Systematic behavior of octupole strengths in ^{46,48,50}Ti

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The level structure of ^{48}Ti has been studied by proton inelastic scattering using a 65-MeV polarized beam. Spin and parity assignments for the excited states below 8 MeV of excitation in ^{48}Ti were made by the distorted-wave Born approximation analysis. The distributions of the excitation strengths for the 2^+, 3^-, and 4^+ states were obtained. The energy-weighted sum rule fractions were found to be 7.12%, 9.35%, and 1.22% for the 2^+, 3^-, and 4^+ states, respectively. The distribution of the octupole excitation strengths in ^{48}Ti is compared with those in ^{46}Ti and ^{50}Ti. The excitation strength corresponding to the first $J^\pi=3^-$ state in ^{50}Ti was found to be fragmented in ^{48}Ti, and this fragmentation was shown to be consistent with the prediction by a simple liquid drop model for deformed nuclei. The systematic behavior of the 3^- states below $1\hbar\omega$ excitation in the Ti isotopes shows that the fine structure of the 3^- excitation strength distribution is closely correlated to the quadrupole deformation of the ground state.

I. INTRODUCTION

The investigation of collective excitation modes of nuclei has been one of the most important subjects in nuclear physics in the past years. The giant resonances, which are typical collective modes of excitation, have been studied at many laboratories. Recently good progress has been made in understanding the structure of the giant resonances from the microscopic point of view through detailed studies of distributions for the excitation strength and of their decay properties.[1]

An isoscalar $J^\pi=3^-$ resonance expected at $\sim 1\hbar\omega$ excitation energy would be of special interest, since the resonance usually appears as an ensemble consisting of many discrete 3^- states. It is called the low-energy octupole resonance (LEOR).[2] Each $J^\pi=3^-$ state in the resonance has been described as a state with a mixed configuration of particle-hole excitations. One isoscalar 3^- state is, in most nuclei, pushed down in excitation energy due to the effect of an attractive two-body residual interaction. This is the first 3_1^- state and is usually most strongly excited among octupole states. Many other 3^- states in the LEOR region are expected to form a bump with a fine structure centered at $32A^{-1/3}$ MeV excitation in closed shell nuclei. These general features of octupole excitations in closed shell nuclei have been observed in the high resolution (p,p') experiments on ^{48}Ca, ^{50}Ti, ^{52}Cr, ^{54}Fe, ^{90}Zr, and ^{208}Pb (Refs. 3 and 4). However, as pointed out by Yntema and Satchler,[5] the 3^- states in ^{46}Ti do not follow these patterns. This particular situation has been discussed in detail by Bernstein.[6] A recent ^{46}Ti(p,p') experiment at Research Center for Nuclear Physics (RCNP) has revealed additional new facts:[7] (1) There is no clear bump of the LEOR in ^{46}Ti, (2) the centroid of the excitation energy of the LEOR decreases to 4.9 MeV which is about half of the excitation value of $32A^{-1/3}$ MeV, and (3) the total excitation strength is considerably weaker than those of the closed shell nuclei. On the basis of the Nilsson model, this unusual behavior of the octupole excitation strength has been qualitatively understood in terms of the coupling effect with the static quadrupole deformation of the ground state.[7]

The importance of the ground-state deformation was first discussed for a few low-lying 3^- states in the typical deformed heavy nuclei such as the Sm and Er isotopes.[8,9] It would be the best to study the coupling effect of octupole excitation with the ground-state deformation after establishing the detailed level structure in the LEOR excitation energy region for these well deformed nuclei.

However, in these heavy nuclei, an experimental difficulty to resolve a large number of the 3^- levels in an extremely high-level-density region prevents us from obtaining accurate information about the structure of the octupole excitation.

On the other hand, fragmentation of octupole excitation has been suggested in the Mg isotopes.[10] The level structure study of the Mg isotopes is also an interesting subject in the view point of the octupole-quadrupole coupling effect. But, there are only two stable even-even isotopes of magnesium, and the octupole excitation is largely fragmented in these magnesium nuclei. Since the ground-state deformation of the Ti isotopes increases in going from ^{50}Ti to ^{46}Ti, the Ti isotopes, thus, seem to provide us a good sample to investigate the systematic trend of the octupole excitation with the changes in the ground-state deformation.

In the present work, the level structure of ^{48}Ti was studied by means of the polarized proton inelastic scattering at 65 MeV. Our aim of this study was to establish the ^{48}Ti level structure over the range of $\sim 1\hbar\omega$ excitation energy, and then to discuss the systematic behavior of the octupole excitation strengths in the Ti isotopes in conjunction with the previous results of ^{46}Ti and ^{50}Ti.[3,6] It is of interest to inquire to what extent the behavior of octupole excitation changes when the deformation of ground state increases in going from ^{50}Ti to ^{46}Ti. In addition, it should be stressed that in the present experiment the spin-parity assignments of the observed states were made with more confidence through the measurement of analyzing powers as well as cross sections.

