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V.V.Volkov, G.F.Gridnev, G.N.Zorin,
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NUCLEON AND NUCLEON GROUP TRANSFER REACTIONS INDUCED IN THE BOMBARDMENT OF ^{197}Au AND ^{232}Th BY ^{12}C, ^{14}N, ^{15}N PROJECTILES

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I. Introduction

The experimental investigations and theoretical analysis show that in the grazing collision of a heavy ion with a nucleus direct reactions with a single or few-nucleon transfer occur x). The study of these reactions may give valuable information on the nucleus surface structure, in particular, on the possible formation of alpha-particle clusters on the heavy nuclei surface /9,10/. The experiments on light nuclei with a strong alpha-clustering observed have indicated that the cross section of the ^4He pick-up by heavy ions is of significant value, exceeding that of the proton and neutron pick-up /11-15/. The ^4He pick-up experiments on heavy ions have not been performed.

The main task of the present work has been the investigation of the ^4He pick-up reactions on heavy nuclei. The experimens have been performed with the external beam of the 150 cm Heavy Ion Cyclotron of the Nuclear Reactions Laboratory. The

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x) See experimental and theoretical reviews in refs. /1-8/.

^{232}Th and ^{197}Au targets were bombarded by ^{12}C , ^{14}N , ^{15}N ions. The dE/dx·E method has been used to detect reaction products. Since this method permits to observe simultaneously many direct reaction channels, the data on ^{3}He , ^{4}He stripping and on the one proton, one neutron, and deuteron transfer have been also obtained.

2. Experimental Procedure

The experimental scheme is shown in fig.1. The collimated ion beam bombarded the thin metal target located in the centre of the scattering chamber. Light products of direct reactions having a long range, passed through the scattering chamber window protected by a thin mylar foil and then were detected by the telescope consisting of an ionization chamber and a semiconductor detector. The telescope was placed on the goniometrical circle outside the scattering chamber. One can find the more detailed description of the scattering chamber in ref./16/.

The two-plate ionization chamber was used in which detected particles passed through both electrodes (1.5 μm Al foil). The electrodes were fixed on the metal discs at the interval of 15 mm between them. The inlet and outlet openings of the ionization chamber were 8 mm and 12 mm in diameter, respectively. The chamber was filled with the 90% argon and 10% methan mixture up to 1 atm. Taking into account a considerable increase in a specific ionization in the case of ^{4}He pick-up we confined ourselves to the resolution of the ionization chamber to about 8%. The construction of the ionization chamber provided a high geometry efficiency of $4.3 \cdot 10^{-3}$ steradian. This was very essential as the preliminary experiments on the ^{232}Th(^{14}N,^{18}F) reaction with the radioactive ^{18}F detection indicated that the cross section of the ^{4}He pick-up on heavy nuclei was very small. The pulses from the ionization chamber and the semiconductor detector after amplification went to the 4096 channel analyser which worked in the two-dimensional regime. The specific ionization axis dE/dX and the energy axis E had scanning on 64 channels. Each isotope and, consequently, each reaction channel has a corresponding hyperbola on the plane with axes dE/dX and E. The main difficulty an experimentator encounters working by $dE/dx \cdot E$ method is a high intensity of elastically scatterred ions, especially at small angles. The difficulty increases with Z of the nucleus target. Due to this reason we limited our measurements to the minimal angle of 30°. It should be noted, however, that this limit turned out to be insufficient in our experiments.

The data obtained were treated with a computer according to the programme developed by one of the authors (G.N.Zorin) and then were plotted as hyperbolas on the plane with axes $dE/dx; E$. Isotopes were identified by comparing the theoretical and experimental hyperbolas. Elastic and inelastic scattering ions and ^{9}Be were used as reference marks. Scattered ions were easily identified by their high intensity, ^{9}Be identification was simplified by the ^{8}Be non-stability (it decayed on its way to the detector). In the case of necessity the additional analysis of the shape of a hyperbola, the specific ionization distribution in hyperbola and the Q reaction was performed. The absolute values of the differential cross sections were determined by normalizing to the elastic scattering cross section/17-21/.

3. Experimental Results

The measurements for the following target-particle combinations were performed: $^{197}Au + {}^{12}C$; $^{232}Th + {}^{12}C$; $^{197}Au + {}^{14}N$; $^{232}Th + {}^{14}N$; $^{232}Th + {}^{15}N$.

The ion energies in the laboratory system were equal to 82 MeV for ^{12}C , 110 MeV for ^{14}N and 98.5 MeV for ^{15}N . The measurements were performed within the angular range 30-130°, on the average in 10°. The 1.5 mg/cm^2 and 2.7 mg/cm^2 targets for gold and 1.5 mg/cm^2 one for thorium were used.

The spectra of direct reaction products displayed on the multi-channel analyser oscilloscope screen during the measurements or on the $dE/dx;E$ plane after the treatment of the results with a computer indicated that direct nuclear reactions with the transfer of nucleons towards the nucleus target as well as towards the impinging nucleus for all target-particle combinations take place. In what follows the reactions of the first type are called stripping reactions and of the second one are called the pick-up reactions, according to the therminology used for lighter projectiles. The terms "nucleus-donor" and "nucleus-receptor" are used to design nuclei giving or capturing nucleons in the reactions.

The first general conclusion one could draw from the review of experimental data is that the variety of reactions and the values of cross sections in stripping reactions turned out to be larger than those in the pick-up reactions. In the stripping reactions, a considerable yield of elements lighter than the impinging nucleus including ^4He , has been observed. On the contrary, only the element neighbouring the impinging nucleus could be reliably identified in the pick-up reactions. The second general conclusion is related to the stripping reaction cross sections, which decrease with Z and A of reaction products, excluding ^{4}He , for which a sharp increase of the cross section was observed.

