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Isovector E2/E0 strength in ^{28}Si studied by the (e,e′n) reaction II

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We have measured the ^{28}Si (e, e′n) reaction in the excitation energy range 28.5−39.5 MeV which is higher than that in the previous experiment. The obtained E1 strength agreed with that of the photo-reaction. The E2-E0 component below 22 MeV showed a difference to that of the (e, e′$p_{0,1,2}$) reaction and was similar to the (e, e′α_1) and (α,α′) reactions which contain dominantly isoscalar resonances. In the higher energy, the present E2-E0 data have a broad bump from 23 to 35 MeV which is not seen in the (α,α′) reaction; it is thought to be attributed to the isovector excitation. This interpretation is partially supported by the result of the ^{28}Si(^{7}Li, ^{7}Be)^{28}Al experiment.

In the previous report of the ^{28}Si(e, e′n) experiment [1], we have shown the isovector (IV) E2-E0 strength of 3.6 MeV wide at 25.2 MeV for the n_{0+1+2} decay channel. But because the experiment was performed at the low excitation energy from 20.5 to 28.5 MeV, the entire structure of the IV- giant monopole and quadrupole resonances (GMR and GQR) was not cleared. Then we have done the same experiment but at the higher excitation energy from 28.5 to 40.5 MeV.

The measurement has been performed using 150 and 200 MeV continuous electron beams from the STretcher Booster (STB) Ring at Laboratory of Nuclear Science (LNS) of Tohoku University. Electron beams of 150-300 nA with a duty factor of 80-90% were bombarded on a 118.8 mg/cm^2 thick silicon (92.2% ^{28}Si) target. Scattered electrons were momentum-analyzed by a double-focusing magnetic spectrometer and detected by a combination of a vertical drift chamber (VDC) on a focal plane and three

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layers of 5, 5, and 8 mm thick plastic scintillation counters behind the VDC. The spectrometer was settled at a scattering angle of $\theta_e = 28^\circ$ at incident energies of 150 and 200 MeV and at $\theta_e = 35^\circ$ at 200 MeV. These correspond to the effective momentum transfer of 0.38, 0.49, and 0.60 fm^{-1}, respectively. Emitted neutrons were measured using eight neutron detectors, which were placed at $\theta_n = 58^\circ$, 83°, 108°, 133°, 158°, 213°, 238°, and 263° to the beam direction. Each detector was 0.85 m distant from the target. The neutron energy was determined by the time of flight (TOF) method. The basic experimental and analytical procedures are the same as in the previous experiment [1].

Figure 1 shows missing energy spectra at some excitation energies. In the previous report, strong decays to the residual states around the ground state were mentioned. In addition, another decay to about 5 MeV higher residual states is seen in the spectra of 29.5, 33.5, and 39.5 MeV in Fig.1. This distributes from about 19 to 24 MeV in the missing energy and its strength is as much as the sum of n_0,

