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БИБЛИОТЕКА

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1. Introduction

Nuclear reactions induced by heavy ions represent an effective way of producing neutron-rich isotopes of light elements. Using the ^{15}N, ^{18}O and ^{22}Ne beams all the known neutron-rich isotopes of He, Li, Be, B, C, N, O, F and Ne, together with eleven new nucleides have been produced [1-3]. The present work is the first attempt to apply nuclear reactions induced by much heavier projectiles, namely by ^{40}Ar ions, for production of nucleides unobserved till now.

The neutron-rich nucleides are produced in multinucleon transfer reactions as a result of (i) stripping of protons from the projectile, (ii) pick-up of neutrons by the projectile, and (iii) nucleon exchange process: (projectile - protons + neutrons). The change of the potential energy of the colliding system in the case of such transmutations of the projectile prefers the reactions on heavy target nuclei [4]. Therefore, the combination of the ^{40}Ar projectile and the ^{232}Th target was chosen. In the collisions of these nuclei the isotopes of Ar, Cl, S, P, Si, etc. should be produced.

The detection and identification of the charged particles with $Z > 8$ is quite difficult. For example, using the combined time-of-flight, $\Delta E-E$ technique one can resolve only the isotopes up to neon /5/. We use a combination of the magnetic analysis and the $\Delta E-E$ technique which gives a much better isotopic resolution.

2. Experimental Procedure

The experiment was performed on the 310 cm heavy-ion cyclotron in Dubna. The external ^{40}Ar beam of about 2.10^{11} particles/s bombarded a metallic ^{232}Th target, 2.8 mg/cm^2 thick. Reaction products emitted from the target at 40^{o} with respect to the incident beam passed the magnetic spectrometer and were detected in the telescope, consisting of two silicon detectors: a 36 μm thick ΔE detector and a surface-barrier E detector. The pulses from both detectors were fed into a converter for two-parameter pulse-height analysis. The chosen region of the two-dimensional $\Delta E, E-\Delta E$ spectrum could be recorded in the 4096-channel analyser, operating in the 64x64 channel mode.

In bombarding ^{232}Th with 290 MeV ^{40}Ar ions the reaction products at $\theta = 40^{o}$ have wide energy spectra with maxima at about 5 MeV/nucleon. The energies of the reaction products reaching the telescope are given by the formula: $E = const.\ B^2 Z_i^2 / A$. Therefore, at a fixed magnetic field B the neighbouring isotopes with mass numbers A and $A+1$ have different energies. In the case of argon isotopes, reaching the telescope in the same charge state Z_i, this difference amounts to 2.5%. After energy deposition in the 36 μm thick ΔE detector, which allows the atomic number Z of the particle to be determined, the difference in energies $E-\Delta E$ rises to about 10%, which is sufficient to distinguish the isotopes.

In order to improve the resolution of the detecting system the effective area of the telescope was limited by a 3 x 5 mm slit. The choice of the entrance angle of the reaction product beam to the telescope turned out to be very important. It was fixed at the value, at which the minimum channelling effect in the silicon detectors was obtained.

3. Results

At the first stage of the experiment several short runs at various values of the magnetic field were performed in order to get information on the energy spectra of the reaction products. Many isotopes of K, Ar, Cl, S, P, Si, Al, Mg and Na, with energies ranging from 100 MeV to 250 MeV, were detected. The maximum yields of the reaction products were observed at about 5MeV/nucleon. Each nucleide was, of course, detected in several charge states Z_i. It was found that at 5 MeV/nucleon the dominant charge states are: $Z_i = Z-1$, $Z_i = Z-2$ and $Z_i = Z-3$. The magnetic field B = 7.270 kG turned out to be the best for detecting the largest number of different nucleides. The results of the 4 h. run at this value of B are presented in fig. 1. Two-dimensional ΔE, $E-\Delta E$ spectrum is shown in order to demonstrate the resolution both in the ΔE and $E-\Delta E$ directions. The energy of each reaction product detected in this run is known exactly: $E(MeV) = 0.79 \cdot (7.27)^2 \cdot Z_i^2 / A$. This relation, together with the data on the energy-range dependence for heavy ions (tables of Northcliffe and Schilling[6] with corrections following from our measurements of the ranges of ^{40}Ar and ^{31}P ions in silicon) was used for identification of the products. The most intensive elastic scattering peak was used as a reference point in the identification procedure. The elastically scattered ^{40}Ar ions, with $Z_i = 16$, were observed at $B = 7.070$ kG and were recorded in the region of the two-dimensional spectrum defined by coordinates: $\Delta E = 82$ channel, $E - \Delta E = 97$ channel. Their energy was calculated from the formula mentioned above as $E(^{40}Ar^{el}) = 0.79 . (7.07)^2 . 16^2/40 =$ $= 252.7$ MeV.