II. EXPERIMENTAL PROCEDURE

The experiment was carried out with the 65-MeV polarized proton beam using the magnetic spectrograph RAIDEN (Ref. 11) at Research Center for Nuclear Physics (RCNP), Osaka University. Polarized protons produced by an atomic-beam-type ion source were accelerated by the RCNP cyclotron up to 65 MeV and momentum analyzed by a tandem monochrometer system and deflected by a cleanup magnet before bombarding the ^{48}Ti target. The target was a self-supporting metallic foil enriched to 99.25% (^{46}Ti: 0.14%, ^{47}Ti: 0.27%, and ^{50}Ti: 0.11%) with 0.495 mg/cm^2 in thickness.

The polarization of the proton beam was monitored by using a sampling-type beam polarimeter upstream of the scattering chamber.[12] The polarimeter consisted of polyethylene ($^{12}CH_2$) target foil and two sets of NaI detectors. The polyethylene target was intermittently inserted into the beam course for some seconds at intervals of a few minutes. Elastically scattered protons were measured by the NaI detectors at $\theta_{lab}=47.5°$. Using the analyzing power of 0.975 for the 65-MeV proton elastic scattering from ^{12}C at $\theta_{lab}=47.5°$, the beam polarization was checked over the whole period of the experiment. In order to obtain good resolution and low background, the measurement with the spectrograph was carried out only when the polyethylene target was out of the beam. In the present experiment, the beam polarization was about 80% and the beam current was $\sim$20 nA. The spin of the proton was periodically reversed in every second to minimize the systematic error.

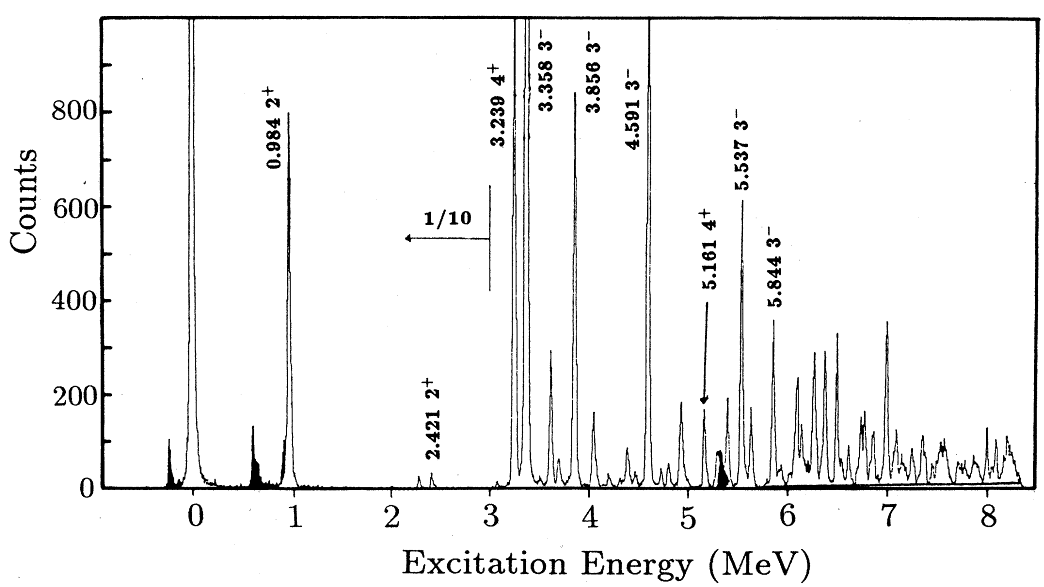
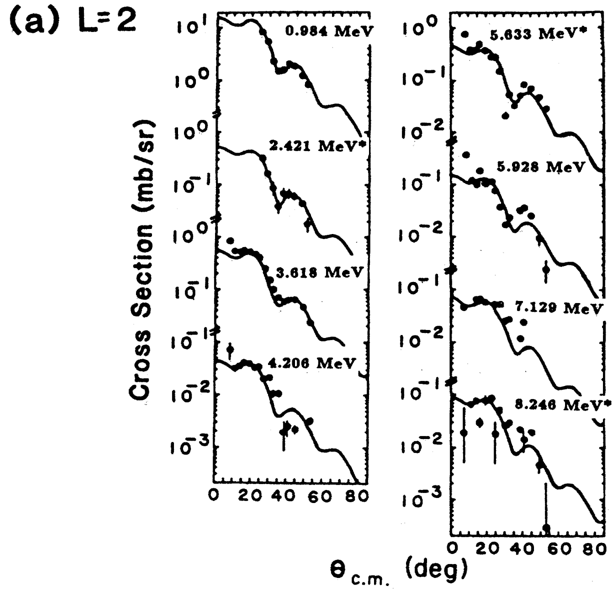


FIG. 1. The energy spectrum of the ^{48}Ti(p,p') reaction at a laboratory angle of 27°. The energies of levels in ^{48}Ti are shown in MeV. Prominent impurity peaks are cross hatched. The background underlying the peaks is shown by the solid line.