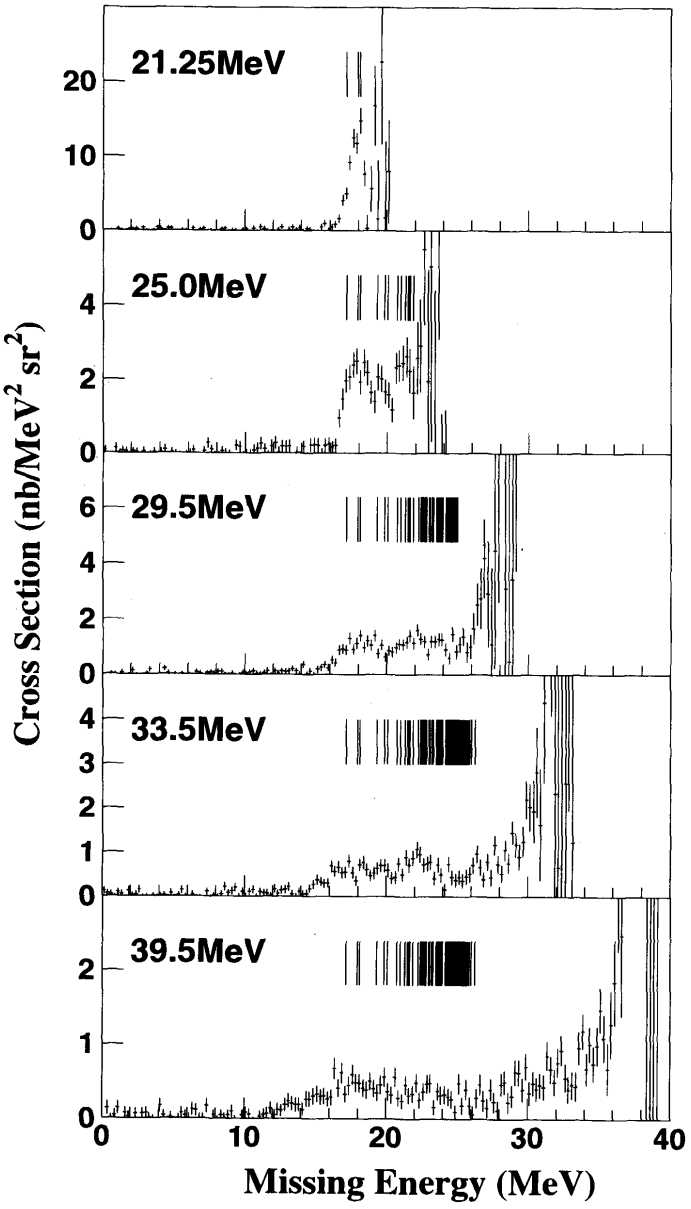

Fig.1. Missing energy spectra at $q_{eff} = 0.49$ fm^{-1} and some excitation energies. Short solid lines above each spectrum are energy levels of the residual nucleus ^{27}Si. They contain levels from n_0(17. 18 MeV) to n_{80} (26. 25 MeV).

n_1, and n_2. There are two levels (n_{13} 21.88 MeV, n_{14} 22.24 MeV) which have the same spin and parity as those of the ground state in ^{27}Si. The proton decay to the levels about 5 MeV higher than the ground state has been seen in the proton quasifree scattering experiment in ^{28}Si [2]. According to the analysis of the momentum density distribution near the same residual state [2], a contribution of 1p-shell proton in addition to those of the 1s and 1d-shells was suggested. Therefore the neutron decay to the higer levels in the present experiment probably contains the contribution of 1p-shell.

In this report, we named n_{012} for events from the neutron decay threshold to 19 MeV and $n_{24\mathrm{MeV}}$ for those from the threshold to 24 MeV in the missing energy spectra.

The angular correlations at each q and ω were fitted by the sum of Legendre functions and form factors were obtained. The E1 and E2-E0 components were derived using the difference of their momentum transfer dependence as the following equation.

$$|F(q,\omega)|^2 = a_{\mathrm{E1}}(\omega)\cdot|F_{\mathrm{E1}}(q)|^2 + a_{\mathrm{E2-E0}}(\omega)\cdot|F_{\mathrm{E2-E0}}(q)|^2. \quad (1)$$

Here, $|F(q,\omega)|^2$ is the obtained form factor at q_{eff} and ω. Parameters $a_{\mathrm{E1}}(\omega)$ and $a_{\mathrm{E2-E0}}(\omega)$ are strengths of E1 and E2-E0 components at excitation energy ω. The momentum-transfer dependence of the form factors, $|F_{\mathrm{E1}}(q)|^2$ and $|F_{\mathrm{E1-E0}}(q)|^2$, were obtained from Goldhaber-Teller [3] and Tassie [4] models, respectively.

Figure 2 shows the decomposed E1 and E2-E0 form factors. Two ^{28}Si (γ, n_{tot}) data [5, 6] in Fig. 2(a) are the deduced form factors to the present experimental condition on the assumption that the reaction is dominated by the E1 transverse transition. In the present experimental region both of the two ^{28}Si(γ, n_{tot}) form factors decrease as the excitation energy increases, and the ^{28}Si(e, e'n_{012}) and ^{28}Si(e, e'$n_{24\mathrm{MeV}}$) data have the same trend. The amplitudes of the present data are almost in agreement with the photo-reactions, and we regard the separation of the E1 strength has been performed successfully.

