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FORWARD-ANGLE ISOTOPIC AND ELEMENT DISTRIBUTIONS INDUCED IN THE ^{18}O (35 · A MeV) + ^{9}Be REACTION

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The double achromatic, large solid angle, high momentum acceptance, and high-resolving separator COMBAS was created in the Flerov Laboratory of Nuclear Reactions, JINR. The layout of experimental setup (separator structure and detector arrangement) is presented. The forward-angle isotopic and element distributions induced in the ^{18}O (35 · A MeV) + ^{9}Be (14mg/cm^2) reaction were obtained and analyzed. The Q_{gg}-systematics, as a criterion for the binary production of isotopes, was used for isotopic yields description.

The double achromatic, large solid angle, high momentum acceptance, and high-resolving separator COMBAS was created [1] in the Flerov Laboratory of Nuclear Reactions, JINR. The fragment-separator will be used in two modes. The first one is a mode of a high-resolving spectrometer. This mode gives a possibility to study reaction mechanisms. The second one is a mode of an efficient in-flight separator. This mode will be used for synthesis and study of properties of short-lived exotic nuclei near the drip-lines. These nuclei will be produced in heavy ion collisions in tandem with cyclotron U-400M at an intermediate energy region. Many kinds of products from different reactions can be produced in the forward angle region, because the intermediate energy projectiles are used. The forward peaked angular distributions will be result of the quasi-elastic reactions, direct processes of nucleons transfer, peripheral dissipative processes, projectile-like and target-like fragmentation, and complete fusion reactions.

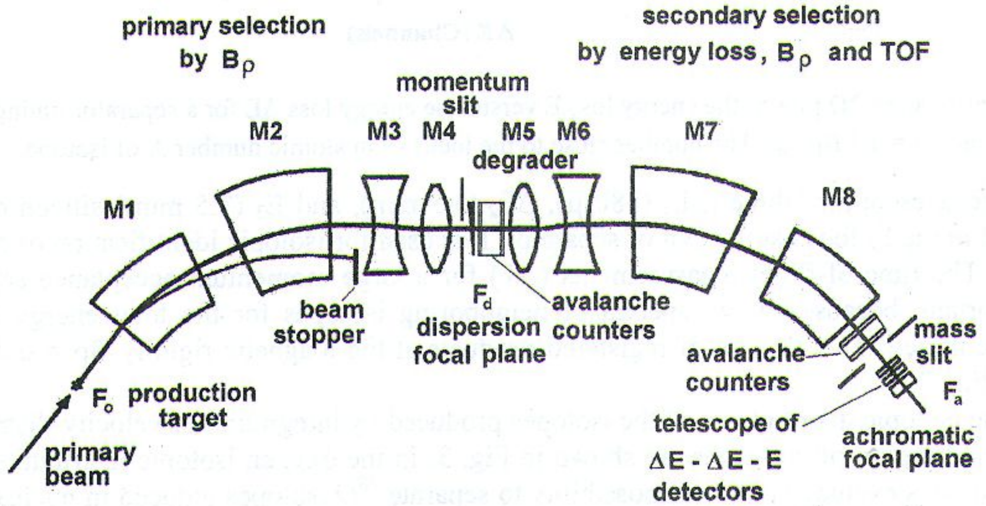

Fig. 1. Experimental layout of separator COMBAS.

The detecting system of experimental setup consists of detectors placed in dispersive (F_d) and achromatic (F_a) focuses (Fig. 1.). The pair of track 2-coordinate (x, y) avalanche counters is placed at the F_d plane and measured the (Δx, Δy) position of particle. Another pair of avalanche counters is placed in the F_a plane. The ΔE/Δx ionization stopping power of these detectors is used for identification of atomic number (Z) of particle. The Δt short timing signal is used for start-stop signals for TDC-converters, which measure the (ΔT) time-of-flight of each particle on a basis between F_d and F_a focal planes. So, these two pairs of (x, y) counters determine the (Δx_1, Δy_1, $\Delta E/\Delta x_1$, Δx_2, Δy_2, $\Delta E/\Delta x_2$, $\Delta\theta_{x1}$, $\Delta\varphi_{y1}$, and $\Delta\theta_{x2}$, $\Delta\varphi_{y2}$) parameters of detected particle. The Δx position together with corresponding them $B\rho$ magnetic rigidity values determine an energy spectrum of particles ($d^2\sigma/dEd\Omega$) and $\Delta\theta_{x1}$ (in F_d) determines an angular distribution of particles ($d\sigma/d\Omega$). A later determination of incoming particle angle is based on using the angular magnification in the F_d plane ($\Delta\theta_{Fd} \approx 2.8\cdot\Delta\theta_{Fo}$) of separator. It is important because of zero-angle installation of device is relative to the beam. It permits us to measure precise angular distributions of fragments in case of total rejection of an intensive primary beam. The $\Delta E/\Delta x$ parameter provides an accurate identification of the Z atomic number of product. An accuracy of $\Delta E/\Delta x$ measurements using the avalanche counter is better than 20 %.

