Zero-degree proton inelastic scattering to the 1^+, T=0 and T=1 states in ^{12}C

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We have measured the zero-degree cross sections for proton inelastic scattering to the 1^+, T=0 (12.7 MeV) and 1^+, T=1 (15.1 MeV) states in ^{12}C at 65, 100, 200, 300, and 400 MeV. The ratios of cross sections $[d\sigma/d\Omega(1^+, T=0)]/[d\sigma/d\Omega(1^+, T=1)]$ at 0° are compared with the calculations in the distorted wave approximation using various effective nucleon-nucleon interactions. The experimental ratios are found to be smaller than the theoretical predictions. It was found that the experimental results were better described by modifying the isovector tensor terms of the effective interactions.

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I. INTRODUCTION

Over the past years many experimental and theoretical studies have been devoted to extracting the effective nucleon-nucleon interaction using the nucleon-nucleus reactions at various bombarding energies. The isovector central components $V_{\sigma\tau}$ and V_τ have been investigated extensively through zero-degree measurements of the (p,n) reactions using the advantage that the contributions of the tensor and spin-orbit components are generally small at forward angles [1–4].

Recently, however, many works suggested that modification of the isovector tensor component $V_\tau{}^T$ was required to reproduce the experimental data. Hintz *et al.* showed that the (p,p') data at 318 MeV on the stretched 12^- and 14^- states in ^{208}Pb were well fitted by reducing the tensor interaction [5]. Baghaei *et al.* measured the cross section, analyzing power, induced polarization, and normal polarization transfer coefficients for scattering of 200 MeV polarized protons from ^{10}B. The data for the isovector stretched transition from the 3^+, T=0 ground state to the 0^+, T=1 state at 1.74 MeV were compared with the distorted wave approximation (DWA) calculations. They modified the $V_\tau{}^T$ and $V_{\sigma\tau}$ terms to reproduce the experimental data [6]. Sakai *et al.* measured the normal polarization transfer coefficient ($D_{NN'}$) at 50, 65, and 80 MeV [7]. They reported that the high momentum components of $V_\tau{}^T$ needed to be reduced to fit the ^{12}C$(p,n)^{12}$N reaction [8]. Wakasa *et al.* performed the zero-degree measurement of $D_{NN'}$ for the ^{6}Li$(p,n)^6$Be(g.s.) reaction at 300 MeV, and suggested that the high momentum component of $V_\tau{}^T$ of the 325 MeV Franey-Love interaction was too large [9]. Nakai *et al.* measured the in-plane polarization transfer coefficients for the ^{6}Li(p,p') reaction at 65 MeV and performed a microscopic DWA by using the M3Y interaction for the first 0^+, T=1 state [10]. Their analysis also showed that the high momentum components of $V_\tau{}^T$ should be substantially reduced.

Brown and co-workers stress that meson and nucleon masses decrease in the nuclear medium according to a QCD-based speculation [11–13]. Some works report that the modification of the effective interaction leads to the reduction of meson masses in the nuclear medium [5,6].

In the present work, we report zero-degree measurements of proton inelastic scattering for the 1^+, T=0 (12.71 MeV) and 1^+, T=1 (15.11 MeV) states in ^{12}C at incident proton energies of 65, 100, 200, 300, and 400, MeV. In (p,p') reactions at zero degrees, it is known that the interactions $V_{\sigma\tau}$ and $V_\tau{}^T$ (through the knock-on exchange process) mainly contribute to the cross sections for 1^+, T=1 and 1^+, T=0 states, respectively [14–16]. The measurement of both 1^+ states under the same experimental condition enables us to determine the ratio of the cross sections for these states accurately. Then the ratio can be a good measure for investigating the isovector tensor component $V_\tau{}^T$ because the strength of $V_{\sigma\tau}$ is well known from studies of (p,n) reactions.

II. EXPERIMENTAL PROCEDURE

The experiment was performed at the Research Center for Nuclear Physics, Osaka University by using the 65

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MeV proton beam from the AVF cyclotron and by using the 100, 200, 300, and 400 MeV proton beams from the Ring cyclotron [17].