In Fig.2(b) the extracted E2-E0 form factors are compared to those of ^{28}Si(e, e'$p_{0,12}$) and ^{28}Si(e, e'α_1) [7]. The α_1 channel dominates in the α decay [7]. As mentioned in the previous report, the present E2-E0 strength seems to be suppressed around 22 MeV. The E2-E0 form factors of ^{28}Si (e, e'p_0) and (e, e'p_{12}) have considerable strength even above 20 MeV except for fine structures, while that of ^{28}Si (e, e'α_1) decreases rapidly from 20 MeV. The present structure seems to be more similar to ^{28}Si (e, e'α_1) than (e, e'p_{12}). This may imply that the E2-E0 strength which was obtained through the (e, e'n) reaction below 22 MeV is dominated by the isoscalar excitation. Above 22 MeV, the present E2-E0 strength increases and has a broad bump from 23 to 35 MeV. The form factors of n_{012} and $n_{24\mathrm{MeV}}$ have the similar behavior and the strength of $n_{24\mathrm{MeV}}$ is twice of n_{012}. The (e, e') data [8] have reported an E2 peak at 24 MeV and this is similar to our n_{012} spectrum.

The E1 and E2-E0 separation in Fig.2 were performed on the condition that the transition charge density radius c of Goldhaber-Teller and Tassie models are the same as that of the charge radius of the ground state c_0. The extracted E1 and E2-E0 strengths might be changed by the transition density radius. The model independent separation in ^{28}Si (e, e'p) [7] have shown that $c = 1.1c_0$ and $c = 0.9c_0$ for E1 Goldhaber-Teller and E2 Tassie models were required, respectively. We have also tried to separate

