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(n,α) REACTIONS ON Te ISOTOPES AT 14 MeV

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Abstract: Energy spectra of alpha particles from (n, α) reactions on Te isotopes have been measured at the angle of zero degree. The characteristic features of all spectra could be explained in terms of a direct process only. The structures of all energy spectra are in a certain correspondence with the single neutron level densities of the residual nuclei. The probabilities of alpha clustering on the surface of the target nuclei have been estimated assuming a knock-out mechanism for the (n, α) reaction.

1. *Introduction*

The analysis of experimental data on (n, α), and (p, α) reactions in the mass region A > 100 shows that alpha particles are emitted in the outgoing channel mainly through a direct mechanism[1-4] and, in particular, through knock-out processes[5-8]. The same conclusion has been drawn from (p, α) studies on heavy nuclei[9] at 40 MeV. The argument speaking in favour of the knock-out mechanism in these reactions is evidenced by a certain correspondence in the structure of the measured energy spectra of alpha particles and the single neutron level densities of the residual nuclei[5, 8]. Theoretical calculations for single neutron level densities were usually based on Nilson's scheme.

Experimental data on (d, p) reactions can also be used for the determination of the neutron level densities of the residual nuclei. The stripping of one neutron from the incoming particle leads to a residual nucleus which can be understood as consisting of an undisturbed nuclear core plus a captured neutron in the lowest or in an excited state. The configuration of the residual nucleus is thus analogous to that obtained in the final channel of the (n, α) knock-out process on the corresponding target nuclei. Consequently, we expect some correspondence in the level density of the residual nuclei both in the (d, p) stripping and in (n, α) knock-out reactions. Furt-

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hermore, the measured alpha particle spectra corresponding to low-lying neutron levels should show different trends in the case of even- and odd-neutron target nuclei. Considering the energy depression caused by pairing of an even number of particles it is obvious that in the (n, α) knock-out mechanism the probability for excitation of the low-lying neutron states of the residual nucleus is greater when the neutron number in the target is even than when it is odd for the neighbouring isotopes.

The present experiment was undertaken to check the above conjectures. Te isotopes are especially suitable for such a study, since the residual Sn nuclei have a closed proton shell and their neutron level structure is relatively simple.

2. *Experiment*

The 14.4 MeV neutrons were obtained from the T(d, n)^{4}He reaction using the 200 keV Cockcroft-Walton accelerator[10] at the Institute »Ruđer Bošković«. The neutron flux was monitored by counting the associated alpha particles from the above reaction. The targets were stable tellurium isotopes deposited on an aluminium backing. The measurements were performed on ^{124}Te, ^{125}Te, ^{126}Te and ^{128}Te. The thickness of the targets was about 1.5 mg/cm^2. A telescope[11] consisting of dE/dx gas proportional counters and a semiconductor E detector, was used to measure the energy spectra of alpha particles. The proportional counters were filled with hydrogen at a pressure of 100 mm Hg. The detector used in this experiment was an n-type silicon surface barrier detector, 13 mm in diameter, with a resistivity of about 2000 Ω cm. The sensitive depth of the detector was sufficiently large to stop alpha particles of about 25 MeV. The pulses from the dE/dx and E detectors were analysed with a two-dimensional 100×100 channel analyser[12] Aluminium foils of the same size as the target backing were used to measure the background. Low background was achieved using a gold lining inside the telescope, hydrogen gas in the proportional counters, and applying the method of two-dimensional analysis.

For the energy calibration of the telescope system a thin ^{241}Am alpha source and alpha peaks from the ^{28}Si (n, α) reactions were used. The calibration was checked with test runs before and after each measurement to examine the stabilities of the particle discrimination system as well as the energy calibration. The energy resolution was about 350 keV for medium-energy alpha particles and was mainly determined by the alpha particle energy loss in the targets. The geometry throughout experiments was such that the full width at half maximum for the window function was about 25°.

The measurements performed include the alpha energy spectra from the (n, α) reaction on Te isotopes at zero degree. (No contribution of alphas from the (n, nα) reactions was observed in the measured spectra: $Q = -1.8245$ MeV, $Q = -2.2467$ MeV, $Q = -2.5352$ MeV and $Q = -3.1657$ MeV for (n, nα) reactions on ^{124}Te, ^{125}Te, ^{126}Te and ^{128}Te, respectively).

