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A.G.Artukh, V.V.Avdeichikov, G.F.Gridnev,
A.N.Mezentsev, V.L.Mikheev, V.V.Volkov

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A.G.Artukh, V.V.Avdeichikov,* G.F.Gridnev,
A.N.Mezentsev, V.L.Mikheev, V.V.Volkov

PRODUCTION OF ^{14}Be IN HEAVY ION REACTIONS

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* On leave from the V.G.Khlopin Radium Institute, Leningrad, U.S.S.R.

The possible nucleon stability of ^{14}Be was first indicated in ref. /1/ and based on the non-linear extrapolation of the binding energies of two neutrons, E_{2n}, for known isotopes with neutron number $N = 10$.

At attempt to produce ^{14}Be in multinucleon transfer reactions by bombarding ^{232}Th with ^{15}N ions has been made by the authors of ref. /2/. It was established that the logarithms of the differential cross sections $(d\sigma/d\Omega)_{40^\circ}$ for the production of the known C, B, Be and Li isotopes are proportional to the mass difference between the initial and final nuclei, Q_{gg}, i.e.,

$$\ln(d\sigma/d\Omega)_{40^\circ} = \text{const} \cdot Q_{gg} . \quad (1)$$

An analogous dependence was obtained in bombarding ^{232}Th and ^{197}Au with ^{16}O ions earlier /3/. For the system $^{232}Th + ^{15}N$, even weakly bound nuclei such as ^{14}B, ^{11}Be and ^{11}Li fit the Q_{gg} systematics of cross sections. This justified the use of this relation to estimate the yield of ^{14}Be. In ref. /2/ one succeeded in recording 20 000 ^{12}Be nuclei. If, in accordance with ref. /1/ E_{2n} for ^{14}Be were equal to 1.9 MeV, one could expect some 70 events of ^{14}Be detection, and about 30 events at $E_{2n} \sim 0.1$ MeV. In the experiments we recorded only three events which may be assigned to ^{14}Be. Since this effect was considerably weaker than that expected and was comparable with the background, this formed the basis for the conclusion drawn in ref. /2/ about the possible particle instability of ^{14}Be.

In 1973, the ^{14}Be production was observed in bombarding ^{238}U with 4.8 GeV protons by J.Bowman and collaborators /4/.

This year, we have reverted to experiments on the production of ^{14}Be in multinucleon transfer reactions with an increased sensitivity of the technique used. In particular, the addition of the time-of-flight technique to the combination of the magnetic analysis and $\Delta E, E$ technique used previously /5/ provided the possibility of reducing the background.

The experiments were carried out using the 310 cm heavy ion cyclotron of the JINR Laboratory of Nuclear Reactions. A metallic ^{232}Th target 20.3 mg/cm^2 thick was bombarded with 145 MeV ^{15}N ions. The reaction products emitted from the target at 40° passed through the magnetic spectrometer and were detected by a telescope of two silicon-surface-barrier detectors, a ΔE detector 40 μm thick and 27 mm in diameter, and a total absorption detector E. The two-dimensional $\Delta E, E$ spectrum was recorded by two 4096-channel analyzers operated in the regime of the $128(\Delta E)\times 64(E)$ channel. The main contributors to the background in the region where ^{14}Be was detected (the peak tails) were partucles with time-of-flight considerable shorter than that of ^{14}Be. In order to reduce this background, the electronic circuit permitted the recording of only those products whose time-of-flight exceeded a threshold of 130 ns.

The investigation of the time microstructure of the external beam from the 310 cm heavy ion cyclotron has shown that the fwhm of the burst duration was 2 ns., the interval between bursts being about 200 ns. The time-of-flight of reaction products from the target to the detector telescope was 50-150 nsec. This made it possible to use a definite phase of the high-frequency voltage on the dees as a starting time mark. The relationship between the time of the arrival of elastically scattered ions in the telescope and the high-frequency phase was regularly checked and established to be kept constant with an accuracy of 3% in prolonged measurements.

An analysis of the energy spectra of C, B and Be isotopes in bombarding ^{232}Th with ^{15}N ions has shown /2/ that they have similar shapes with the fwhm of about 20 MeV and regularly change in the positions of their maxima. The maximum yield of ^{14}Be is most likely to be expected at the same magnetic rigidity BR as that for ^{12}Be.