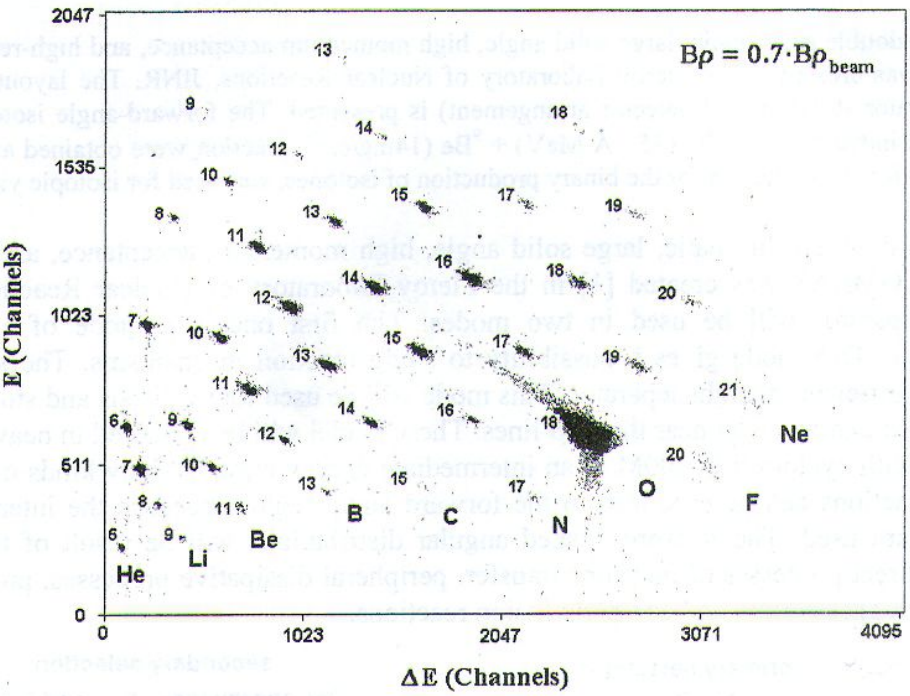

Fig. 2. Identification 2D plot of the energy loss E versus the energy loss ΔE for a separator tuning on rigidity at $B\rho = 0.7\cdot B\rho_{beam}$. The number close to the locus is an atomic number A of isotope.

The telescope of three (ΔE_1 (380 μ), ΔE_2 (3.5 mm), and E_3 (7.5 mm)) silicon detectors is positioned in the F_a focus at the exit of separator. It is used for isotopic identification of products by A and Z. The time-of-flight measurements (ΔT) for a large momentum acceptance separator are very important, because energy spectra of neighboring isotopes for the total energy acceptance (40 %) are mixed. The 2D plot of registered products at the magnetic rigidity $B\rho = 0.7\cdot B\rho_{beam}$ is shown in Fig. 2.

The isotopic distributions of the isotopes produced by integration of velocity-distributions in the measured region of velocities are shown in Fig. 3. In the oxygen isotopic distribution the yield of ^{18}O isotope is excluded due to impossibility to separate ^{18}O isotopes induced in nuclear reactions from the primary beam particles. Isotopic distributions for all elements have bell-like shapes except distributions of *He* isotopes. The most intensive yields correspond to the masses of stabile isotopes. The light isotope side of distribution increases depends on decrease of a number of stripped protons. The isotopic distribution of *He* (element with a maximum number of stripping protons) decreases exponential. Accumulation of the lightest proton rich isotopes for each element, especially for the lightest elements, is affected by contributions of evaporative lightest particles. It is correlates with the yields, which increase the low-energy part of velocity distributions of these isotopes.