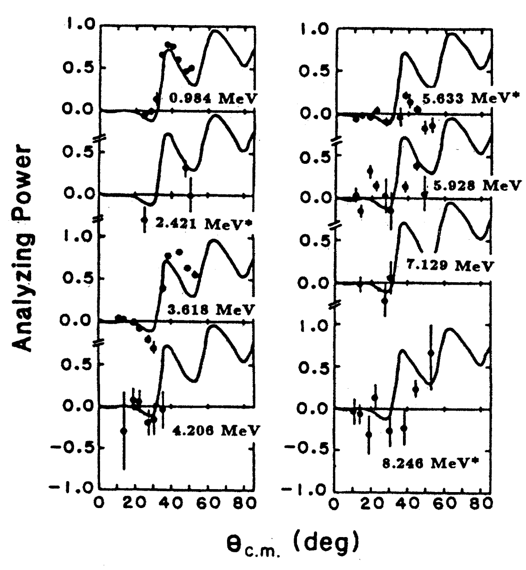


FIG. 2. (a) Experimental angular distributions of cross sections and analyzing power for 2^+ states in ^{48}Ti. The solid lines represent $L=2$ DWBA calculations. The spin and parity assignments for the states denoted by the mark "*" are of less confidence because of their disagreement between the analyzing power data and the DWBA predictions. (b) Experimental angular distributions of cross sections and analyzing power for 3^- states in ^{48}Ti. The solid lines represent $L=3$ DWBA calculations. The spin and parity assignments for the states denoted by the mark "*" are of less confidence because of their disagreement between the analyzing power data and the DWBA predictions. (c) Experimental angular distributions of cross sections and analyzing power for 4^+ states in ^{48}Ti. The solid lines represent $L=4$ DWBA calculations.

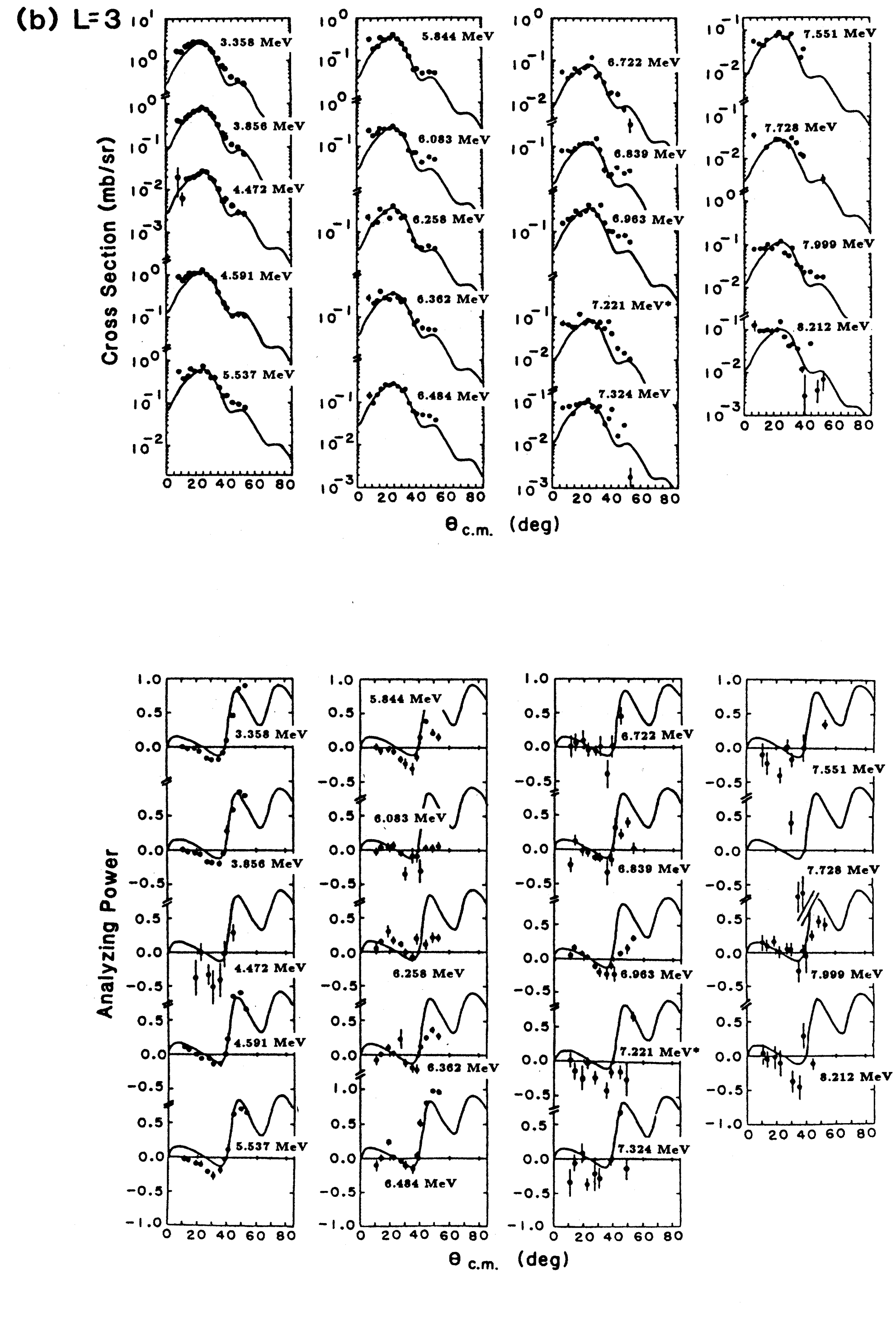
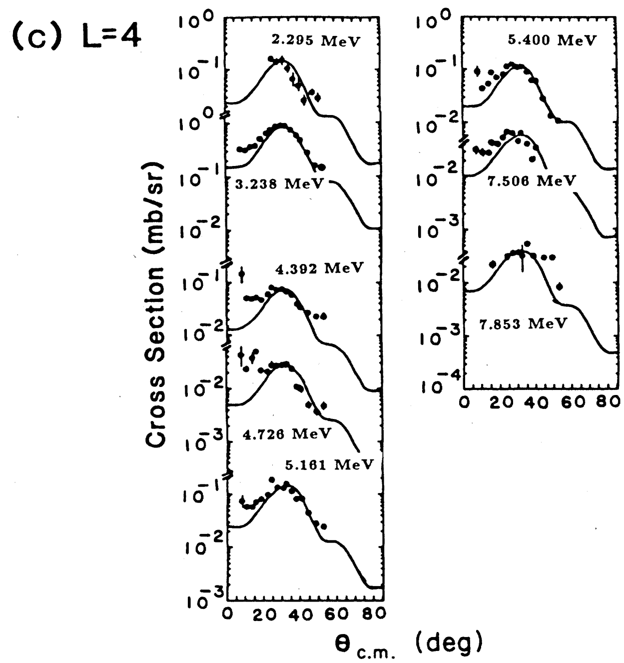