During the 40 hour measurements at BR = 10.50 kGm, which corresponds to the maximum ^{12}Be yield in working with a given target, 16 events of ^{14}Be production were recorded reliably. Figure 1 shows the yields of Be, Li and He isotopes in this bombardment. The number of the $E_0-\Delta E$ channel from the two-dimensional spectrum served as an identification parameter. The counting rate in each $E_0-\Delta E$ channel was equal to the sum of the counting rates in the ΔE channels, corresponding to the specific losses in energy of a given isotope with the ion charge equal to its atomic number. The dashed line shows the results of the calibration measurements without discriminating particles by their time-of-flight. Solid lines with shaded areas show the peaks obtained in the main measurements with time-of-flight discrimination. The ion flux in the main measurements by a factor of 30 exceeded that having passed through the target in the calibration measurements. It is seen from this figure that time-of-flight discrimination efficiently suppresses the detection of light products and, correspondingly, the background due to the "tails" of the amplitude spectra in the ΔE and E detectors.

The ^{15}N ion flux which passed through the target during the measurements corresponds to the production of 100 000 ^{12}Be nuclei passed through the detector telescope in the focal plane of the magnetic spectrometer. So, the ratio of the ^{12}Be yield to that of ^{14}Be is about 6000. This ratio corresponds to the upper limit on the ^{14}Be production cross section (3×10^{-5} mb/sr) established in ref. /2/. Thus, the particle stability of ^{14}Be, found in experiments with high energy protons /4/ has now been substantiated by our experiments using heavy ions. This leads to the question of the reasons why the production

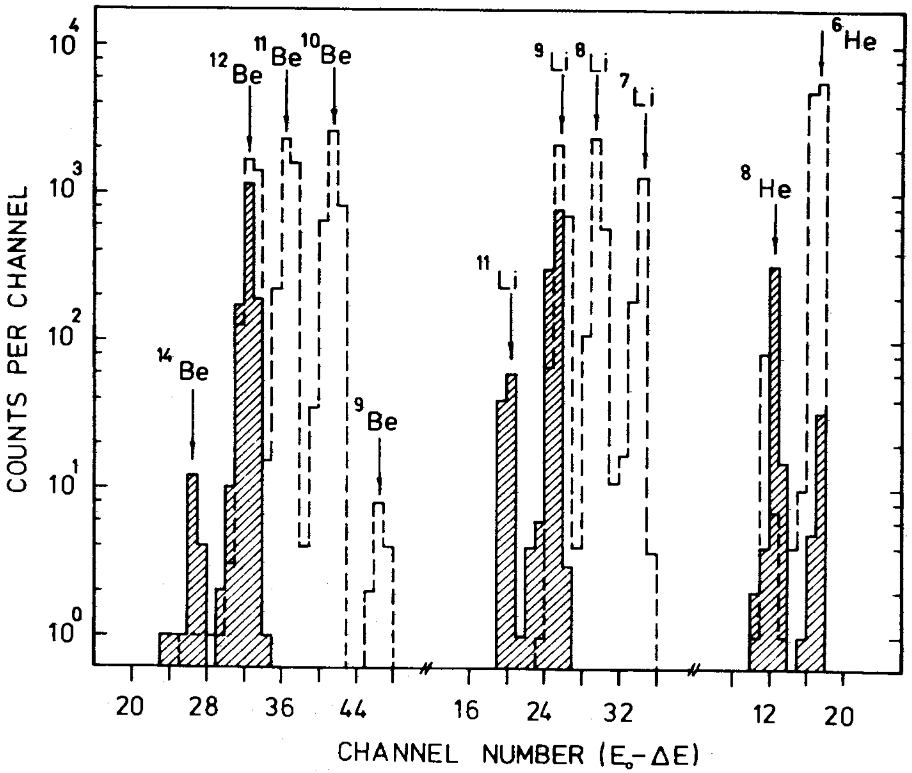

Fig. 1. The yields of Be, Li and He isotopes at the bombardment of ^{232}Th with 145 MeV ^{15}N ions, BR = = 10.50 kGm. The dashed line corresponds to calibration measurements without time-of-flight discrimination. Shaded peaks were obtained in the main measurements with time-of-flight discrimination. The ion flux passing through the target in the main measurements was 30 times as large as that in calibration measurements.