A. Zero-degree measurement at E_p=65 MeV

The 65 MeV data were obtained by using the spectrometer RAIDEN, which consisted of quadrupole ($Q1$)–dipole ($D1$)–multipole (M)–dipole ($D2$)–quadrupole ($Q2$) magnets [18]. A small emittance of beam was realized by adjusting the several beamline slits. Then the beam was transported to the target through the two sweeping magnets. A clean beam was obtained by rejecting a halo component with the baffle slits after the sweeping magnets. The beam intensity was monitored by a sampling-type current monitor consisting of a carbon target and NaI scintillators, which was usually used as a beam polarimeter [19]. The carbon target was inserted into the beam line for 10 s at intervals of 40 s. The measurements of proton spectra were performed only when the current monitor was out of the beamline. The typical beam intensity and spot size on target were 0.1 nA and 2 mm (width) × 1 mm (height), respectively.

A large carbon target with a size of 50 mm (width) × 30 mm (height) and a thickness of 1.0 mg/cm^2 was used in order to reduce the background due to edge scattering from the target holder. The defining slits of the spectrometer were removed to reduce the background due to edge scattering from them. The movable beam stopper between $D1$ and $D2$ of the RAIDEN was used to reduce the background. The primary beam was stopped by lead blocks placed between $D2$ and $Q2$ magnets.

The detector system at the focal plane consisted of two vertical-drift-type multiwire drift chambers (MWDC's), each of which had an effective area of 400 mm (width) × 80 mm (height), and two plastic scintillators placed behind the MWDC's. The counter covered an energy range of 1 MeV. The efficiency of each MWDC was more than 99%, and its position resolution was 200 μm. An angular accuracy of 2.0 mrad was achieved by tracking information. Coincidence signals from the two plastic scintillators were used to generate the event trigger. Two different magnetic fields were used to measure the 1^+ T=0 (12.7 MeV) and 1^+ T=1 (15.1 MeV) states in ^{12}C. The overall energy resolution was typically 20 – 30 keV.

B. Zero-degree measurements at E_p=100, 200, 300, and 400 MeV

Data were taken at 100, 200, 300, and 400 MeV using the spectrometer GRAND RAIDEN [20]. After defining the emittance, the proton beam was injected to the Ring cyclotron from the AVF cyclotron. The accelerator parameters were adjusted in order to obtain a halo-free beam. The beam intensity was monitored again by using a sampling-type current monitor, consisting of a polyethylene (CH_2) target and plastic scintillators. The typical beam intensity and spot size on the target were 0.1 nA and 1 mm (width) × 1 mm (height), respectively.

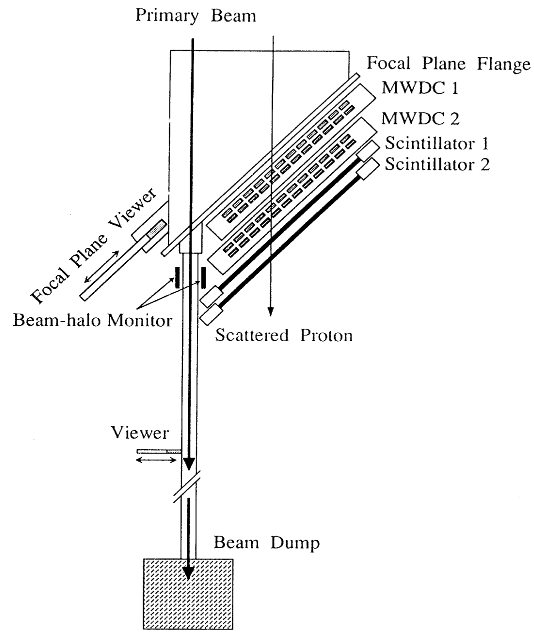

FIG. 1. The experimental setup for zero-degree measurements using the spectrometer GRAND RAIDEN.

We used a thick ^{12}C target of 30 mg/cm^2 with the size of 50 mm (width) × 30 mm (height). The defining slits of the spectrometer were adjusted to minimize the background due to the beam halo. Both of the 1^+ unnatural parity states were measured at the same time with one magnetic field setting.

The counter system consisted of two MWDC's [21], each of which had an effective area of 1150 mm × 45 mm, and two plastic scintillators placed behind the MWDC's. Each of these MWDC's also had an efficiency greater than 99%. A position resolution of 200 μm and an angular accuracy of 1.6 mrad were achieved. Coincidence signals from the plastic scintillators were used to generate the event trigger. For the measurements at 200, 300, and 400 MeV, the primary beam passed through the spectrometer and was extracted from the focal plane as shown in Fig. 1. The beam was transported to the beam dump by tuning the magnetic fields of two dipole magnets of the GRAND RAIDEN. For the measurement at 100 MeV, the beam was stopped by lead blocks and movable beam stoppers placed behind the second dipole magnet. The overall energy resolution was 200 – 300 keV depending on the energy resolution of the incident beam.