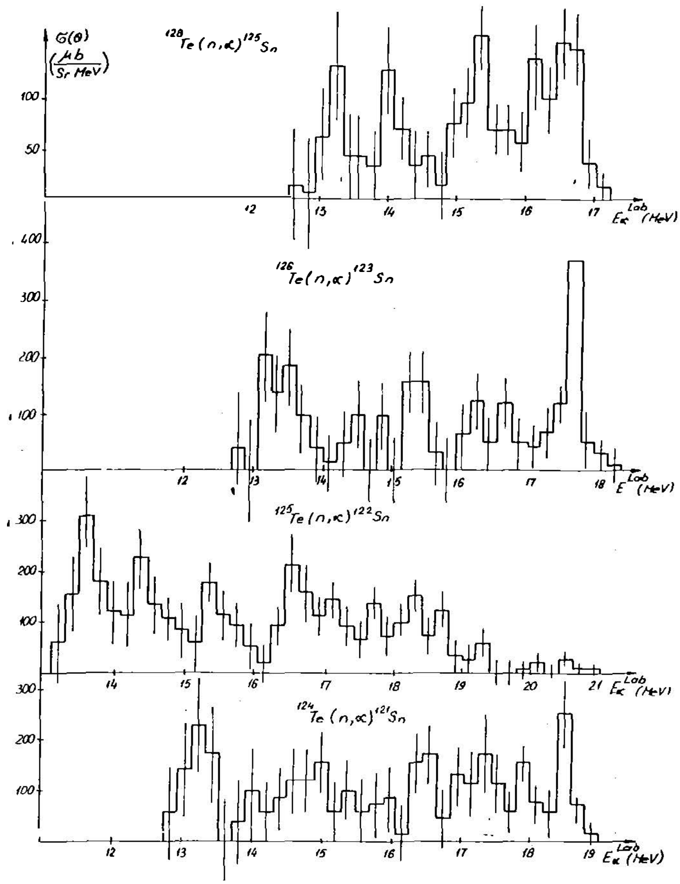
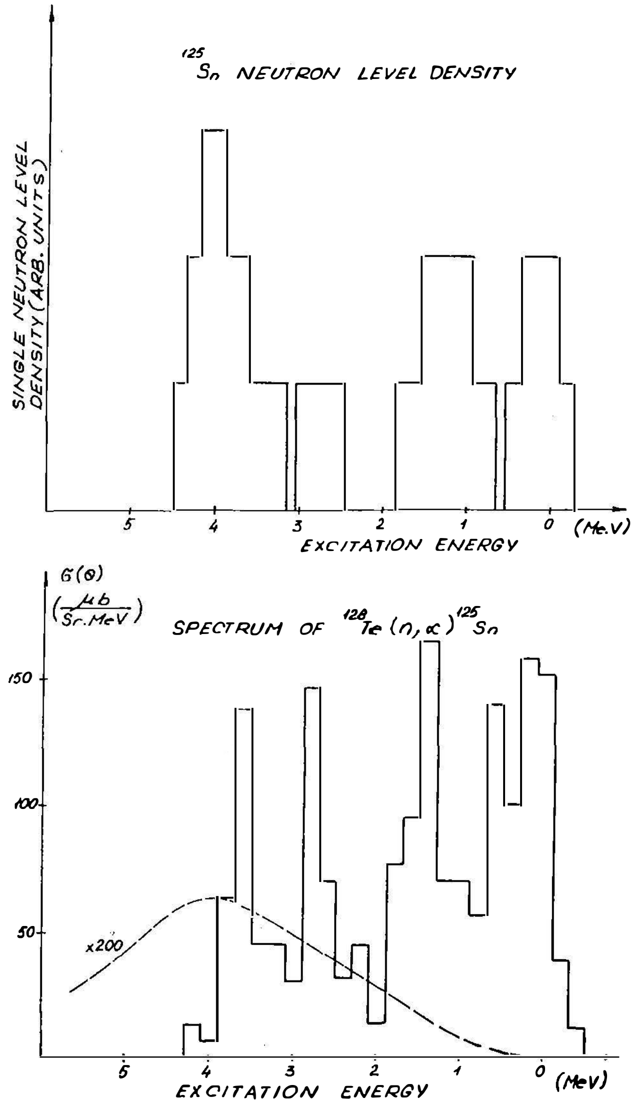


Fig. 1. Energy spectra of alpha particles from (n, α) reactions on Te isotopes at $\Theta = 0°$. The error bars indicate the statistical errors only.