cross section for ^{14}Be disagrees with the Q_{gg} systematics following eq. (1). For the system ^{232}Th + ^{15}N, this systematics is presented in Fig. 2. In ref. /2/ the assumption about the applicability of the Q_{gg} systematics to the estimation of the production cross section for ^{14}Be was based on the fact that ^{11}Li well fitted the Q_{gg} systema-

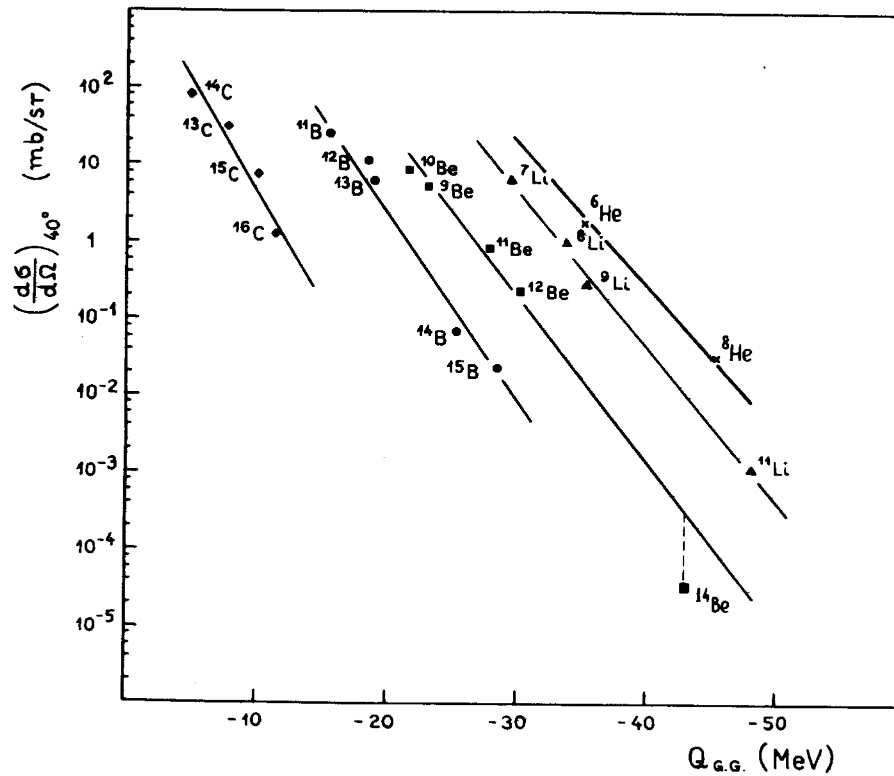

Fig. 2. The Q_{gg} systematics of cross sections of multinucleon transfer reactions for the system ^{232}Th + ^{15}N at the projectile energy of 145 MeV.

tics. As compared with ^{14}Be, ^{11}Li has a considerably larger value of Q_{gg}, a somewhat larger N/Z ratio and a yield close to that expected for ^{14}Be. The data from ref. /6/ indicate that E_{2n} is equal to 0.17 MeV and 0.41 MeV for ^{11}Li and ^{14}Be, respectively. This implies that dissociation processes are expected to manifest themselves on ^{14}Be less strongly than on ^{11}Li.

Apparently some features of transfer reaction mechanisms can manifest themselves in cross sections for the production of weakly bound nuclei. The isotope ^{11}Li is produced by the stripping of four protons from ^{15}N , while ^{14}Be is formed in the exchange reaction involving the stripping of three protons and pick-up of two neutrons. Since the isotope ^{13}Be is particle unstable, for the production of ^{14}Be, the heavy nucleus must transfer to the light one at once a neutron pair into the ^{14}Be state located below E_{2n} = 0.41 MeV. It is possible that this may lead to the deviation of the ^{14}Be production cross section from the Q_{gg} systematics.

The extensive data available on multinucleon transfer cross sections indicate that relation (1) is fulfilled for isotopic production cross sections most reliably in the case of nucleon stripping from a projectile [7]. This requirement has been met in experiments on the search for ^{10}He (ref. [8]) by bombarding ^{232}Th with ^{15}N ions, where ^{10}He might be produced as a result of the stripping of five protons from ^{15}N.

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