C. Data reduction

The major background in the spectra was supposed to originate from the beam halo and multiple scattering events inside the spectrometer. These background components varied with the beam energy as well as beam conditions. Information on time of flight (TOF) of rf and scintillators was used to reject background events at

65 and 100 MeV. The different flight path lengths of scattered protons in the spectrometer cause the broadening of the arrival time at the focal plane. This broadening was corrected by using the correlation between the horizontal incident angle and the exit angle at the focal plane. Figure 2(b) shows the two-dimensional spectrum of scattered particles for the experiment at 65 MeV. The loci positioning at the lower part in this spectrum correspond to the true events from the $^{12}C(p,p')$ reaction, whereas the upper part is the background due to the edge scattering from the beam stopper. These background events were rejected by the software cuts in the offline analyses.

For the experiments at 200, 300, and 400 MeV, vertical position information was quite effective in reducing the background because the vertical width of the true events at the focal plane was very narrow [full width at half maximum (FWHM) 10–15 mm] as a result of the small beam size at the target. Figure 3(b) shows the two-dimensional spectrum of vertical and horizontal positions of scattered particles for the experiment at 300 MeV. The area at the middle contains the true events, whereas the upper and lower parts correspond to the background events.

The solid angle was determined by selecting events with horizontal angles between ± 10 mrad using the tracking information from the focal plane counters. The vertical angular acceptance was determined by the defining slits of the spectrometer (± 40 mrad). The typical final spectra at 65 and 300 MeV are shown in Fig. 2(a) and Fig. 3(a), respectively. The 1^+ unnatural parity states can be seen clearly. This is the first systematic measurement of the proton inelastic scattering at zero degrees, although there was a report on the successful zero-degree measurement of the $^{12}C(p,p')$ reaction at 185 MeV at Indiana University Cyclotron Facility (IUCF) [22]. For the data at 300 and 400 MeV, the isoscalar 2^- (18.2 MeV) and isovector 2^- (19.4 MeV) states can also be observed. The peak area for each 1^+ state was obtained by fitting the spectrum with Gaussian peak shapes and polynomial fitting of the continuum background. The spectra after the background subtraction are shown in Fig. 4, which clearly shows that the ratio of the two 1^+ states is almost constant at $E_p \geq 100$ MeV.

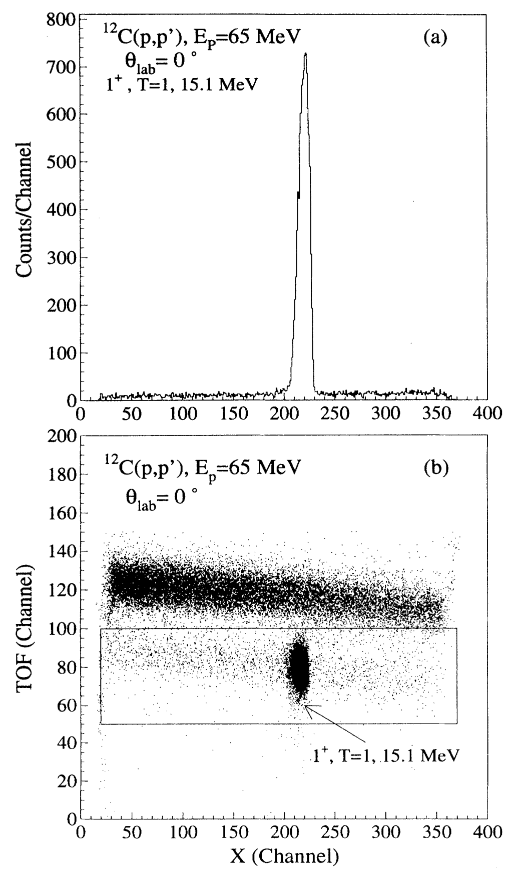

FIG. 2. Upper: Representative spectrum taken at 65 MeV after the software cuts. Lower: Two-dimensional plot of proton events taken at 65 MeV. The X and Y axes correspond to the momentum of scattered particles and the corrected TOF, respectively.