FIG. 2. (*Continued*).



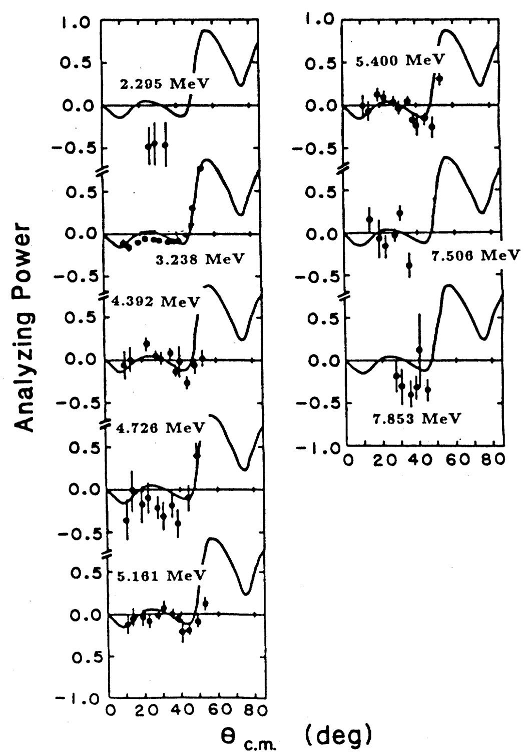


FIG. 2. (*Continued*).

The solid angle of the spectrograph was set at 3.2 msr with the angular acceptance of $\pm 1.15°$ in the reaction plane. The focal plane detector[13] consisted of one position-sensitive gas counter of 1.5 m in length, two gas proportional counters as ΔE detectors, and a plastic scintillation E counter.

The position information (x) along the focal line for the inelastically scattered protons was obtained by charge division method. The information on the vertical direction (y) was obtained from the measurement of the drift time of electrons originating in the ionization process of the counter gas by protons. The position and drift-time information were recorded on a magnetic tape in the list mode. The data stored in the magnetic tape were analyzed off-line where particle identification and background reduction were obtained by taking two-dimensional gates being set in the ΔE-E and x-y spectra. The energy resolution obtained was about 30 keV in full width at half maximum, which was mainly due to energy spreading of the polarized proton beam. Cross sections and analyzing powers were measured in the range 8°–52° by the step of about 3°. Additional data at 8°, 16°, 24°, 32°, and 40° were taken with the unpolarized proton beam. Two series of the measurements at each scattering angle were required to obtain the inelastic proton spectra covering the energy range of $0 \le E_x \le 8.5$ MeV because of the limited energy bite of the spectrograph ($\Delta E_x \sim 4.5$ MeV).

Figure 1 shows a typical spectrum of the inelastic proton scattering on ^{48}Ti at $\theta_{\text{lab}}=27°$, where 3^- states are populated most strongly. The energies of some of the strongly populated states are shown in the figure. The excitation energies were determined through the calibration of the focal plane with the known excitation energies[14] of the low-lying states in ^{48}Ti up to about 5 MeV. The calibrated energies of strongly excited states below $E_x \sim 5$ MeV agreed within ± 5 keV or less with those used in the calibration. The energy values obtained in the present experiment were thus estimated to be accurate within 10 keV or less for the states at $E_x \ge 5$ Mev.

