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A.G.Artukh, G.F.Gridnev, V.L.Mikheev,
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# NEW ISOTOPES $^{22}O$, $^{20}N$, $^{18}C$ PRODUCED IN TRANSFER REACTIONS WITH HEAVY IONS

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# NEW ISOTOPES $^{22}$O, $^{20}$N, $^{18}$C PRODUCED IN TRANSFER REACTIONS WITH HEAVY IONS

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For the first time the problem of the nuclear stability boundaries and existence of neutron-rich isotopes of light elements has been considered in detail by A.I.Bas, V.I.Goldansky ans Ya.B.Zeldovich/1/.

The $^{8}$He, $^{11}$Li, $^{12}$Be, $^{15}$B, $^{17}$C, $^{19}$N, $^{21}$O isotopes are the heaviest ones of all known at present. The $^{8}$He isotope has been produced by various methods including the experiments on spontaneous and induced nuclear fission. The remaining isotopes have been obtained in high energy proton experiments/2,3,4/.

The transfer reactions with heavy ions which give a variety of products/5/ have been used in our experiments to produce new neutron-rich isotopes.

In order to identify the reaction products a combination of the magnetic analysis and the $\Delta E \times E$ method was employed. Instead of one semiconductor detector as it has been done by Jacmart et al./6/ a telescope consisting of thin and thick semiconductor detectors was put into the focal plane of the magnetic analyzer.

The energy of particles hitting the given point of the focal plane of the magnetic analyzer is described by the expression

$$E = \frac{1}{2}(e\,B\,R)^2\;Z_i^{\,2}/m\;, \qquad (1)$$

where e is the electron charge, BR is the magnetic rigidity, $Z_i$ is the particle charge in units e , and m is the particle mass.

Since for particles having the atomic number $Z \geq 2$ some various charge states $Z_i$ are possible, then particle identification according to the $Z_i^2/m$ parameter is ambiguous. By putting the $\Delta E$ , E telescope instead of a single detector into the magnetic analyzer focus we have a possibility to eliminate this ambiguity, and at the same time to retain all the advantages of the magnetic analysis, in particular, the high isotope resolution.

The experiments were performed by using the external beam of the 310-cm heavy ion cyclotron at Dubna. Our magnetic analyzer with the homogeneous field and double focusing has the following parameters:

| | |
|---|---|
| bending radius is | 1.26 m |
| bending angle | 70° |
| $B_{max}$ | 18 kG |
| luminocity | $3.10^{-3}$ sr |
| momentum dispersion | 12.7 mm/1% |

momentum resolving power with the source 1 cm i.d. 0.3%.

A silicon detector used for measuring specific energy loss was 26.2 $\mu$m thick and 1 cm in diameter.

A target of metallic $^{232}$Th , 5 mg/cm$^2$ thick was bombarded by 122 MeV $^{18}$O ions about $10^{12}$ p/sec intensity. The reaction products were detected at an angle of 60° which corresponded to the scattering angle in the case of tangential nuclear collision.

Pulses from the $\Delta E$ and E detectors after being amplified were sent to the input of the multichannel amplitude analyzer operating in the 64x64 channel mode.

Two-dimensional amplitude spectra are descrete systems both on E and $\Delta E$ maxima lying at the hyperbolic curves. The curves can be described approximately by the equation $(\Delta E)^{1/2} \times E = \mathrm{const} \times BR. \times Z \times Z_i$ which is obtained from the known relation

$$\Delta E = \mathrm{const} \times m \times Z^2$$

when equation (1) is taken into account.

The $\Delta E$ and E detectors were energy-calibrated by elastically scattered ions. By using relation (1), and range-energy curves the energies released by the given isotopes in the $\Delta E$ and E detectors were found and the points on the $\Delta E$, E plane corresponding to the given isotopes were determined. As shown by the example of oxygen isotopes (Fig. 1), for each of the isotope there exists optimal magnetic rigidity with which the largest relative yield is observed.

The results obtained with the magnetic rigidity of 8.17 kG.m corresponding to the maximum yield of the heaviest isotopes are shown in Figs. 2 and 3. The channel number along the E axis for curves with $Z_i = Z$ in a two-dimensional spectrum is the identification parameter in Fig. 2. Each point is a sum of counts in the channels $\Delta E$ corresponding to specific energy loss for the given isotope. Along with the known isotopes some new ones have been obtained $^{22}O$ (about 100 events), $^{20}N$ (about 60 events) and $^{18}C$ (about 50 events).

Fig. 3 presents spectra from the $\Delta E$ detector which correspond to the cross sections of the two-dimensional spectrum along the $E$ axis in the maxima of new isotope yields. As is seen, the separation of new isotopes according to the $\Delta E$ parameter is also sufficiently reliable. It is worth noting that with the account of equation (1) for the isotopes of the given element $\Delta E \propto m^2$.

