Nuclear Data for Science and Technology (1988 MITO), 747–750, Copyright © 1988 JAERI.

# ENERGY SPECTRA OF α PARTICLES EMITTED FROM THE (p,α) AND (n,α) REACTIONS

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Abstract : We have measured the energy spectra of α particles emitted from (p,α) reactions on $^{112}$Cd, $^{118}$Sn, $^{120}$Sn, Sb, $^{128}$Te and $^{130}$Te with 18 MeV protons in order to clarify the shell and odd-even effects in the preequilibrium processes of (p,α) and (n,α) reactions. From the experimental results, it was found that there are no appreciable shell and odd-even effects on target nuclei in the gross (p,α) energy spectra lower than 20 MeV in the preequilibrium process. They can be explained well by the α knockout model using the effective Q values which are shell independent. The fine structures of the energy spectra for the (p,α) reactions on nuclei around atomic number 50 can be qualitatively explained using the three-nucleon pickup model under the assumption that the states excited in the (p,α) reaction are formed by the coupling of two-neutron hole states excited in a reaction such as the (p,t) reaction and one-proton hole states excited in a reaction such as the (d,$^3$He) reaction. The similar three-nucleon pickup model can explain qualitatively the fine structures of the energy spectra for the (n,α) reactions on nuclei around neutron numbers 50 and 82.

((p,α) reaction, (n,α) reaction, energy spectra, α-knockout process, three-nucleon pickup process)

## Introduction

Under the assumption of the three-nucleon pickup mechanism, the (p,α) reactions on proton-magic nuclei and near proton-magic nuclei are analogous to the (n,α) reactions on neutron-magic nuclei (N=50 or 82) and near neutron-magic nuclei, because for both reactions one nucleon is picked up from magic or near magic shell states and two nucleons are picked up from BCS states. In the present experiment, therefore, we have measured systematically and accurately the double differential cross sections of the (p,α) reactions on $^{112}$Cd, $^{118}$Sn, $^{120}$Sn, Sb, $^{128}$Te and $^{130}$Te in order to clarify the shell and odd-even effects on the (p,α) reactions on nuclei around atomic number 50.

## Experimental procedure

Proton beams of 18 MeV from the tandem Van de Graaff accelerator at Kyushu University were analyzed by a beam analyzing magnet and brought into a scattering chamber. The targets were self-supporting metallic foils except for $^{128}$Te and $^{130}$Te which have 0.2 mg/cm$^2$ gold backings. An α detecting system consists of a ΔE-E counter telescope[1] of two silicon surface barrier detectors having thicknesses of 15 and 300 μm, respectively.

Emitted α particles were identified and separated from other reaction products by means of a particle identifier. The α-particle spectra were measured at angles ranging from 20° to 160° in steps of 20°.

## Experimental results

Energy spectra of α particles integrated over angle are shown by the histograms in Fig.1. The figure indicates clearly a shell effect. The energy spectra for $^{112}$Cd, $^{118}$Sn and $^{120}$Sn fall sharply to zero near 20 MeV. The energy spectra for Sb, $^{128}$Te and $^{130}$Te, which are near magic nuclei with a few nucleons outside the magic shell, also fall sharply near 20 MeV and have some weak structures above 20 MeV which correspond to discrete levels or groups of levels of the residual nuclei.

The energy spectrum for an odd-mass nucleus Sb is compared with that for even-even nucleus $^{128}$Te in Fig.1. The ground state Q-values on $^{121}$Sb, $^{123}$Sb and $^{128}$Te are 6.92, 6.74 and 4.16 MeV, respectively. In spite of the large Q-values difference, the shape and magnitude of the energy spectrum for Sb are almost similar to those for $^{128}$Te, except for some weak structures above 22 MeV and the evaporation region below 15 MeV in the spectrum for Sb.

## Theoretical analyses and discussions

The experimental energy spectra have been analyzed in terms of the statistical evaporation model and the preequilibrium exciton model.

We calculated the (p,α) cross sections for the preequilibrium process using an α-knockout model introducing the effective Q values[1,2] which are shell independent, the uniform spacing model, and the pairing correlation.

In Fig.1 the dashed and dotted-dashed curves are the calculated preequilibrium and evaporation energy spectra, respectively. The solid curves are the sum of these. The calculated energy spectra reproduced well the experimental gross energy spectra for all the targets as shown in Fig.1. This fact means that there exist no appreciable shell and odd-even effects on target nuclei in the gross (p,α) energy spectra lower than 20 MeV in the preequilibrium process.