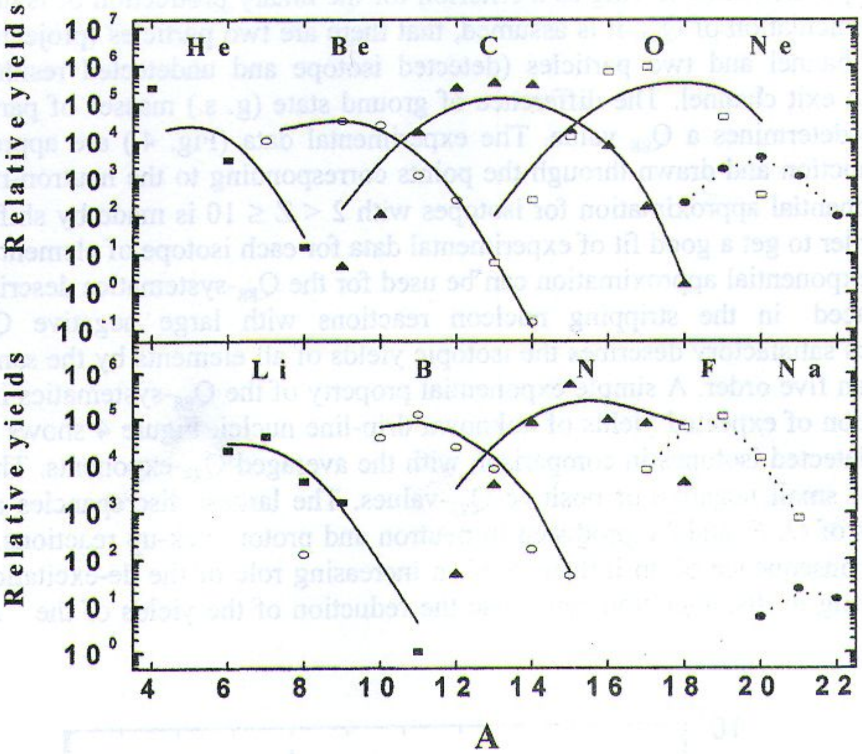

Fig. 3. Measured relative isotopic yields versus the mass number A of products. The ^{18}O isotope yield is excluded because of too high relative intensity. The solid lines present intensities of isotopes simulated using program LISE [2]. The dotted lines for the *F*, *Ne*, and *Na* isotopic distributions induced in the proton pick-up reactions are drawn by hand through the experimental points.

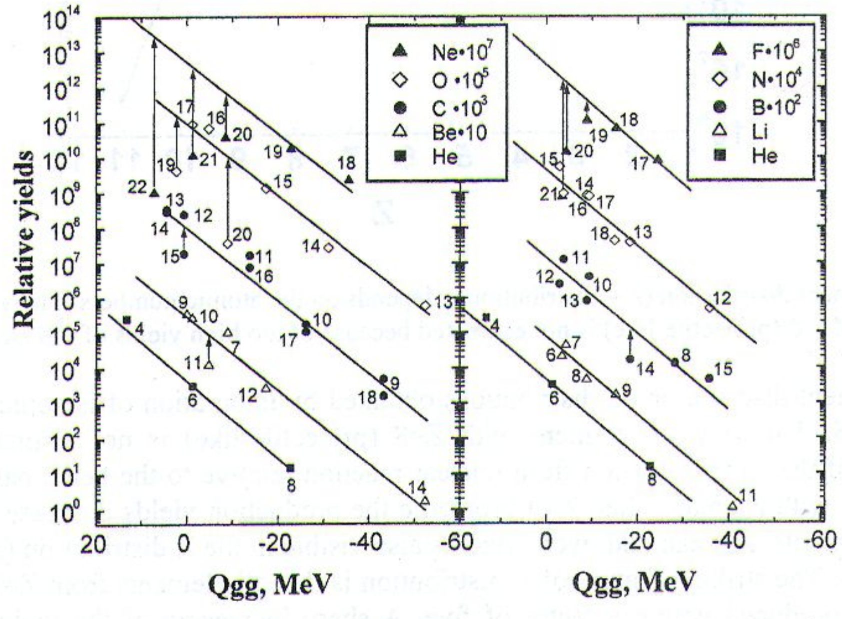

Fig. 4. Measured relative isotopic yields of elements with $2 \le Z \le 10$ depend on the Q_{gg}-values (the Q_{gg}-systematics). The value Q_{gg} is calculated by formula $(M_p + M_t) - (M_{det} + M_{undet})$, where M_p, M_t, M_{det}, and M_{undet} are the ground state masses of projectile, target, detected isotope, and undetected isotope (the partner of detected isotope in the exit channel of reaction) accordingly. The arrows for the isotopes *O*, *F* and *Ne* show a decrease in the yields of isotopes, as a possible consequence of an influence of de-excitation effects. The numbers near isotopes (in frames) show the scale factors of the experimental yields.

The Q_{gg}-systematics serving as a criterion for the binary production of isotopes is shown in Fig. 4. In the calculation of Q_{gg}, it is assumed, that there are two particles (projectile and target) in the entrance channel and two particles (detected isotope and undetected residue of composite systems) in the exit channel. The difference of ground state (g. s.) masses of partners before and after collision determines a Q_{gg} value. The experimental data (Fig. 4.) are approximated by the exponential function and drawn through the points corresponding to the neutron-rich isotopes ^{6}He and ^{8}He. Exponential approximation for isotopes with $2 < Z \leq 10$ is made by shifting of the same exponent in order to get a good fit of experimental data for each isotope of element. Figure 1 shows that a simple exponential approximation can be used for the Q_{gg}-systematics description of isotopic yields, produced in the stripping nucleon reactions with large negative Q_{gg} values. The Q_{gg}-systematics satisfactory describes the isotopic yields of all elements by the same exponent in a range more than five order. A simple exponential property of the Q_{gg}-systematics is very important for the prediction of expected yields of unknown drip-line nuclei. Figure 4 shows the decreases of the yields of detected isotopes in comparison with the averaged Q_{gg}-exponents. They are observed in the range of small negative or positive Q_{gg}-values. The largest discrepancies are observed for heavy isotopes of *O*, *F*, and *Ne* produced in neutron and proton pick-up reactions. The mentioned decrease is a consequence of an influence of an increasing role of the de-excitation effects. Their structure favoring to disintegration can cause the reduction of the yields of the ^{11}Be, ^{14}B, and ^{15}C isotopes.