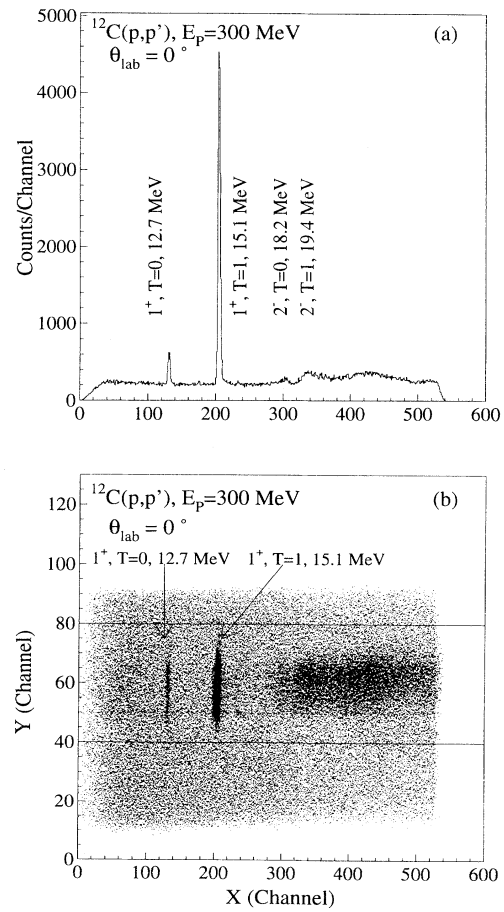

FIG. 3. Upper: Representative spectrum taken at 300 MeV after the software cuts. Lower: Two-dimensional plot of proton events taken at 300 MeV. The X and Y axes correspond to the momentum of scattered particles and the vertical position at the focal plane, respectively.

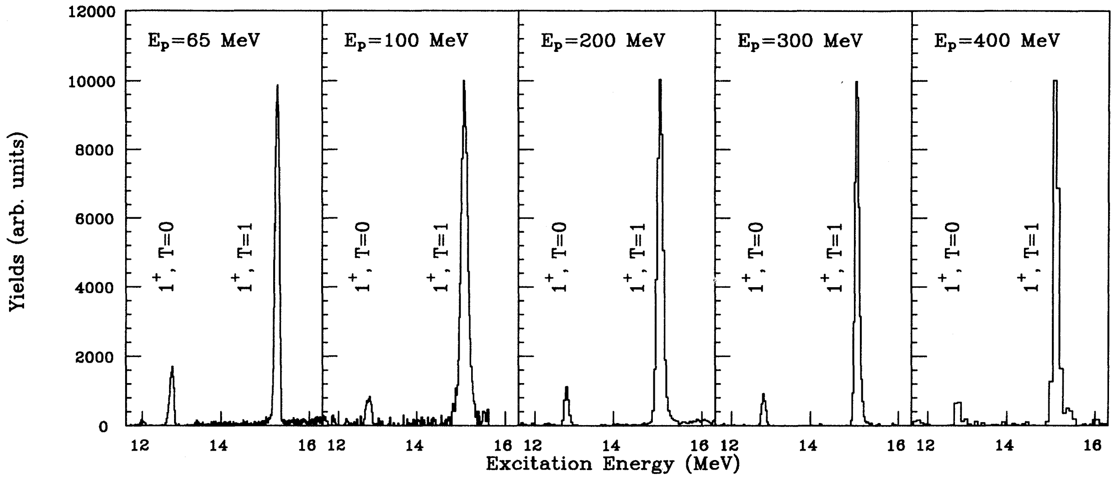

FIG. 4. Representative spectra of the $^{12}C(p,p')$ reaction at zero degrees after the background subtraction. Peaks are labeled with their spin and isospin. The spectra are normalized to give a constant peak height for the 1^+, T=1 state.

III. DISTORTED WAVE ANALYSIS

The cross sections for the two 1^+ states in ^{12}C have been calculated with the program code DWBA91 developed by Raynal [23]. The optical potential parameters were taken from Refs. [24–27]. The wave functions of Cohen and Kurath [28] were employed in the present DWA calculation. Transition densities were generated from the spectroscopic amplitudes obtained by the harmonic oscillator single particle wave functions. The oscillator length parameters of 1.57 fm and 1.87 fm were used for the 1^+ T=0 state and T=1 state, respectively [14].

Three different sets of effective interactions were examined in our calculations and they are denoted here by the labels FL, PF, and PD. The FL is the parametrization of the free nucleon-nucleon t matrix by Franey and Love [29]. The FL parameters for 50, 100, 210, 325, and 425 MeV were used for the calculations at E_p=50, 100, 200, 300, and 400 MeV, respectively. The PF and PD were derived from the Paris potential [30]. The PF denotes the Paris free interaction and the PD is the Paris density-dependent interaction [31]. The PF parameters of 50, 100, 200, 300, and 400 MeV and the PD parameters of 100, 200, 300, and 400 MeV were used in the DWA analyses for those incident energies.