As shown in Fig.2, we found that the energy spectrum from the $^{120}$Sn (p,α) reaction shows a striking resemblance in shape to that from the $^{120}$Sn (p,t) reaction[3]. Both spectra have sharp peaks near 0 and 1.2 MeV and broad peaks near 2.5-5 MeV of excitation energies of the residual

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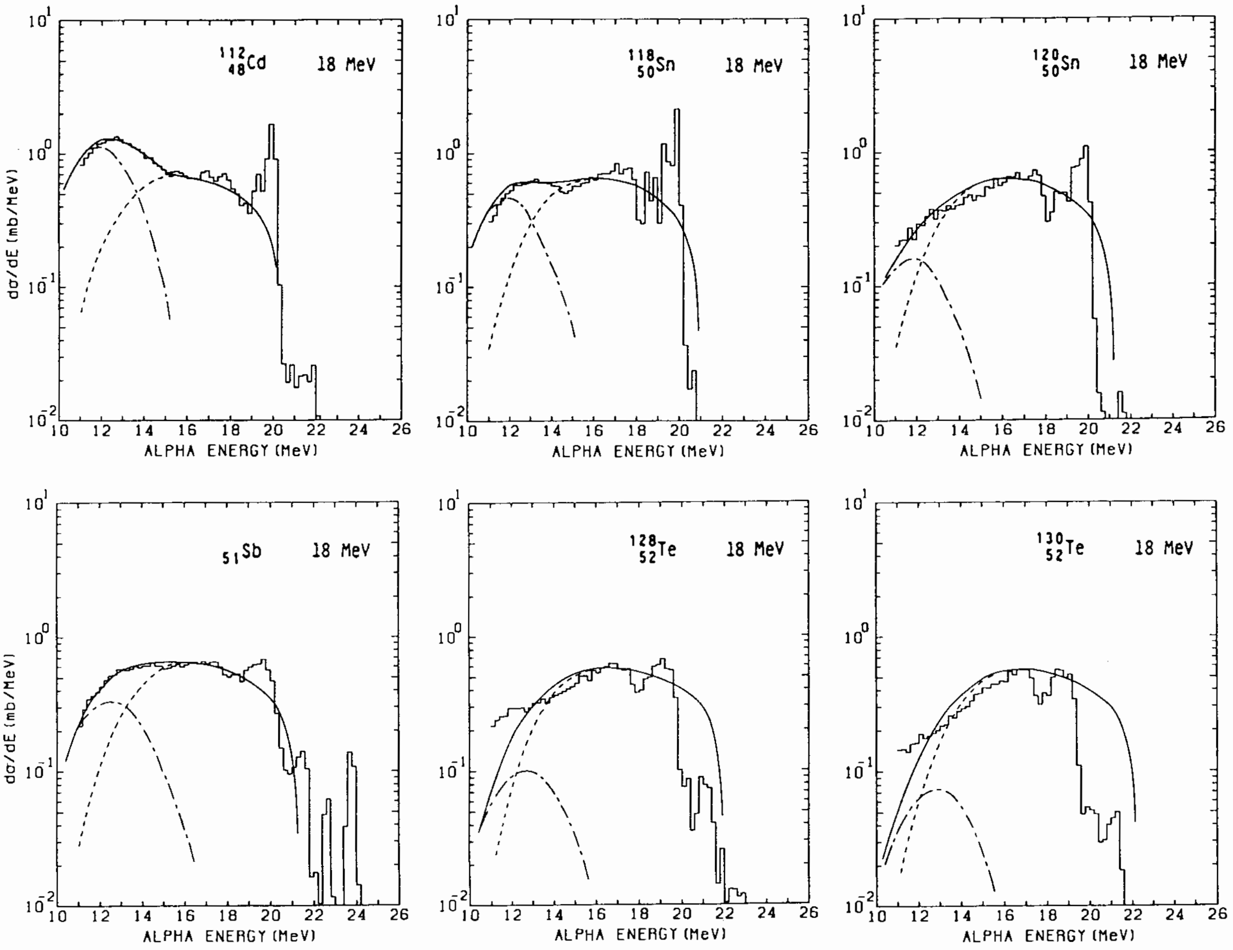

Fig.1 Energy spectra of α particles for $^{112}$Cd, $^{118,120}$Sn, Sb and $^{128,130}$Te. The histograms show the experimental energy spectra.

nuclei. This feature can be qualitatively explained by using a pickup model as follows.