The area and location of each peak were automatically searched for and fitted by the program code SPECFIT.[15] Yields of each peak were converted to cross section values of inelastic scattering by using the quoted target thickness, the solid angle of 3.2 msr, and collected charge. In order to check the accuracy of cross-section values, elastic scattering from ^{48}Ti was measured. They agreed with the prediction of the optical model calculation by Noro *et al.*[16] within 10%. Thus we believe that errors in the absolute cross sections are less than 10%.

III. ANALYSIS

Distorted-wave Born approximation (DWBA) calculations were carried out by the code ECIS79 (Ref. 17) in order to make the spin-parity assignments of excited states by comparison with the experimental cross sections and analyzing powers. The macroscopic form factors were of conventional collective type. In the calculations, the coupled channel effect was neglected, and the results after one iteration were used for comparison with experimental data. The full Thomas terms of the spin-orbit part were taken into account to obtain good fits with the data of the analyzing power. The parameters of the optical potential used were those obtained by Noro *et al.*[16] for the proton elastic scattering at 65 MeV on ^{48}Ti. The effect of the Coulomb excitation in the DWBA calculations was not observed for the states excited with $L \ge 2$ angular momentum transfers. In Fig. 2, the experimental angular distributions of cross sections and analyzing powers are compared with the results of the DWBA calculations for 2^+, 3^-, and 4^+ states. Two requirements for the spin-parity assignment of natural-parity states were set in the present work: The one is the agreement between the theory and the experiment of the first and largest local maximum of the angular distributions of cross sections; the other is the agreement of scattering angle where the analyzing powers change drastically from negative to positive values (see Fig. 2).

Proton inelastic scattering is able to excite isovector states and unnatural-parity states as well. It is, in principle, impossible to extract only the isoscalar natural-parity states in the present work. But most states excited in the present experiment at $E_p=65$ MeV are assumed to be isoscalar natural-parity states because of the following reasons: (1) All the strongly excited natural-parity states, of which angular distributions are well described in the macroscopic DWBA calculations, are also observed in (α,α') experiments,[18] (2) the theoretical prediction[19] shows that the unnatural-parity states are relatively weakly excited at $E_p \sim 65$ MeV, and (3) isovector

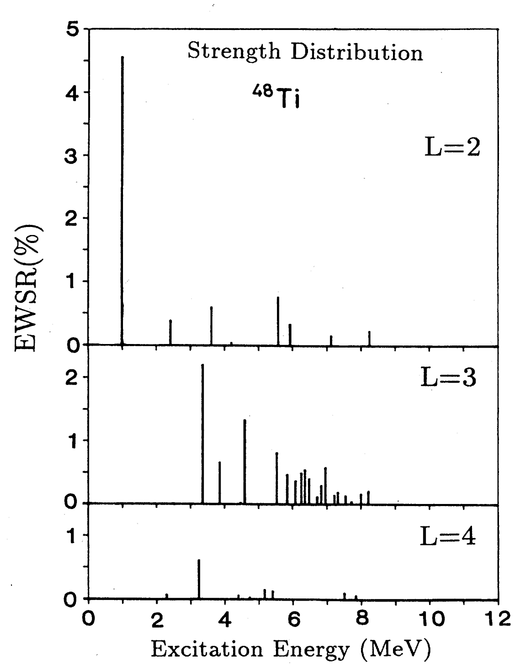


FIG. 3. Distribution of the energy-weighted sum rule (EWSR) fractions (%) for the 2^+, 3^-, and 4^+ strengths found in the ^{48}Ti(p,p') reaction.

TABLE I. Present inelastic proton scattering results for the excitation energies, spin-parity assignments (J^{π}), deformation lengths (β_L), EWSR fractions for the states in ^{48}Ti compared with previous results. Spin-parity assignments for the states with the parentheses include some ambiguities because of their weak excitation strengths.

	Present work			Previous work			
		(p,p')		$(p,p')^a$		$(\alpha,\alpha')^b$	
E_x (MeV)	J^{π}	β_L	EWSR (%)	J^{π}	β_L	J^{π}	β_L
0.984	2^+	0.201	4.57	2^+	0.22	2^+	0.21
2.295	4^+	0.03	0.07				
2.421	(2^+)	0.037	0.39			2^+	0.058
2.465							
2.997							
3.062							
3.239	4^+	0.078	0.62	4^+	0.15	4^+	0.082
3.358	3^-	0.110	2.20	3^-	0.18	3^-	0.079
3.511	6^+	0.019	0.02				
3.618	2^+	0.038	0.60				
3.702							
3.789							
3.856	3^-	0.057	0.67	3^-	0.10	3^-	0.056
4.046	(5^-)						
4.077							
4.157							
4.206	2^+	0.011	0.05				
4.310							
4.348	(2^+)						
4.392	4^+	0.022	0.07				
4.472	3^-	0.011	0.03				
4.532							
4.591	3^-	0.073	1.33	3^-	0.17	3^-	0.070
4.726	4^+	0.014	0.03				
4.802	$(2^+,3^-,4^+)$						
4.900							
4.978						2^+	0.045
5.000							
5.161	4^+	0.031	0.15			4^+	0.036
5.277							
5.329						$(2^+,4^+)$	0.051
5.400	4^+	0.027	0.13				
5.537	3^-	0.052	0.82	3^-	0.11		
5.578	(3^-)						
5.633	(2^+)	0.035	0.77				
5.777							
5.844	3^-	0.039	0.48	3^-	0.10	3^-	(0.054)
5.928	2^+	0.022	0.34				

natural-parity states are expected to appear above $E_x = 10.672$ MeV, which is the excitation energy estimated for the ground-state analog.[20]