IV. DISCUSSION

A. Comparison of the experimental ratio with the DWA calculations

For the 1^+, T=0 transition at zero degrees, it is reported that there is substantial contribution from the isovector tensor component $V_\tau{}^T$ through the knock-on exchange processes [14–16]. The contributions of the isoscalar tensor component $V_0{}^T$ and the spin-orbit component $V_0{}^{LS}$ are quite weak at forward angles because they are noncentral forces. The contribution of the spin central component V_σ is also very small because of the weakness of V_σ. The 1^+, T=1 transition at zero degrees is dominated by $V_{\sigma\tau}$, which is almost constant at the intermediate energy region. Noncentral components $V_\tau{}^T$ and $V_\tau{}^{LS}$ have only small contributions to the cross sections at forward angles. Therefore the ratio of these cross sections for 1^+ states is expected to be sensitive to the strength of the isovector tensor component. One advantage of this experiment is that we could measure the two 1^+ unnatural parity states in ^{12}C simultaneously except at 65 MeV. This enables us to determine the ratio of the cross sections for these two states accurately. Moreover, the ratio at zero degrees is relatively stable to the wave functions and optical potential parameters in the DWA calculations.

The experimental ratio R, defined by the following equation, was compared with the DWA calculations:

$$R \equiv \frac{d\sigma/d\Omega(1^+, T=0, 12.7\ \mathrm{MeV})}{d\sigma/d\Omega(1^+, T=1, 15.1\ \mathrm{MeV})}. \quad (1)$$

The results of DWA calculation are shown in Fig. 5 together with the experimental results. It should be noted that the experimental ratios of $E_p \geq 100$ MeV are almost constant ($R \simeq 0.09$) which is also seen in Fig. 4 , and are smaller than almost all the DWA calculations. Both the experiment and calculations show a tendency that the ratio increases rapidly at low energy. The calculated values with the FL are larger than experimental data at 65, 100, and 200 MeV, while at 300 and 400 MeV they almost reproduce the data. The ratios calculated by using the PF and PD are larger than the experimental values. The results with the PD reproduce the experimental values better than the results with the PF. This is somewhat confusing, because it suggests that the medium effect is more important at higher energies.

Various effects on the ratio which might be caused by

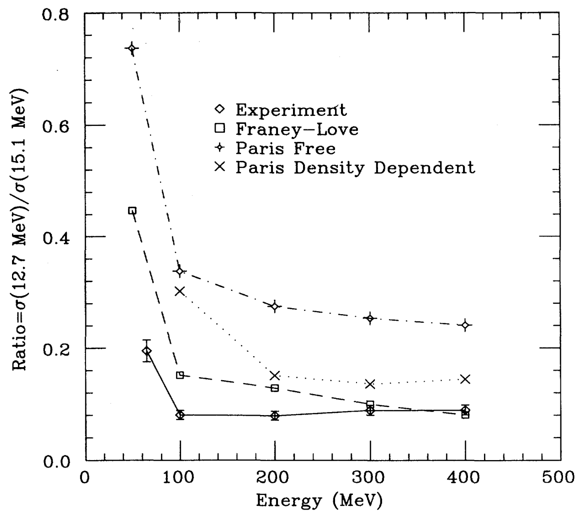

FIG. 5. The ratio of the cross sections of the 1^+, T=0, E_X=12.7 MeV and 1^+, T=1, E_X=15.1 MeV states. The dashed line corresponds to the use of the FL free NN t matrix interaction, the dot-dashed line represents the calculation results with the PF interaction, and the dotted line shows the results with the PD interaction.

the ambiguities of the parameters used in the DWA calculations were examined. The results with different optical potentials at 200 MeV [14] showed that the change of the ratio was within 18%. The use of another oscillator length parameter 1.7 fm for both states [32] showed that the ratio was stable within 10%. We also performed a DWA analysis with a Woods-Saxon form factor instead of harmonic oscillator, and it was found that the variation was less than 15%. Thus we came to think that a modification of the effective interaction is needed to reproduce our zero-degree data.

B. Modification of the interaction

It is reported that the DWA calculations for the 1^+, T=1 state are in good agreement with the experimental data at various incident energies [14,16,32]. Therefore it seems that there is not so much room to modify the effective interactions contributing to the 1^+, T=1 state. On the other hand, it has been reported that DWA calculations overestimate the experimental cross sections of the 1^+, T=0 state at forward angles over the whole range of incident energies [14,16,32]. The transition to the 1^+, T=0 state is dominated by the isovector tensor component $V_\tau{}^T$ through the knock-on exchange term. Thus one of the candidates is to modify the $V_\tau{}^T$.