Removal of a proton from the Z=50 closed proton shell leads to a simple proton-hole spectrum as observed in (d,$^3$He) experiments[4] on tin isotopes. The two-neutron transfer strength is concentrated in a few collective states due to the superconductivity of the neutron core as exhibited in the Sn(p,t) reactions. Therefore we expect that the states populated in the Sn(p,α) reaction are formed by combining these two excitations in a weak-coupling scheme. The (d,$^3$He) reaction[4] on Sn isotopes can only excite pure hole components ($J\pi$ = $9/2^+$, $1/2^-$, $3/2^-$ etc.). Among them the $1g_{9/2}$ strength is known to be dominant. Therefore the states excited in Sn(p,α) reaction are mainly formed by combining one proton hole state $1g_{9/2}$ and two-neutron hole state. Thus the energy spectrum for the $^{120}$Sn(p,α) reaction shows a striking similarity in shape to that for the $^{120}$Sn(p,t) reaction.

The (p,t) reaction on even tin isotopes excites zero-quasiparticle state ($J\pi$ = $0^+$) and two-quasiparticle states ($J\pi$ = $2^+$, $3^-$, $4^+$, $5^-$, $6^+$, $7^-$, $8^+$, $9^-$ and $10^+$) in the major shell. The $0^+$ state and one of the $2^+$ states correspond to the ground and the first excited states, respectively, of the residual nucleus. Other two-quasiparticle states are considered to be distributed in the energy region of 2.5-5 MeV, where a broad peak is observed in $^{120}$Sn(p,t) reaction as shown in Fig.2.

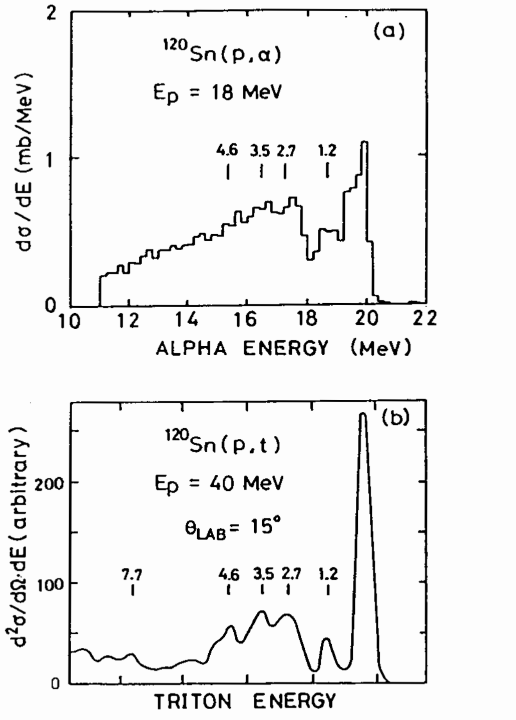

Fig.2 Measured energy spectra of particles emitted from the $^{120}$Sn(p,t) and $^{120}$Sn(p,α) reactions.

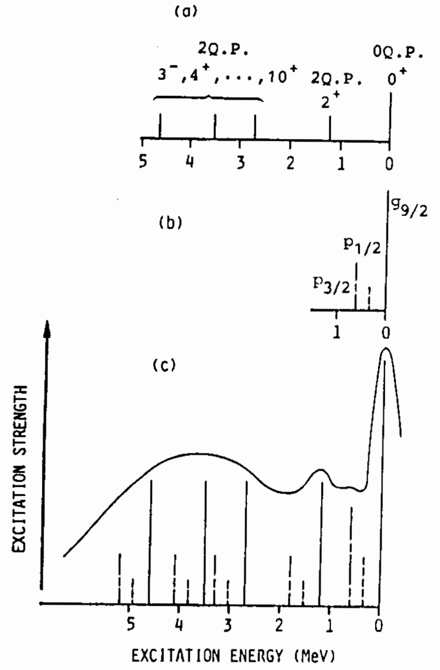

Fig.3 Schematic illustrations of the excitation energies and strengths of the states of the residual nuclei.
(a): Sn(p,t) reaction.
(b): Sn(d,$^3$He) reaction.
(c): Sn(p,α) reaction from which the states are formed by combining two excitations ((a) and (b)).