The energy-weighted sum rule (EWSR) fractions and the deformation lengths were derived by using the procedure given by Satchler.[21] In Table I, the present results are summarized and compared with the previous inelastic scattering data.[18,22] The present results on deformation lengths β_L for highly excited states largely differ from those of Ref. 22. However, they are found to be mostly consistent with the α scattering results of Ref. 18. It is not clear whether the large differences between the present results and those of Ref. 22 are due to experimental or calculational problems.

We identified 82 peaks. Among them, the spin-parity assignments were made for about 40 states. The deformation parameters and EWSR fractions were obtained for ~ 30 states. We found 8 2^+ levels, 20 3^- levels, and 9 4^+ levels. In Fig. 3, the distributions of the EWSR fractions for each state are shown as a function of the excitation energy. The amounts of the EWSR fractions were 7.12%, 9.35%, and 1.22% for the quadrupole, octupole, and hexadecapole states at $E_x \leq 8.2$ MeV, respectively. Some small parts of the EWSR fractions are possibly missed in the present analysis. This might be due to a statistical fluctuation in the excitation strength distribution and/or to the experimental problem of observing widely distributed strength at high excitation energy.

TABLE I. (*Continued*).

	Present work			Previous work			
		(p,p')		(p,p')[a]		(α,α')[b]	
E_x (MeV)	J^π	β_L	EWSR (%)	J^π	β_L	J^π	β_L
6.025							
6.083	(3^-)	0.034	0.38				
6.139							
6.200							
6.258	3^-	0.039	0.51			3^-	(0.051)
6.332							
6.362	3^-	0.040	0.56			3^-	(0.052)
6.484	3^-	0.035	0.42	2^+	0.09		
6.503							
6.542							
6.604							
6.641							
6.687							
6.722	3^-	0.019	0.13				
6.757							
6.816	(3^-)						
6.839	3^-	0.029	0.31				
6.963	3^-	0.039	0.59				
7.036	(4^+)						
7.082	$(3^-,4^+)$						
7.116							
7.129	(2^+)	0.014	0.16				
7.162							
7.221	(3^-)	0.020	0.15				
7.245							
7.324	3^-	0.022	0.20				
7.357							
7.506	(4^+)	0.020	0.10				
7.551	3^-	0.019	0.14				
7.618	(4^+)						
7.583	$(2^+,3^-)$						
7.692							
7.728	(3^-)	0.011	0.05				
7.771							
7.853	(4^+)	0.016	0.06				
7.876							
7.905							
7.999	3^-	0.020	0.17				
8.057							
8.093							
8.178							
8.212	3^-	0.022	0.21				
8.246	(2^+)	0.016	0.23				
8.267							

[a]Reference 22.
[b]Reference 18.

IV. DISCUSSION

Figure 4 shows the distribution of the EWSR fractions for 3^- states in ^{48}Ti, which is compared with those in ^{46,50}Ti. The first 3_1^- state at $E_x=3.358$ MeV in ^{48}Ti exhausts 2.2% of the octupole EWSR value. The strength distributions in Fig. 4 show that the centroid of 3^- states becomes lower in excitation energy and weaker in strength with decreasing neutron number in the Ti isotopes. The 3_1^- state in ^{48}Ti is still the strongest. A clear separation between the 3_1^- state and the others, which is clear in ^{50}Ti, disappears in ^{48}Ti and ^{46}Ti.

In the scheme of the liquid drop model with quadrupole deformation, the isoscalar octupole vibration mode has an excitation energy depending only on the $L=3$ quantum number. The deformation of the ground state causes a splitting of the octupole state depending on the K quantum numbers. Bohr and Mottelson suggest that the relative excitation energies of the fragmented states are proportional to $3K^2-L(L+1)$ (Ref. 23). These general considerations might be extended to the low-lying 3_1^- states. According to this model, even a strong low-lying

3_1^- state in ^{50}Ti is expected to split into four 3^- states if the ground state were deformed in a quadrupole shape. Note that the 3_1^- state in ^{50}Ti has a main configuration of $(\pi s_{1/2})^{-1}(\pi f_{7/2})$ wave function.[4] The relative energies of these four states may be expressed as

$$\Delta E_x = \alpha[3K^2 - L(L+1)] \ , \qquad (1)$$

where α is a constant relating to the intrinsic one-particle–one-hole (1p-1h) excitation. It is interesting to point out here that the relative energy ΔE_x becomes zero in the case of $L=3$ and $K=2$.