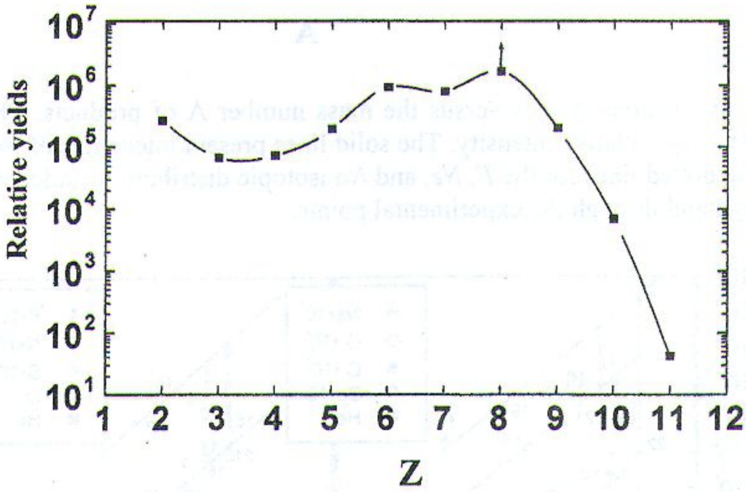

Fig. 5. The element distribution (Z – distributions) depends on the atomic numbers. The yield of element with Z = 8 (projectile-like) is not estimated because of too high yields of ^{18}O isotope.

The element distribution (Z-distribution) obtained by integration of isotopic distributions is shown in Fig. 5. The yield of element with Z=8 (projectile-like) is not estimated because of unknown yield of the ^{18}O production from nuclear reaction relative to the beam particles intensity. For the products with Z greater than Z of projectile the production yields decrease with increasing of Z value of products. A weak odd-even effect is also visible in the Z-distribution (an enhancement effect of carbon). The striking feature of Z-distribution is that all elements from Z=2 up to Z=7 are relatively equal produced within a factor of five. A sharp increasing of the yield of the lightest element with Z=2 is observed.

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ІЗОТОПНІ ТА ЕЛЕМЕНТНІ РОЗПОДІЛИ, ОТРИМАНІ В РЕАКЦІЇ ^{18}O (35 · A MeB) + ^{9}Be ПІД ПЕРЕДНІМИ КУТАМИ

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У Лабораторії ядерних реакцій ім. Г.Н. Флерова (ОІЯД) запущено в експлуатацію двічі ахроматичний, широкозахватний, високороздільний сепаратор КОМБАС. Представлено структуру експериментальної установки (структура сепаратора й розташування детектуючої системи). Було виміряно й проаналізовано ізотопні та елементні розподіли, отримані в реакції ^{18}O (35 · A MeB) + ^{9}Be (14 мг/см^2) під передніми кутами. Для опису закономірностей виходів ізотопів використано Qgg-систематику як критерій бінарної реакції утворення ізотопів.

ИЗОТОПНЫЕ И ЭЛЕМЕНТНЫЕ РАСПРЕДЕЛЕНИЯ, ПОЛУЧЕННЫЕ В РЕАКЦИИ ^{18}O(35 · A МэВ) + ^{9}Be ПОД ПЕРЕДНИМИ УГЛАМИ

А. Г. Артюх, Г. Ф. Гриднев, А. Г. Семченков, М. Грушецкий, Ф. Косцельняк, О. В. Семченкова, Ю. М. Середа, Я. Шмидер, Ю. Г. Тетерев, И. Н. Вишневский

В Лаборатории ядерных реакций им. Г.Н. Флерова (ОИЯИ) запущен в эксплуатацию дважды ахроматический, широкозахватный, высокоразрешающий сепаратор КОМБАС. Представлена структура экспериментальной установки (структура сепаратора и расположение детектирующей системы). Были измерены и проанализированы изотопные и элементные распределения, полученные в реакции ^{18}O (35 · A МэВ) + ^{9}Be (14 мг/см^2) под передними углами. Для описания закономерностей выходов изотопов использована Q_{gg}-систематика как критерий бинарной реакции образования изотопов.