The long-range parts of the isovector tensor component are well known from the one-pion exchange model, whereas the short-range part has not been determined so accurately. Thus we tried to modify the real part of the short-range components of $V_\tau{}^T$, whose ranges are 0.15 fm in the FL and 0.175 fm in the PF, respectively.

The isovector and isoscalar tensor interactions are described [33] with the tensor-even $V^{\rm TNE}$ and tensor-odd force $V^{\rm TNO}$ by the form

$$V_\tau^T = \frac{1}{4}(-V^{\rm TNE} + V^{\rm TNO}), \tag{2}$$

$$V_0^T = \frac{1}{4}(V^{\rm TNE} + 3V^{\rm TNO}). \tag{3}$$

In momentum space, the tensor part of the FL is parametrized as

$$V_\tau^T(q) = 32\pi \sum_i \frac{V_i^T q^2 R_i^7}{[1+(qR_i)^2]^3} \tag{4}$$

and that of the PF as

$$V_\tau^T(q) = 32\pi \sum_i \frac{V_i^T q^2}{[q^2+\mu_i^2]^3}, \tag{5}$$

where R_i are the ranges of the interactions and μ_i are the mass parameters (inverse ranges). The isovector tensor interaction was modified in such a way as to keep the isoscalar tensor interaction $V_0{}^T$ unchanged according to Ref. [5]. Therefore under the condition of $V_0{}^T=\frac{1}{4}\times(V^{\rm TNE}+3V^{\rm TNO})$ equal to a constant, the short-range parts of $V^{\rm TNE}$ and $V^{\rm TNO}$ were changed to reproduce the experimental ratio. The modified and unmodified real tensor interactions are shown in Fig. 6. The strengths of the modified interactions shown in Fig. 6 are given in Table I, which would be useful to try the present data in the analysis of other data. The $V_\tau{}^T$ of the FL for 210 and 325 MeV needed reduction to fit the experimental data. The FL of 425 MeV can almost reproduce the experimental data. For the PF, a larger reduction of $V_\tau{}^T$ was needed at all incident energies. One of the reasons for the large modification is due to the ambiguity of the Paris potential itself. We did not show the modification

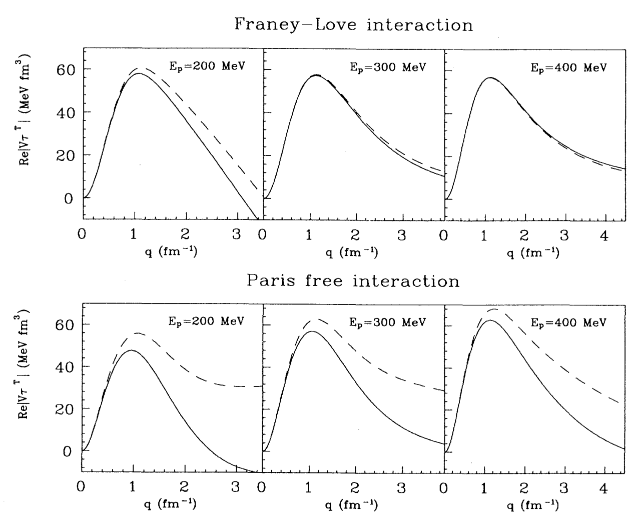

FIG. 6. Modified (solid line) and unmodified (dashed line) isovector tensor interaction $V_\tau{}^T$.

TABLE I. Strengths of the shortest-range parts of the real isovector tensor interaction $V_\tau{}^T$ modified to fit data R. Numbers in parentheses indicate power of 10. The units are MeV fm^{-2}.

E (MeV)	Interaction	Original V^{TNE}	Original V^{TNO}	Modified V^{TNE}	Modified V^{TNO}
200	FL	3.25631(5)	5.09043(4)	3.69449(5)	3.62983(4)
300	FL	-6.10415(3)	7.31966(3)	1.573(1)	5.27976(3)
400	FL	-3.01782(4)	-6.93196(3)	-3.46422(4)	-5.44396(3)
200	PF	-5.45885(3)	6.99608(3)	2.93215(3)	4.19903(3)
300	PF	-6.16615(2)	5.81629(3)	4.58898(3)	4.08109(3)
400	PF	3.96491(3)	4.56919(3)	8.40507(3)	3.08914(3)