According to Eq. (1), the location of each fragmented 3^- state depends only on K^2. The location of the third 3^- state with $K=2$ is expected to remain at the unperturbed position of the original 3^- state in the spherical nucleus. In fact, the excitation energies of the third 3^- states at 4.591 MeV in ^{48}Ti and at 4.194 MeV in ^{46}Ti are close to the excitation energy 4.410 MeV of the 3_1^- state in ^{50}Ti. In order to examine whether or not the above-mentioned macroscopic picture is qualitatively valid for the 3_1^- states in the Ti isotopes, we tentatively assumed that candidates of the expected four 3^- states are those at $E_x = 3.358$, 3.856, 4.591, and 5.537 MeV in ^{48}Ti, and also those at $E_x = 3.059$, 3.569, 4.194, and 5.945 MeV in ^{46}Ti (Ref. 7). The energy intervals between the above four states in the ^{46,48}Ti nuclei are 0.498, 0.735, and 0.946 MeV in ^{48}Ti, and 0.510, 0.625, and 1.751 MeV in ^{46}Ti, respectively. If we normalize the energy interval between the first and the second 3^- states in each Ti isotope, we get the results of 1:1.48:1.90 for ^{48}Ti, and 1:1.23:3.43 for ^{46}Ti, respectively. On the other hand, the estimation in the liquid drop model gives the ratio of 1:3:5,

$$\Delta E_x(K=1) - \Delta E_x(K=0) : \Delta E_x(K=2) - \Delta E_x(K=1) : \Delta E_x(K=3) - \Delta E_x(K=2) = 1:3:5 \ .$$

The macroscopic understanding of the fragmentation mechanism of the 3^- state might be qualitatively supported by the facts that the strength of the first 3_1^- state in ^{50}Ti roughly agrees with the summed strength of the above-mentioned four 3^- states in ^{46,48}Ti and that the energy locations of the third 3^- states roughly agree with that of the first 3_1^- state in ^{50}Ti.

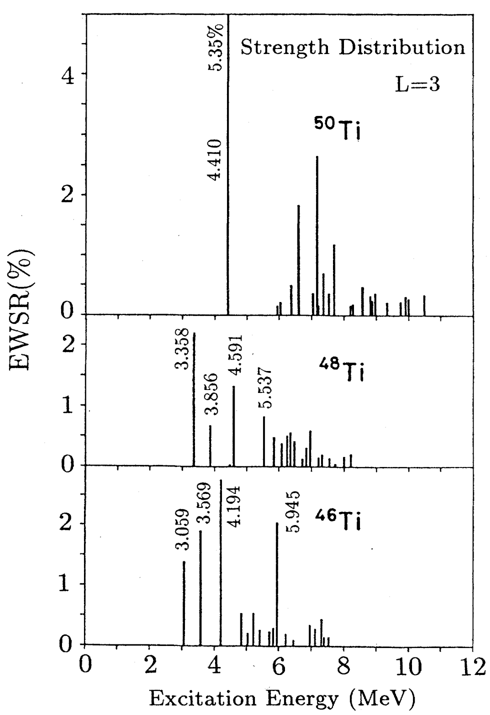


FIG. 4. Strength distributions of the EWSR fractions of the octupole excitation strengths found in the isotopes of ^{50}Ti, ^{48}Ti, and ^{46}Ti. Energies of levels are shown in MeV.

We treat each 3^- state except for the four strongly excited 3^- states mentioned above in ^{46,48}Ti as the members of the 3^- state in the LEOR. The experimental centroids of the LEOR are found to be 6.0, 6.8, and 7.7 MeV in ^{46,48,50}Ti. The centroid of the LEOR in ^{46,48}Ti shifts downward with increasing deformation of the ground state. On the other hand, the centroids calculated from the energy systematics of the LEOR for spherical nuclei ($32A^{-1/3}$ MeV), are 8.9, 8.8, and 8.7 MeV of excitation energy in ^{46,48,50}Ti, respectively. The experimental result shows a trend opposite to the systematics. In connection to this phenomenon, Nishizaki and Ando have made an interesting theoretical prediction. They show that in a fluid-dynamical model, the high-energy octupole resonance splits into four resonances due to the ground-state deformation, and the centroid energy shifts downward compared with the energy systematics of $118A^{-1/3}$ MeV.[24] Similar downward shifts are also observed for the LEOR and the first 3_1^- state in the Ti isotopes as the deformation of the ground state increases.