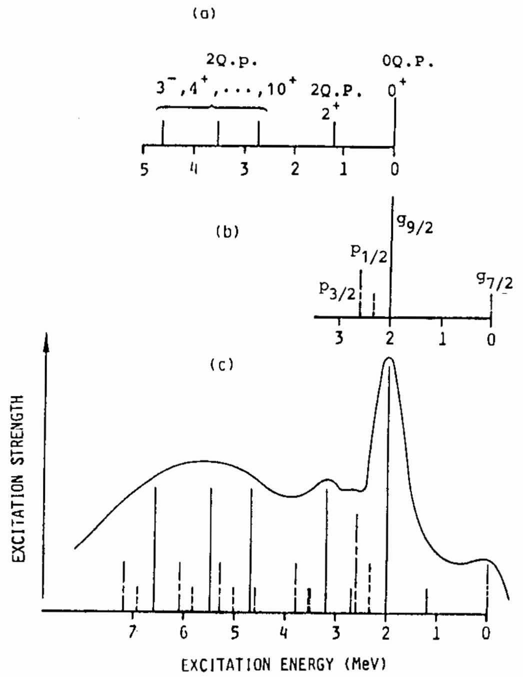

Fig.4 Schematic illustrations of the excitation energies and strengths of the states of the residual nuclei.
(a): Te(p,t) reaction.
(b): Te(d,$^3$He) reaction.
(c): Te(p,α) reaction from which the states are formed by combining two excitations ((a) and (b)).

The situation of three-nucleon pickup process is shown schematically in Figs.3 and 4. The excitation energies and strengths of the states excited in Sn(p,t) and Sn(d,$^3$He) reactions are shown schematically in Figs.3(a) and 3(b), respectively. Figure 3(c) shows the excitation energies and strengths of the states excited in Sn(p,α) reaction which are formed by combining these two excitations (Figs.3(a) and 3(b)) in the weak-coupling scheme. Figure 3(c) corresponds to the energy spectrum from the Sn(p,α) reaction and shows the similar shape to the measured energy spectra from the (p,α) reactions on $^{112}$Cd, $^{118}$Sn and $^{120}$Sn. Thus the fine structures of the energy spectra from the (p,α) reactions on $^{112}$Cd, $^{118}$Sn and $^{120}$Sn can be qualitatively explained by using the pickup model.

For Sb or Te, one or two protons are added in the $1g_{7/2}$ orbit outside the Z=50 closed proton shell. The excitation energies and strengths of the states excited in Te(p,t), Te(d,$^3$He) and Te(p,α) reactions are shown schematically in Figs.4(a),4(b) and 4(c), respectively.

The energy spectra above 20 MeV from the (p,α) reaction on Sb, $^{128}$Te and $^{130}$Te correspond to one-proton pickup from the $1g_{7/2}$ orbit. The energy spectra below 20 MeV are due to mainly the one-proton pickup from Z=50 closed proton shell and show structures duller than those in the cases of Cd and Sn because of the proton pickup from the deep states ($1g_{9/2}$, $2p_{1/2}$, $2p_{3/2}$) which produces the fragmentation[5] of single-particle levels. Thus the fine structures of the energy spectra from the (p,α) reactions on Sb, $^{128}$Te and $^{130}$Te can be qualitatively explained.

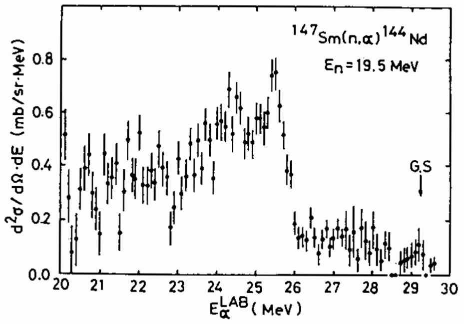

Fig.5 Energy spectrum of α particles from the $^{147}$Sm(n,α) reaction at the neutron energy of 19.5 MeV.
This spectrum was measured by Glowacka et al..

Glowacka et al[6]. have reported the energy spectra of α particles emitted from the $^{147}$Sm(n,α) reaction at neutron energies of 12.4, 14.1, 18.2 and 19.5 MeV. The energy spectrum for $^{147}$Sm(n,α) reaction is shown in Fig.5. Since the energy spectra for the $^{147}$Sm(n,α) reaction show a striking similarity in shape to that from the Sb(p,α) reaction, a following explanation of the energy spectrum is possible. Peaks near 29 MeV and near 27.5 MeV of the α-particle energy correspond to one-neutron pickup from unpaired and paired neutrons in $2f_{7/2}$ orbit outside the N=82 core, respectively. The energy spectra below

26 MeV correspond mainly to the one-neutron pickup from the N=82 core, and show similar structures to those from the (p,$\alpha$) reaction on nuclei around Z=50. Namely, the (n,$\alpha$) spectrum has two large peaks near 25.5 and 24.5 MeV and a broad peak around 22 MeV.

Haight et al[7]. have reported the energy spectra of $\alpha$ particles from the 14 MeV (n,$\alpha$) reaction on nuclei around N=50. Although these energy spectra are very poor, these spectra are not inconsistent with those predicted by analogy with the present (p,$\alpha$) reaction.

The authors are very indebted to the members of the Nuclear Physics Laboratory of Department of Physics, Kyushu University, for facilities and use of the accelerator.

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