of the interaction for E_p=65 and 100 MeV, because the experimental data could not be reproduced by reduction of the isovector tensor component only. It seems that the interactions used here are not suitable at low incident energies, where the reaction mechanism may become more complicated. In our analysis, the reduction of the 325 MeV FL parameter of $V_\tau{}^T$ by about ×0.95 (at $q\sim$ 2 fm^{-1}) was needed. Our result was small in comparison with the conclusion of Hintz *et al.* that reduction by ∼ ×0.5 at the same momentum transfer was needed [5]. On the other hand, the reduction of $V_\tau{}^T$ for the 210 MeV FL by ∼ 0.13 at $q\sim$ 3 fm^{-1} was required in our analysis. Our result is consistent with the results of Stephenson and Tostevin quantitatively [34], although they also enhanced $V_{\sigma\tau}$ based on the idea of the reduction of the ρ meson mass in the nuclear medium. If we enhance $V_{\sigma\tau}$ according to their idea, the reduction of $V_\tau{}^T$ becomes small. It should be mentioned that the reduction of $V_\tau{}^T$ from our results is small compared with other works, but our result is consistent qualitatively with them on the point that reduction of $V_\tau{}^T$ is required to reproduce the experimental data. It was also found that the effect of the reduction of $V_\tau{}^T$ became more important as the incident proton energy decreased.

V. SUMMARY

We have measured proton inelastic scattering to the 1^+, T=0 (12.7 MeV) and 1^+, T=1 (15.1 MeV) states at zero degrees for incident proton energies of 65, 100, 200, 300, and 400 MeV. The ratio of cross sections for these two 1^+ states was determined. The ratio was almost constant over the energy range from 100 MeV to 400 MeV, and increased at low energy. Microscopic DWA analyses were performed using the Franey-Love, Paris free, and Paris density-dependent interactions. Microscopic calculations with these interactions in most cases overestimate the experimental ratio. The experimental results were better reproduced by reducing the isovector tensor terms of the effective interactions.

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[1] C. D. Goodman, C. A. Goulding, M. B. Greenfield, J. Rapaport, D. E. Bainum, C. C. Foster, W. G. Love, and F. Petrovich, Phys. Rev. Lett. **44**, 1755 (1980).
[2] T. N. Taddeucci, J. Rapaport, D. E. Bainum, C. D. Goodman, C. C. Foster, C. Gaarde, J. Larsen, C. A. Goulding, D. J. Horen, T. Masterson, and E. Sugarbaker, Phys. Rev. C **25**, 1094 (1981).
[3] W. G. Love, K. Nakayama, and M. A. Franey, Phys. Rev. Lett. **28**, 1401 (1987).
[4] C. J. Horowitz, Phys. Lett. B **196**, 285 (1987).
[5] N. M. Hintz, A. M. Lallena, and A. Sethi, Phys. Rev. C **45**, 1098 (1992).
[6] H. Baghaei, R. A. Lindgren, P. Slocum, E. J. Stephenson, A. D. Bacher, S. Chang, J. Lisantti, J. Liu, C. Olmer, S. Wells, S. W. Wissink, B. L. Clausen, J. A. Carr, S. K. Yoon, and F. Petrovich, Phys. Rev. Lett. **69**, 2054 (1992).
[7] H. Sakai, N. Matsuoka, T. Noro, T. Saito, A. Shimizu, H. Tosaki, M. Ieiri, K. Imai, A. Sakaguchi, T. Takeuchi, and T. Motobayashi, Nucl. Instrum. Methods Phys. Res. Sect. A **257**, 279 (1987).
[8] H. Sakai, K. Hatanaka, N. Matsuoka, T. Saito, A. Shimizu, M. Ieiri, K. Imai, and T. Motobayashi, J. Phys. G **10**, L139 (1984).
[9] T. Wakasa *et al.*, Phys. Rev. C **51**, 2871 (1995).
[10] Y. Nakai, M. Nakamura, H. Sakaguchi, H. Togawa, T. Nakano, S. Hirata, O. Kamigaito, M. Iwaki, H. M. Shimizu, H. Kaneko, F. Hiei, Y. Sakemi, S. Kobayashi, M. Yosoi, and H. Ikegami, Phys. Rev. C **45**, 451 (1992).
[11] G. E. Brown, A. Sethi, and N. M. Hintz, Phys. Rev. C **44**, 2653 (1991).