The experimental total strengths of 3^- states in ^{46,48}Ti are found to decrease to two thirds of that in ^{50}Ti. In order to check whether this decrease is meaningful or not, we carried out the shell-model calculation using the simple spherical harmonic oscillator wave function to estimate the total strength of the 3^- states in $1\hbar\omega$ excitation in fp-shell nuclei. A brief prescription similar to the present calculation has been given in Ref. 25. The results are compared with the experiments in Fig. 5. The shell-model estimation indicates that about 16% of the isoscalar octupole EWSR value should be exhausted in each nucleus. The experimental results for closed shell nuclei[3,4,26] show a trend to be larger than the theoretical estimations. However, the experimental fractions of the

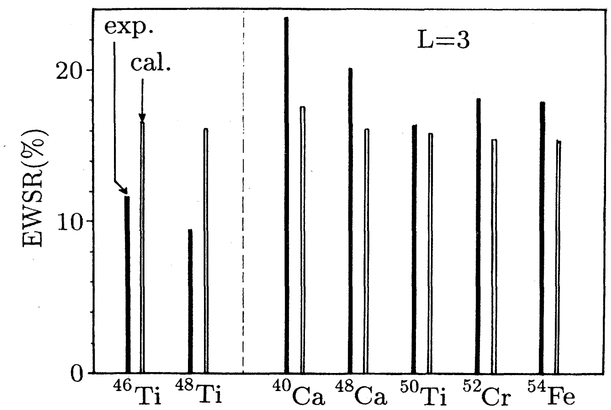


FIG. 5. The 3^- EWSR fractions exhausted in the region of $1\hbar\omega$ excitation in various $f_{7/2}$ shell nuclei. Experimental data are shown by the black histograms. The white histograms are the results of the simple shell-model estimations using the harmonic oscillator wave functions. The results for ^{40}Ca are taken from Ref. 26.

EWSR values in ^{46,48}Ti are found to decrease to about two thirds of the theoretical one.

There remains a possibility that due to the experimental difficulty in finding weakly excited states, some of the weak 3^- strength is missed in the present experiment. It seems to be very unlikely that the strength of the 3^- states missed in the present analysis below 8 MeV of excitation significantly changes the experimental value of EWSR, since the probability of the missing strength due to the presence of strong states is considered to be small. In addition, it should be noted that we found no significantly strong peaks above 8 MeV of excitation in ^{48}Ti when we examined the proton energy spectrum at $\theta_{\rm lab}=24°$ up to 11 MeV. There is, however, a possibility that the strength of the LEOR is quite spread and a part of the strength is shifted to the higher excitation region.

V. SUMMARY AND CONCLUSION

The nuclear structure of ^{48}Ti was studied up to $E_x=8.2$ MeV through polarized-proton inelastic scattering at $E_p=65$ MeV. The angular distributions of cross sections and analyzing powers were measured. About 80 discrete peaks were analyzed in the present work. The high-resolution experiment ($\Delta E \sim 30$ keV) enabled us to observe the fine structure of the octupole excitation in the region of $1\hbar\omega$ excitation. The collective model DWBA analysis has been made for the spin-parity assignment of each state. The deformation lengths were extracted for the natural-parity states in ^{48}Ti. The EWSR fractions observed in the present experiment were 7.12%, 9.35%, and 1.22% for quadrupole, octupole, and hexadecapole excitations, respectively.

The observed result of the strength distribution of the octupole excitation in ^{48}Ti was compared with those in ^{50}Ti and ^{46}Ti. The systematic behavior of the octupole excitations in ^{46,48,50}Ti was able to be understood qualitatively in terms of the deformation effect. The systematics of the octupole excitations in the Ti isotopes have the following features.

(a) The first 3_1^- state at 3.358 MeV is the strongest among the 3^- states in ^{48}Ti just like in the case of ^{50}Ti. Its strength is, however, about one third of that in ^{50}Ti. The summed strength of four low-lying 3^- states at 3.358, 3.856, 4.591, and 5.537 MeV in ^{48}Ti is nearly equal to the strength of the first 3_1^- state in ^{50}Ti. This suggests that the fragmentation mechanism of octupole states similar to the case in ^{46}Ti also occurs in ^{48}Ti.

(b) As the deformation of the ground states increases in the titanium isotopes starting from ^{50}Ti to ^{46}Ti, the strength of the first 3_1^- state in each nucleus becomes weaker and fragmented.

(c) We estimated theoretical EWSR values for octupole excitations within $1\hbar\omega$ jump using the harmonic oscillator wave functions. The experimental EWSR strengths in ^{46,48}Ti are found to be considerably weak compared with the theoretical estimations. Note that the EWSR values experimentally observed in closed shell nuclei are nearly equal to the theoretical ones.

As discussed in our previous paper on ^{46}Ti (Ref. 7), the random-phase approximation (RPA) calculation including the deformation effect is expected to explain that the first 3_1^- state and the other 3^- states in the LEOR considerably intermingle as the ground-state deformation increases. The present systematic study of the octupole excitations in the Ti isotopes shows that a treatment discriminating the first 3_1^- state from the 3^- states in the LEOR in deformed nuclei is not adequate as an analyzing method of the octupole excitations. In order to obtain a theory which successfully describes low-lying 3^- states in deformed nuclei, the experimental excitation strength distribution of 3^- states over the LEOR region would be an essential ingredient to be supplied. We would like to point out that in order to better confront theory with experimental data, the determination of K quantum numbers from gamma-ray spectroscopy work is important. It is of interest to note here that some evidence for the importance of the effect of the Coriolis interaction on the splitting of octupole states[27] has recently been presented for the octupole states in ^{168}Er by Meyer *et al.*[28] We can expect the rich information on the Coriolis interaction as well as the quadrupole-octupole coupling effect from the detailed studies of the octupole strengths.

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