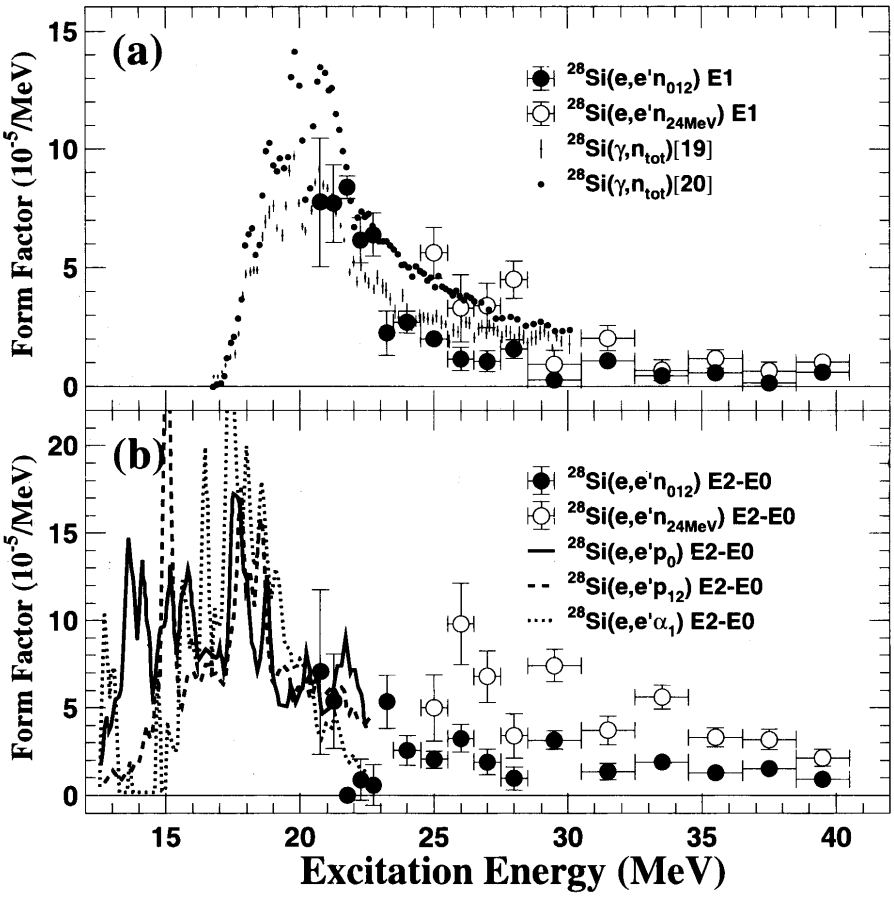

Fig.2. Comparisons of the present E1 and E2-E0 form factors at (a) q_{eff} = 0.49 and (b) 0.60 fm^{-1} to the photo and electron scattering reactions. Large closed and open circles are the present n_{012} and $n_{24\mathrm{MeV}}$ data. (a) Two ^{28}Si (γ, n_{tot}) data [5, 6] are the form factors which were deduced from the photo-reaction cross sections. (b) The solid and dashed lines are the E2-E0 form factors at q = 0.68 fm^{-1} in the ^{28}Si(e, e'p_0), (e, e'p_{12}), and (e, e'α_1) experiments [7].

E1 and E2-E0 using these parameters. The integrated E1 form factors by the excitation energy increased by 7 and 8% for n_{012} and $n_{24\mathrm{MeV}}$, respectively, compared to the result in $c = c_0$. The E2-E0 form factor decreased 6 and 7%. But E1 and E2-E0 gross structures did not change.

Figure 3 shows comparisons of the present E2-E0 distribution with other reactions which can probe selectively isoscalar or isovector excitations. Bold solid lines in Fig.3(a) and (b) are the E0 and E2 distributions by the (α, α') experiment [9]. They are normalized to the present data around 22 MeV so as not to exceed the (α, α') data because the (e, e'n) reaction is sensitive to both of isoscalar and isovector excitations. Both of (α, α') data decrease monotonically from about 20 MeV, while the present data has a broad bump from 23 to 35 MeV. This difference may suggest that the bump in our work is the isovector nature. The present structure in ω =20−23 MeV resembles the E2 spectrum in the (α, α') reaction and it does not contradict to the similarity to the E2-E0 distribution in ^{28}Si(e, e'α_1)