The quantities $\Delta E$, $E$ for $^{18}C_{+6}$, $^{20}N_{+7}$ and $^{22}O_{+8}$ differ by $\approx$ 5% from the corresponding values for $^{12}N_{+5}$, $^{14}O_{+6}$ and $^{17}F_{+7}$ ions at the same magnetic rigidity. Because of the insufficient number of channels of the analyzer (64x64) there was a possibility that the heaviest isotopes are partially imitated by those light ones, though the $^{13}N_{+5}$, $^{15}O_{+6}$ and $^{18}F_{+7}$ isotopes next to this were not observed.

As has been shown by our special experiments the yield of isotopes in the charge states $Z_1 = Z$ at initial energies about a hundred MeV is 50 times higher than in the states $Z_1 = Z-2$. The test runs with magnetic rigidities corresponding to the observation of totally ionized $^{12}N$, $^{14}O$, $^{17}F$ with the same initial energy as for $Z_1 = Z-2$ showed that these isotopes can produce not larger than 1% of the effect ascribed to new heavy isotopes.

When analyzing the obtained results it is of interest to note that along with neutron pick-up reaction by means of which heavy isotopes of oxygen were obtained, the exchange reactions of $(-xp, +yn)$ type were observed resulting in heavy isotopes of nitrogen and carbon.

The production of obtained isotopes due to the fission reaction is considered to be ruled out since the yield of light elements in fission is reduced with increasing their atomic number whereas in our experiments the reverse regularity is observed. The high energies (about 93 MeV for $^{22}O$) and relatively narrow energy spectrum (FWHM of about 8 MeV for $^{22}O$) are the evidence that the detected isotopes are the products of transfer reactions.

Since we do not know the excitation energies of final products of nuclear reactions and in the case of exchange reactions their detailed mechanism too, then for the values of the mass excess $M-A$ of new isotopes only the upper limits can be given. Hence, for $^{22}O$ $M-A < 20.5$ MeV in the $^{12}C$ scale. For the privilege of comparison by the calculation data/7/ $(M-A)^{22}O$ is $\approx$ 13 MeV.

Since the time-of-flight through the detection system is $\approx 10^{-7}$ sec our detection of new isotopes makes it possible to drew the conclusion on their nuclear stability.

The heaviest isotopes known before the present investigation have been obtained in our experiments in much larger quantities. Thus, about 1700 events of $^{21}O$, 1700 events of $^{19}N$ and 400 events of $^{17}C$ were detected. The results shown in Fig. 2 were obtained for 6 hours of measurements. This corresponds to the production cross section of $^{22}O$ equal to $5.10^{-30}$ cm$^2$/sr and of $^{21}O$ equal to $10^{-28}$ cm$^2$/sr. In experiments with high energy protons for tens of hours of measurements only tens of $^{21}O$, $^{19}N$, $^{17}C$ production events were detected, which corresponds to the cross section of about two orders of magnitude smaller than obtained by ourselves.

Thus, the production of neutron-rich nuclei in transfer reactions with heavy ions is rather promising.