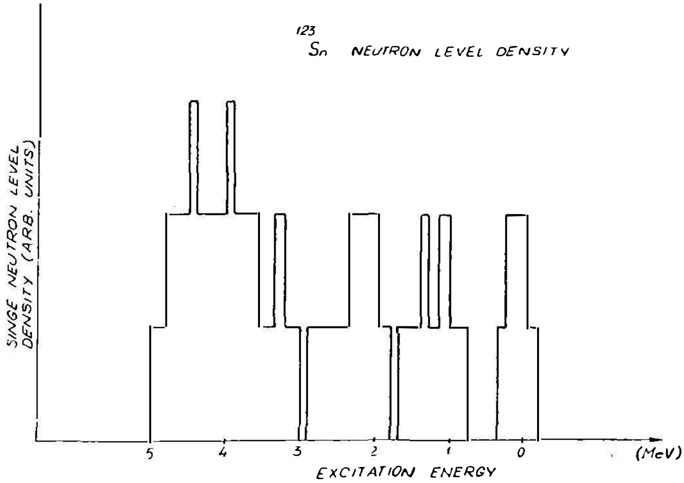
3. *Results and analysis*

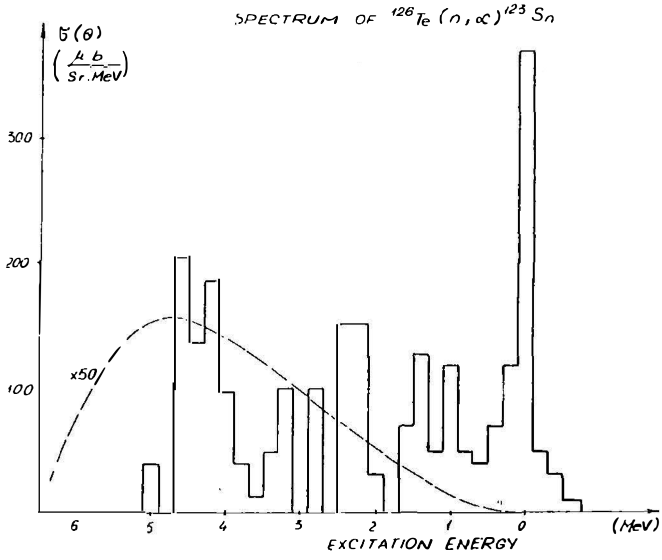
Figure 1 shows the energy spectra of alpha particles measured for (n, α) reactions on Te isotopes at 14.4 MeV. A feature common to all spectra is some specific structure quite different from the statistical shape. It was not possible to obtain meaningful spectra at energies below 12 MeV, since



the background in silicon increases very rapidly in this region, and Coulomb barrier effects greatly inhibit the probability of alpha particle emission.

The comparison of single neutron level densities of the residual Sn nuclei with the corresponding measured alpha spectra is shown in Figs. 2a—c. The dashed lines represent the statistical spectra obtained by the evaporation model calculation. The calculation was performed on the basis of the Weisskopf-Ewing[13] formula. The values of inverse cross sections for alpha particles were taken from Huizenga et al.[14] and those for neutrons and pro-





tons from Mani et al.[15]. The energy dependence of the level density was taken to be

$$\varrho(U) \sim U^{-2} \exp\,(2 \cdot (a \cdot U)^{1/2}) \ .$$

In this calculation the excitation energy U was calculated taking the pairing correction given by Cameron[16], and the level density parameter, $a = 17$ MeV^{-1}, was chosen close to that used by Facchini et al.[17]. This value is also in agreement with Gilbert's[18] calculation. The disagreement between the statistical predictions and experimental results both in the energy and in the structure of the spectra leads to the conclusion that direct processes contri-