Well separated islands in fig. 1 are labelled by the nucleide symbol and the number describing the charge state of the ion. The islands corresponding to isotopes of one element (in a fixed charge state) are situated along the straight lines, succesively lower with increasing mass number. In the upper part of fig. 1 a distinct, not labelled island is seen (at $\Delta E = 82$ channel, $E - \Delta E = 97$ channel). The island represents the elastically scattered ^{40}Ar ions which have been recharged in passing through the magnetic field. Without recharging, none of elastically scattered ^{40}Ar can reach the telescope for $B = 7.270$ kG. It was estimated that in vacuum of 3.10^{-5} mm Hg the recharging effect is of the order of 0.01%, so it can cause a visible background only in the case of the elastically scattered ions which are at least 10^3 times more intensive (at

$\theta = 40^{\circ}$) than the other reaction products observed in the experiment.

The quantitative results of the run with $B = 7.270$ kG are shown in fig. 2. The yields of almost all the observed nucleides are given. The counts in a few adjacent ΔE channels were summed along the lines corresponding to the given element (for $Z_i = const$) and plotted in the logarithmic scale versus the $E - \Delta E$ channel number. Fig. 2 shows a very good isotopic resolution, even for Ar isotopes.

Apart from the nucleides already known, 17 new nucleides, namely: $^{29,30}Mg$, $^{31,32,33}Al$, $^{33,34,35,36}Si$, $^{35,36,37,38}P$, $^{39,40}S$ and $^{41,42}Cl$ have been reliably detected. It means that they live at least 10^{-7}s (the time of flight from a target to a telescope), and consequently, they can decay only through weak interaction processes. The cross sections for production of the discovered nucleides are quite large. They range from 0.1 mb/sr(^{30}Mg) to 7 mb/sr (^{35}P), at $\theta = 40^{\circ}$. Thus, one can conclude that the nuclear reactions induced by the ^{40}Ar ions can be used for the spectroscopic studies of the new neutron-rich nucleides in the region $Z < 18$.

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References

1. A.G. Artukh, G.F. Gridnev, V.L. Mikheev and V.V. Volkov. Nucl. Phys., A137, 348 (1969).
2. A.G. Artukh, V.V. Avdeichikov, L.P. Chelnokov, G.F. Gridnev, V.L. Mikheev, V.I. Vakatov, V.V. Volkov and J.Wilczyński, Phys.Lett., 32B, 43 (1970).
3. A.G. Artukh, V.V. Avdeichikov, G.F. Gridnev, V.L. Mikheev, V.V. Volkov, and J. Wilczynski. Nucl. Phys., A168, 321 (1971).
4. A.G. Artukh, V.V. Avdeichikov, J. Erö, G.F. Gridnev, V.L. Mikheev, V.V. Volkov and J. Wilczynski. Nucl.Phys., A160, 511(1971).
5. G.W. Butler, A.M. Poskanzer and D.A. Landis. Nucl. Instr., 89, 189 (1970).
6. L.C. Northcliffe and R.F. Schilling. Nucl. Data Tables, A7, 233 (1970).