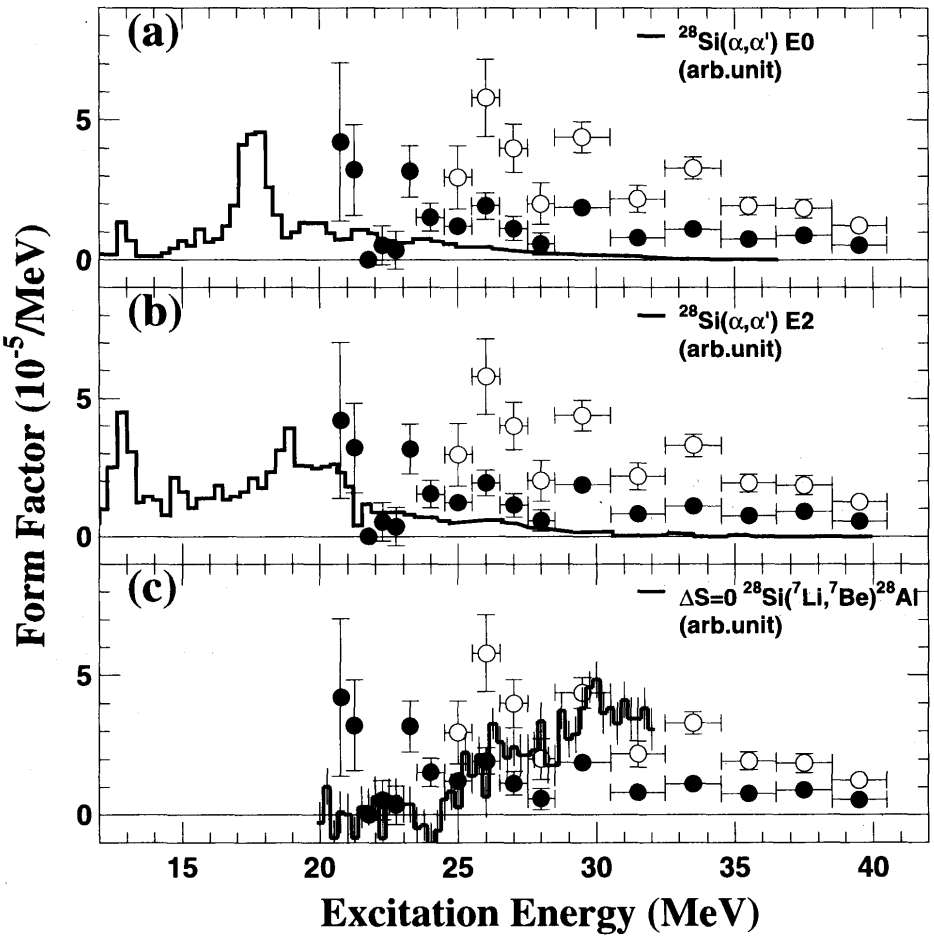

Fig.3 Comparisons of the present E2-E0 form factor at q_{eff} = 0.49fm^{-1} to the isoscalar and isovector favored reactions. Large closed and open circles are the present n_{012}, and $n_{24\mathrm{MeV}}$ data. The solid lines in (a) and (b) are the E0 and E2 cross sections through the (α, α') experiment [9], respectively. These data are normalized to the present data at around 22 MeV. The solid line in (c) is the strength distribution of the ΔS = 0 component in the ^{28}Si(^{7}Li,^{7}Be)^{28}Al reaction [10]; the contribution from the GDR has been already subtracted. This has been normalized to the present $n_{24\mathrm{MeV}}$ data at 29.5 MeV.

reaction shown in Fig.2(b).

Figure 3(c) compares to the ΔS=0 component of the ^{28}Si(^{7}Li, ^{7}Be)^{28}Al reaction [10]. The contribution of the isovector giant dipole resonance (IV-GDR) has already been subtracted and the isovector E2-E0 reaction seems to be the main process. These data have been normalized to the present $n_{24\mathrm{MeV}}$ data at 29.5 MeV. Both data resemble each other in the suppression around 22 MeV and the increase from that energy. This supports that the present data contain isovector E2 or E0 strengths.

The exhausted fraction of the EWSR [11] for the present E2-E0 strength was calculated. The E0 reduced transition probability per excitation energy dB(E0)/dω was derived using the relation [12] :

$$\frac{dB(E0)}{d\omega} = \frac{16\pi}{25} \frac{dB(E2)}{d\omega} . \qquad (2)$$

The EWSR exhaustion of E0 and E2 was assumed to be equal because E0 and E2 strengths can not be separated in the present experiment. For n_{012} in ω=23.0−40.5 MeV, 9.6(±0.8)% was obtained for the isovector E0 and E2 EWSR. For $n_{24\mathrm{MeV}}$ in ω=25.5−40.5 MeV, the fraction became 19.5 (±1.3)%. But there is a mixing of the isoscalar excitation as shown in Fig. 3(a) and (b), then the exhaustion for the