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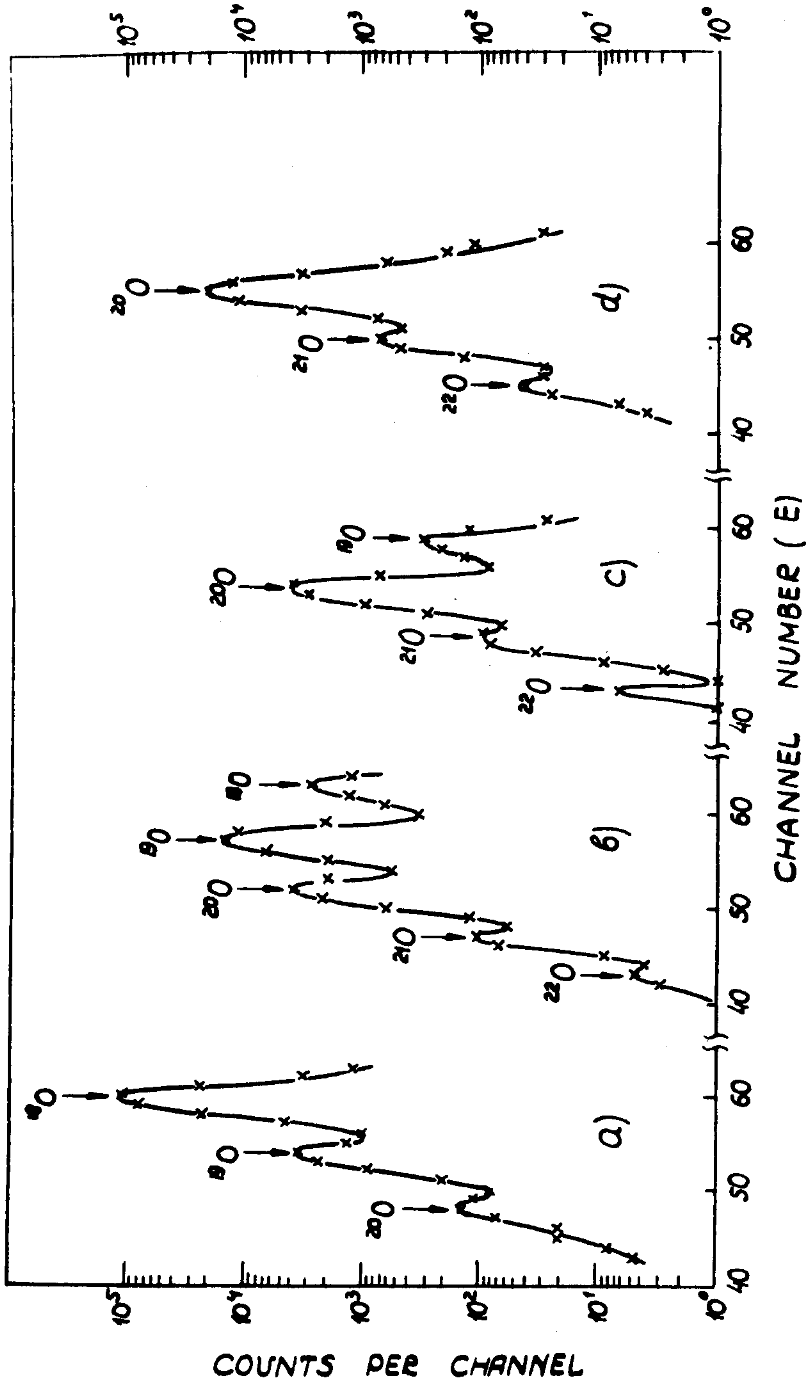

Fig. 1. Relative yield of oxygen isotopes vs magnetic rifidity in bombarding $^{232}Th$ by $^{18}O$

a) BR = 7.87 kG.m. The maximum of the a elastic peak, the ion flux through the target I = $2.3\times10^{14}$ particles;