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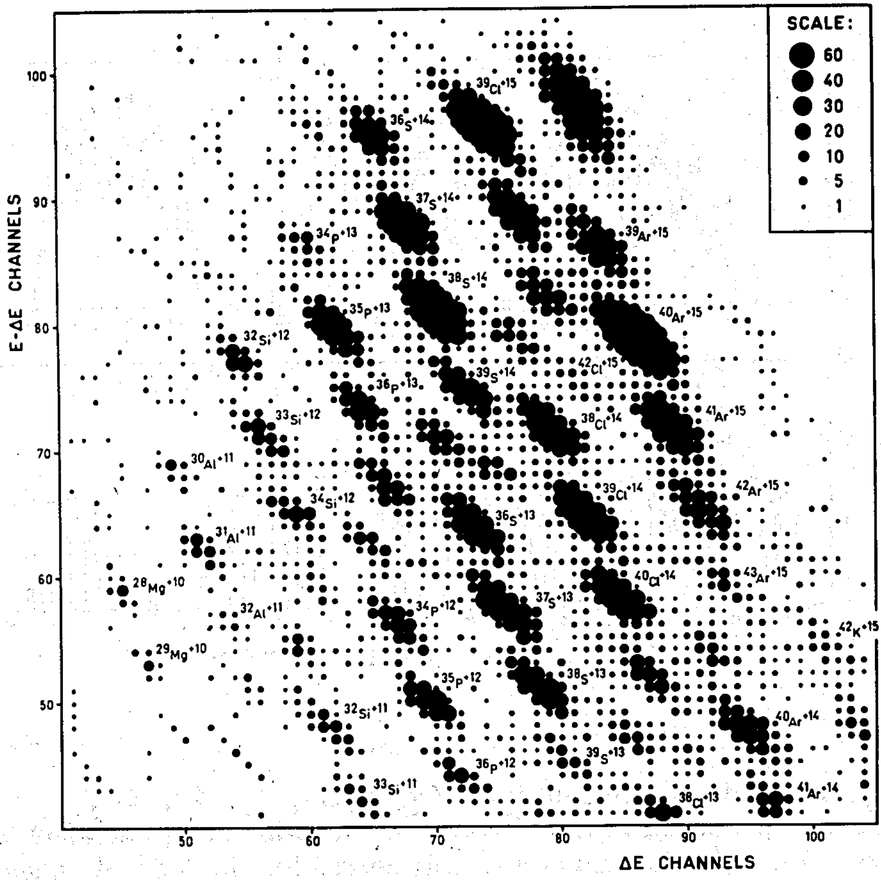

Fig. 1. Two-dimensional $\Delta E, E-\Delta E$ spectrum obtained in bombardment of a ^{232}Th target with 290 MeV ^{40}Ar ions. The combination of the magnetic analysis and the $\Delta E - E$ technique was used as the detection system.

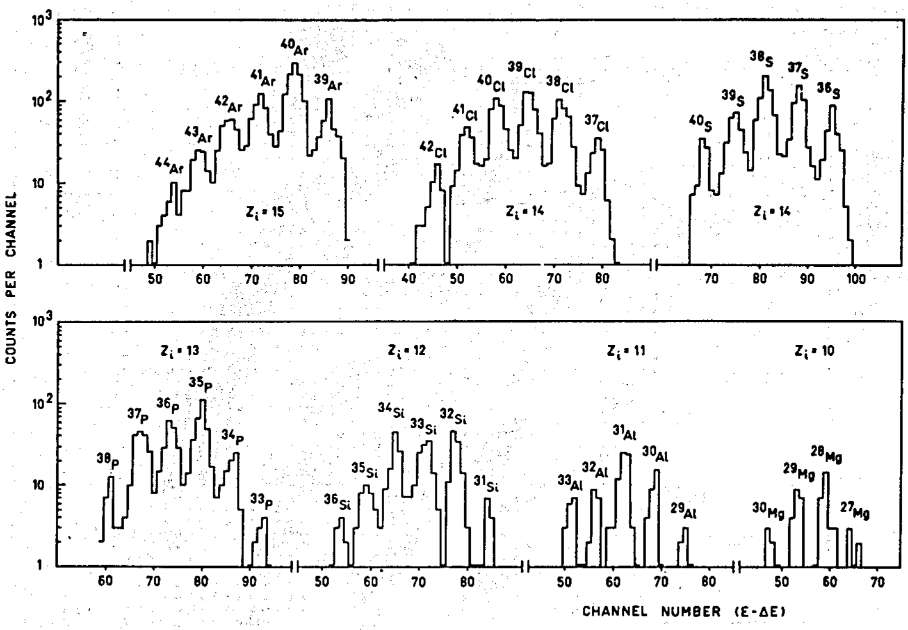

Fig. 2. Yields of different ions of Mg, Al, Si, P, S, Cl, and Ar produced in the $^{232}Th + {}^{40}Ar$ reaction at $E({}^{40}Ar) = 290$ MeV and $\theta = 40^{\circ}$. The yields were measured for the discrete energies of the reaction products: E (MeV) $= 41.75\ Z_i^2/A$.