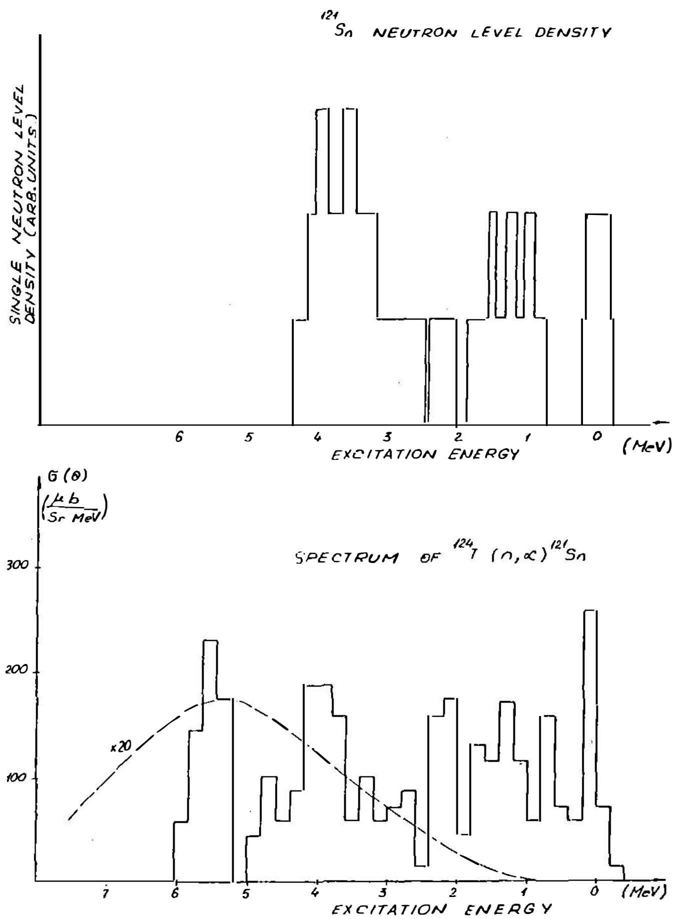


Fig. 2a-c. Energy spectra of alpha particles from (n, α) reactions on Te isotopes, compared with the corresponding neutron level densities of the residual nuclei (see the text). The statistical spectra (dashed lines) corresponding to the level density parameter $a = 17$ MeV^{-1} are normalized to the value $\sigma_{tot}/4\pi$ assuming the isotropy of the angular distribution.

bute predominantly in the investigated reactions. Assuming a knock-out process in these reactions one expects only the single neutron levels to be strongly excited. The incoming neutron knocks out an alpha cluster from the nuclear surface and occupies a single particle neutron level in the residual nucleus. A compound nucleus or pick-up process would not strongly excite single neutron states. Knock-out processes are considered to occur mainly on the surface of the target nuclei with even neutron number. The pairing of even neutron numbers seems to contribute to alpha clustering on the surface. This is borne out by the fact that the cross section for the (n, α) reaction on ^{125}Te (odd neutron number) is smaller for low lying states of the residual nucleus (Fig. 1) than the cross sections for Te isotopes with even neutron number. This evidence as well as the single neutron structure in alpha energy spectra support the assumption of a knock-out mechanism in these reactions.

The single neutron level densities in Figs. 2a-c were calculated from (d, p) experimental data[19, 20] on Sn isotopes under the following assumptions: The states strongly excited in (d, p) reactions are single neutron states; all single neutron states are excited with equal probability, and the energy spread is about 350 keV for all alpha particles. Figures 2a-c show that the structure of the measured alpha energy spectra is in correspondence with the single neutron level density of the residual nucleus. A similar regularity was observed in several other heavy nuclei[5, 8].

Table
Comparison of experimental cross sections

Target	Q(MeV)[25]	σ_{exp} (0°) (mb/sr)	σ_{act} (mb)*	Probability
^{124}Te	4.3567	0.67 ± 0.06	14.8 ± 7	2 ± 1
^{125}Te	6.5572	0.75 ± 0.08	—	—
^{126}Te	3.3967	0.45 ± 0.03	2.32 ± 0.9	0.35
^{128}Te	2.6017	0.35 ± 0.02	0.52	0.1

The probability of alpha clustering on the surface of the target nucleus can be obtained on the basis of Hodgson's[21] model. Following the calculations of Veselić et al.[8] we estimated the probability »*p*« for a surface nucleon to be a constituent of an alpha cluster. In the calculations we used Majumdar's[22] values for the total cross sections of (n, α) reactions on Te isotopes, and we assumed the contribution of a neutron alpha knock-out process only. The Table shows the experimental results of the present work, compared with the data obtained by Majumdar. The Table also presents the values calculated for the investigated alpha clustering probability. The experimental value of 14.8 mb obtained by correction by the state multiplicity factor for the ^{124}Te (n, α) reaction is inconsistent with our measurement. In this case the unreasonable result for the probability »*p*« indicates that Majumdar's value is somewhat overestimated. The values of alpha clustering probability obtained in the ^{126}Te (n, α) and ^{128}Te (n, α) reactions are consistent with other findings[23, 24] in this mass region. For the ^{125}Te (n, α) reaction the clustering probability could not be calculated, since the data on the total cross section were not available.

* Ref.[22]

4. Conclusion

In the present investigations the energy spectra of alpha particles measured from the $^{124, 125, 126, 128}$Te (n, α) reactions favour a knock-out mechanism. Before extending these findings and conjectures one must look for precise angular distribution data with improved resolution of energy spectra. However, the measurement of the angular distribution from the Te (n, α) reactions is difficult to perform because of the very low cross section, and it is possible only with improved experimental facilities.

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(n, α) REAKCIJE NA IZOTOPIMA Te KOD 14 MeV NEUTRONA

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Sadržaj

Koristeći teleskop koji se sastojao od dva dE/dx proporcionalna brojača i površinskog silicijevog E detektora, i primjenom metode dvodimenzionalne analize izmjereni su energetski spektri alfa čestica iz (n, α) reakcija na izotopima telura kod nula stupnjeva. Iz oblika energetskih spektara zaključeno je da se radi o direktnom mehanizmu, posebno o knock-out procesu. Ocijenjena je vjerojatnost da nukleon na površini jezgre bude sastavni dio nakupine nukleona u obliku alfa čestice, pretpostavljajući knock-out proces za proučavanje (n, α) reakcije.