b) BR = 8.03 kG.m I = $1.9\times10^{15}$ particles

c) BR = 8.10 kG.m I = $1.9\times10^{15}$ particles

d) BR = 8.17 kG.m I = $1.4\times10^{16}$ particles

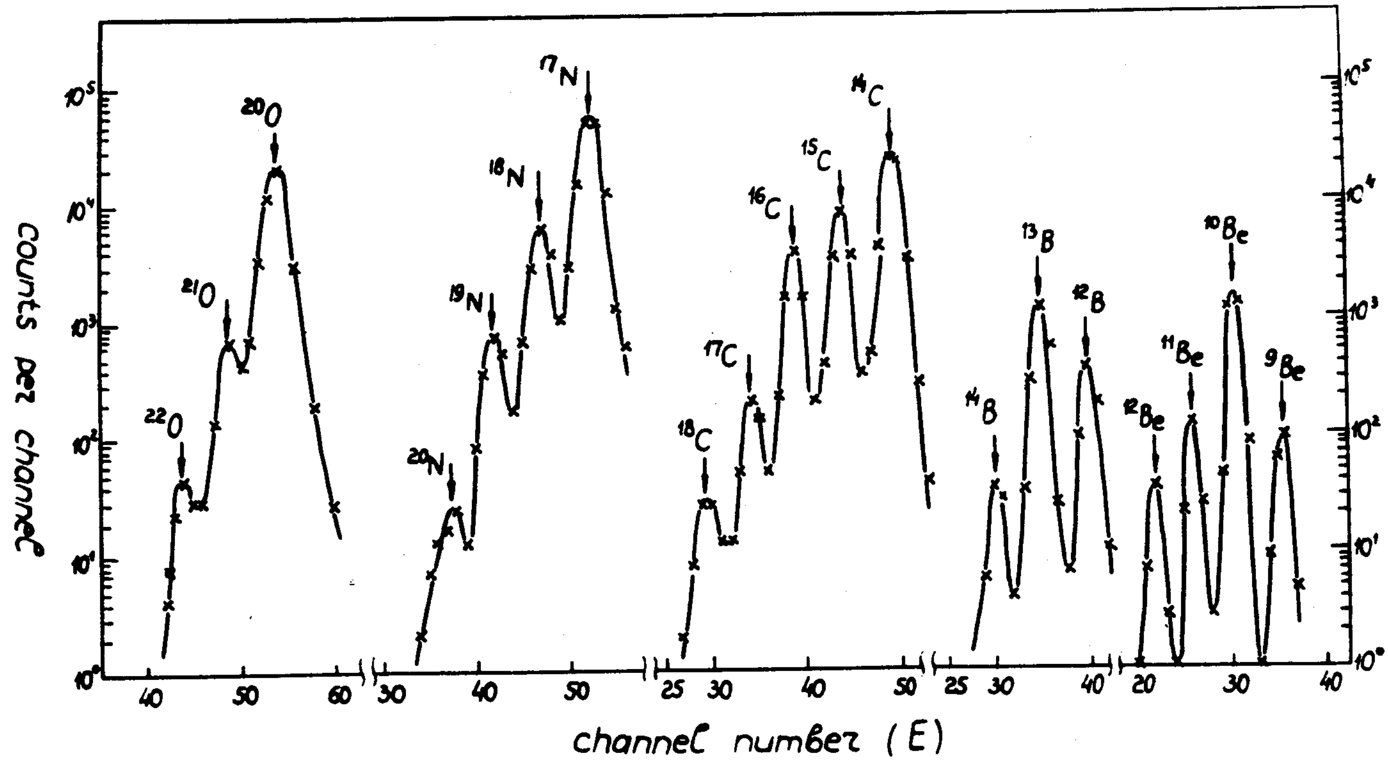

Fig. 2. Yields of oxygen, nitrogen, carbon, boron and beryllium isotopes in bombarding $^{232}$Th by $^{18}$O. The identification parameter is the channel number E from a two-dimensional spectrum for the curves $Z_1 = Z$.

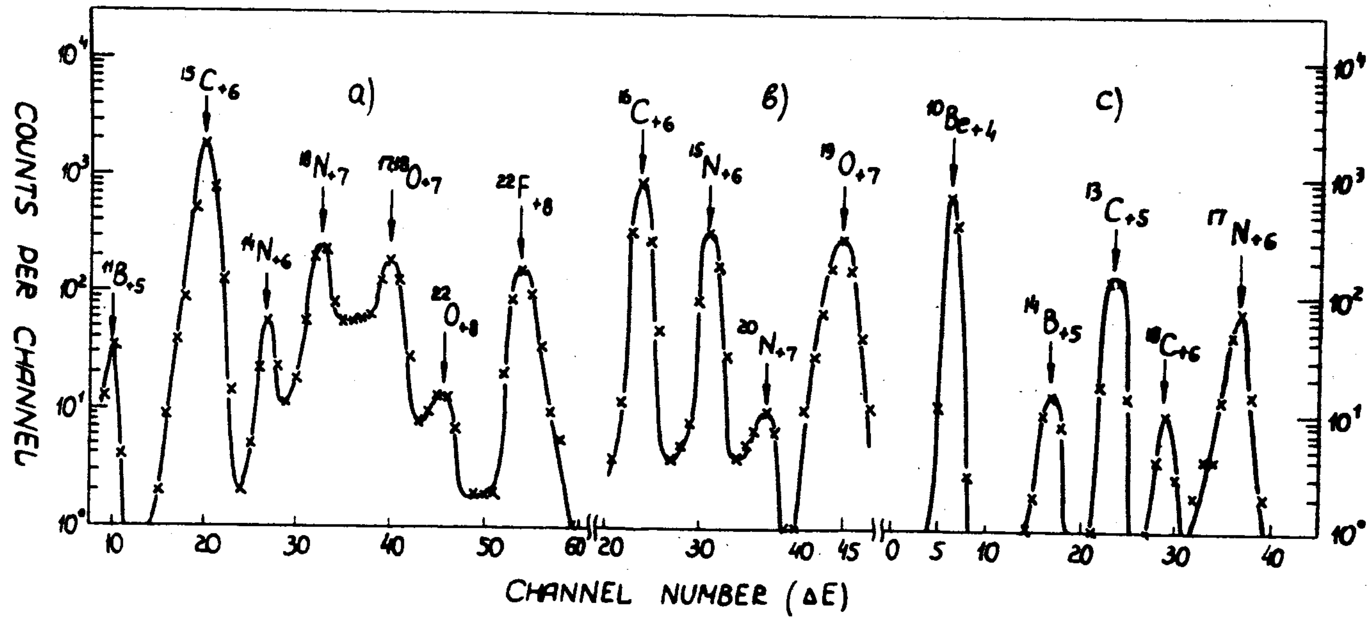

Fig. 3. Spectra from the ΔE detector which correspond to the cross sections of the two-dimensional spectrum along the axis in the maxima of new isotope yields.

a) $^{22}O_{+8}$ 45 channel E

b) $^{20}N_{+7}$ 38 channel E

c) $^{18}C_{+6}$ 30 channel E.