[12] G. E. Brown and Mannque Rho, Phys. Rev. Lett. **66**, 2720 (1991).
[13] A. Hosaka and H. Toki, Nucl. Phys. **A529**, 429 (1991).
[14] J. R. Comfort, G. L. Moake, C. C. Foster, P. Schwandt, and W. G. Love, Phys. Rev. C **26**, 1800 (1982).
[15] J. R. Comfort, Sam M. Austin, P. T. Debevec, G. L. Moake, R. W. Finlay, and W. G. Love, Phys. Rev. C **21**, 2147 (1980).
[16] J. R. Comfort, G. L. Moake, C. C. Foster, P. Schwandt, C. D. Goodman, J. Rapaport, and W. G. Love, Phys. Rev. C **24**, 1834 (1981).
[17] I. Miura, T. Yamazaki, A. Shimizu, K. Hosono, T. Itahashi, T. Saito, A. Ando, K.Tamura, K. Hatanaka, M. Kibayashi, M. Uraki, H. Ogata, M. Kondo, and H. Ikegami, in *Proceedings of the 13th International Conference on Cyclotrons and their Applications,* edited by G. Dutto and M. K. Craddock (World Scientific, Singapore, 1993), p. 3.
[18] H. Ikegami, S. Morinobu, I. Katayama, M. Fujiwara, and S. Yamabe, Nucl. Instrum. Methods **175**, 335 (1980).
[19] T. Ichihara *et al.*, RCNP Annual Report, 1981, p. 194.
[20] M. Fujiwara *et al.*, in Proceedings of the International Symposium on Heavy Ion Research with Magnetic Spectrograph, edited by N. Anantaraman and B. Sherrill, NSCL Technical Report No. MSUCL-685, 1989, p. 283.
[21] T. Noro *et al.*, RCNP Annual Report, 1991, p. 177.
[22] A. D. Bacher, G. P. A. Berg, D. Bilodeau, W. J. Braithwaite, C. C. Foster, J. Lisantti, T. Rinckel, P. Schwandt, K. Solberg, E.J. Stephenson, S. P. Wells, and Y. Wang, IUCF Newslett. **47**, 23 (1990).
[23] J. Raynal, computer code DWBA91, Service de Physique Theorique, CEA-Saclay, 1991 (unpublished).
[24] M. Ieiri, H. Sakaguchi, M. Nakamura, T. Noro, H. Sakamoto, H. Ogawa, M. Yosoi, T. Ichihara, Y. Takeuchi, H. Togawa, T. Tsutsumi, H. Ikegami, and S. Kobayashi, J. Phys. Soc. Jpn. Suppl. **55**, 1106 (1986).
[25] J. R. Comfort and B. C. Karp, Phys. Rev. C **21**, 2162 (1980).
[26] K. W. Jones, C. Glashausser, R. de Swiniarski, S. Nanda, T. A. Carey, W. Cornelius, J. M. Moss, J. B. McClelland, J. R. Comfort, J. -L. Escudie, M. Gazzaly, N. Hintz, G. Igo, M. Haji-Saeid, and C. A. Whitten, Jr., Phys. Rev. C **33**, 17 (1986).
[27] F. T. Baker, D. Beatty, L. Bimbot, V. Cupps, C. Djalali, R. W. Fergerson, C. Glashausser, G. Graw, A. Green, K. Jones, M. Morlet, S. K. Nanda, A. Sethi, B. H. Storm, W. Unkelbach, and A. Willis, Phys. Rev. C **48**, 1106 (1993).
[28] S. Cohen and D. Kurath, Nucl. Phys. **73**, 1 (1965).
[29] M. A. Franey and W. G. Love, Phys. Rev. C **31**, 488 (1985).
[30] M. Lacombe, B. Loiseau, J. M. Richard, R. Vinh Mau, J. Côté, P. Pirès, and R. de Tourreil, Phys. Rev. C **21**, 861 (1980).
[31] H. V. von Geramb, in *The Interaction between Medium Energy Nucleons with Nuclei*, edited by H. O. Meyer, AIP Conf. Proc. No. 97 (AIP, New York, 1982), p. 44.
[32] W. Bauhoff, S. F. Collins, R. S. Henderson, G. G. Shute, B. M. Spicer, V. C. Officer, K. A. Amos, I. Morrison, D. W. Devins, D. L. Friesel, and W. P. Jones, Nucl. Phys. **A410**, 180 (1983).
[33] W. G. Love and M. A. Franey, Phys. Rev. C **24**, 1073 (1981).
[34] E. J. Stephenson and J. A. Tostevin, in *Proceedings of the International Conference on Spin and Isospin in Nuclear Interactions,* edited by S. W. Wissink, C. D. Goodman, and G. E. Walker (Plenum, New York, 1991), p. 281.