relativistic kinematical effects in calculating the responses are non-negligible.

References

[1] H. Gao et al., Phys. Rev. C 50 (1994) R546.
[2] J.-O. Hansen et al., Phys. Rev. Lett. 74 (1995) 654.
[3] C. E. Jones et al., Phys. Rev. C 52 (1995) 1520.
[4] S. Ishikawa, H. Kamada, W. Glöckle, J. Golak, H. Witała, Phys. Lett. B 339 (1994) 293.
[5] J. Golak, H. Witała, H. Kamada, D. Hüber, S. Ishikawa, W. Glöckle, Phys. Rev. C 52 (1995) 1216.
[6] S. Ishikawa, H. Kamada, W. Glöckle, J. Golak, H. Witała, in: H. Ejiri, T. Kishimoto, T. Sato (Eds.), Proc. IV Int. Symp. on Weak and Electromagnetic Interactions in Nuclei, Osaka, 1995, (World Scientific, Singapore, 1995, p. 439.
[7] S. Ishikawa, W. Glöckle, J. Golak, H. Witała, H. Kamada, to be submitted for publication.
[8] H. Gao, Nucl. Instr. and Meth. A 402 (1998) 277, these Proceedings.
[9] M. Lacombe et al., Phys. Rev. C 21 (1980) 861.
[10] S. Galster et al., Nucl. Phys. B 32 (1971) 221.
[11] E. van Meijgaard, J.A. Tjon, Phys. Lett. B 228 (1989) 307.