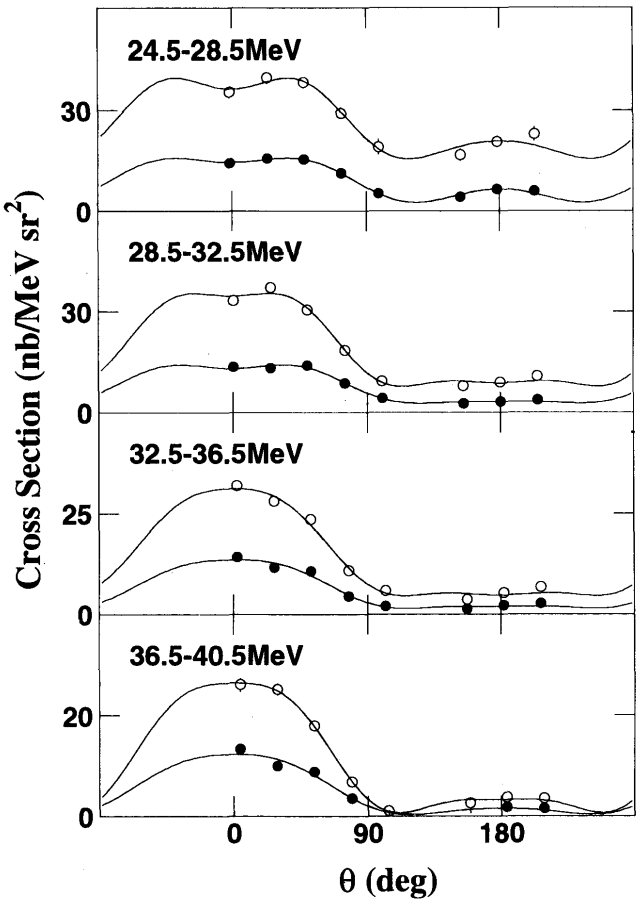

Fig.4 Angular correlations with respect to the momentum transfer direction at q_{eff} = 0.60 fm^{-1} and some excitation energies. The closed and open circles are the present n_{012} and n_{24MeV} data. The solid lines are the fits by Legendre polynomials.

isovector E0 and E2 may become smaller than the above values.

Finally, we briefly mention about the angular correlation. Figure 4 shows some angular correlations for q_{eff}=0.60 fm^{-1} at some ω values. The correlations for excitation energies above 30 MeV become extremely forward peaked and the strength of the backward direction is small and flat. Such a forward peaked correlation has been seen in the ^{16}O(e, e'p$_0$) experiment [13] at near ω and q. The angular correlation of ^{16}O(e, e'p$_0$) has been reproduced by the direct-knockout+GDR model and almost all of the cross section in higher excitation energies can be attributed to the direct-knockout process. However, the direct-knockout process in the (e, e'n) reaction in the kinematics near the present experiment is so small [14] and the charge exchange process (e, e'p) (p, n) originating from the direct-knockout process may contribute. The mixing of such process in addition to the resonance process may have to be taken into consideration in the higher excitation energy where the GDR strength becomes extremely weak.

In summary, the ^{28}Si(e, e'n) reaction has been measured at ω=28.5−39.5 MeV and q_{eff}=0.38, 0.49, and 0.60 fm^{-1} in order to follow up the previous result. The decay channel at about 5 MeV higher than the ground state of ^{27}Si was newly observed. E1 and E2-E0 components at each excitation energy were

separated using a difference in the momentum transfer dependence. The E2-E0 structure of our result in the lower excitation energy is similar to the E2-E0 strength of the (e, e' α_1) reaction and the E2 strength of the (α, α') reaction. This suggests that almost all the E2-E0 strength in the (e, e'n) reaction in the lower energy ($\leq$22 MeV) is isoscalar nature. At higher energies than 22 MeV, we observed a broad bump in the region 23−35 MeV. A comparison to the (α, α') reaction implied that the bump consists of the isovector E2-E0 excitation. This interpretation does not contradict to the result obtained by the ^{28}Si(^{7}Li, ^{7}Be)^{28}Al experiment.

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Reference

[1] K. Kino *et al.* : Research Report of LNS, Tohoku Univ. **33**, (2000) 1.

[2] J. Mougey *et al.* : Nucl. Phys. **A262**, (1976) 461.

[3] M. Goldhaber and E. Teller : Phys. Rev. **74**, (1948) 1046.

[4] L.J. Tassie : Aust. J. Phys. **9**, (1956) 407.

[5] J.T. Caldwell, R.R. Harvey, R.L. Bramblett and S.C. Fultz : Phys. Lett. **6**, (1963) 213.

[6] A. Veyssière *et al.* : Nucl. Phys. **A227**, (1974) 513.

[7] Th. Kihm *et al.* : Phys. Rev. Lett. **56**, (1986) 2789. ; Th. Kihm, Ph. D. thesis, University of Mainz, 1985.

[8] R. Pitthan *et al.* : Phys. Rev. C **19**, (1979) 299.

[9] D.H. Youngblood, Y.-W. Lui, and H.L. Clark : Phys. Rev. C **65**, (2002) 034302.

[10] S. Nakayama *et al.* : Phys. Rev. C **46**, (1992) 1667.

[11] S. Kamerdzhiev, J. Speth, and G. Tertychny : Nucl. Phys. **A624**, (1997) 328.

[12] G.O. Bolme *et al.* : Phys. Rev. Lett. **61**, (1988) 1081.

[13] V.F. Dmitriev *et al.* : Nucl. Phys. **A464**, (1987) 237.

[14] H. Diesener *et al.* : Nucl. Phys. **A696**, (2001) 293.