3.1. ^{4}He Pick-Up

On the $dE/dx, E$ plane in the region where the hyperbolas corresponding to the ^{4}He pick-up were assumed to be only a few pulses were detected. Due to a small yield no information about the angular distribution and the energy spectrum of the reaction were obtained. Only the upper limit of the total cross section was determined (see Table 1.).

3.2. Single Nucleon Transfer

a) Transfer of One Proton

The transfer of one proton has been estimated in the stripping reactions $^{197}Au(^{12}C, {}^{11}B)^{198}Hg$, $^{232}Th(^{12}C, {}^{11}B)^{233}Pa$ and in the pick-up reaction $^{232}Th(^{15}N, {}^{16}O)^{231}Ac$. Fig.2 shows the angular distributions for the former two reactions. The ^{11}B energy spectra measured at the angles corresponding to differential cross section maxima are shown in fig.5. The arrows above the scale indicate the ^{11}B energy for the final nuclei in ground states. In the $^{232}Th(^{15}N, {}^{16}O)$ reaction the proton pick-up occurs mainly into the ground state. The pick-up of the proton in the $(^{12}C, {}^{13}N)$ and $(^{14}N, {}^{15}O)$ reactions were not detected due to the small cross section. The total cross sections of the reactions are seen in Table 1. They have been calculated by integration differential cross sections. The values of $d\sigma/d\theta$ for the angles less than 30° is assumed to vanish gradually to zero. This conclusion follows from refs./15,16, 26/.

b) Transfer of One Neutron

The identification of one neutron transfer at small angles is a difficult task due to a high intensity of elastic scattering particles, therefore we have measured the differential cross sections and the energy spectra only for the angles corresponding to the cross section maxima. Fig.4 represents energy spectra for the neutron pick-up reactions: $^{232}Th(^{12}C,^{13}C)$; $^{232}Th(^{14}N,^{15}N)$; $^{197}Au(^{14}N,^{15}N)$; $^{232}Th(^{15}N,^{16}N)$ and for the one neutron stripping reaction $^{232}Th(^{15}N,^{14}N)$ The schemes of the final nuclei-receptor levels are placed above the spectra for the pick-up.

We considered it useful to estimate in some cases also the total cross sections of the one neutron transfer. For this purpose the ratio of the full cross section to the differential cross section in the maximum based on the data of refs. /16,23/ was found. These data were used to calculate the cross sections of the one neutron transfer in our case (see Table 1).

3.3 Transfer of a Few Nucleons

a) The Deuteron Transfer

The deuteron transfer was identified in the pick-up reactions $^{197}Au(^{14}N,^{16}O)$; $^{197}Au(^{12}C,^{14}N)$; $^{232}Th(^{12}C,^{14}N)$ as well as in the stripping one $^{197}Au(^{14}N,^{12}C)$. The angular distributions and energy spectra were measured for $(^{14}N,^{16}O)$ and $(^{14}N,^{12}C)$ reactions. The data are shown in figs. 3,6. As for the reaction $(^{12}C,^{14}N)$ the yield was so small that the detailed characteristics were not obtained; Table 1 presents only the total cross sections. Due to the same reason we have not detected the deuteron pick-up in the reaction $(^{15}N,^{17}O)$.

Above the energy spectrum ^{16}O from the reaction $^{197}Au(^{14}N,^{16}O)$ there is the level scheme for the final nucleus-receptor. The insufficient apparatus resolution does not allow to identify the transition to separate levels, nevertheless, the spectrum shape indicates that the deuteron pick-up occurs chiefly on the excited levels of the final nucleus ^{16}O . The deuteron stripping reaction (^{14}N, ^{12}C) is accompanied by the high excitation of the final nuclei; the spectrum maximum corresponds to the 21 MeV excitation energy.

b) ^{3}He, ^{4}He Transfers

The ^{3}He and ^{4}He transfers were observed only in the stripping reactions: $^{197}Au(^{12}C,^{9}Be)$; $^{232}Th(^{12}C,^{9}Be)$; $^{197}Au(^{14}N,^{10}B)$. The angular distributions of the reactions are seen in figs. 2 and 3, the energy spectra are presented in figs. 5 and 6.

The final nucleus ^{9}Be from the reaction (^{12}C, ^{9}Be) has no bound excited levels, therefore its energy spectrum reflects directly the spectrum excitations of the nucleus-receptor . The arrows show the ^{9}Be energy corresponding to the ^{3}He transfer to the ground state of the nucleus-target. The transfer of ^{3}He to the states of high excitation energy is noteworthy (14 MeV for ^{197}Au and 13 MeV for ^{232}Th) . At the ^{4}He transfer the excitation energy reaches 28 MeV, though the ^{10}B nucleus might be excited in this case. The total cross sections of the ^{3}He and ^{4}He stripping are given in Table 1.

The inaccuracy in determining the peak position in angular distributions is of 2-3^{o}. The dead time of the analyser causes the main error in measuring the effective cross sections (the average rate being about 2000 pulses per sec.). However, we managed to exclude this factor by normalizing the yield to the elastic scattering cross section. According to our estimates, the error in measuring the absolute cross section in the case of the reliable isotope identification does not exceed 20-25%. In the case of the neutron transfer reaction it increases to 30%. In energy spectra the error by estimating the excitation energy does not exceed 1 MeV, while the energy distribution widths being obtained with a 0.5 MeV accuracy.

4. Discussion of Results

4.1 ^{4}He Pick-Up

The main experimental result obtained by the ^{4}He pick-up investigations is the small value of the reaction cross section. As is seen from Table 1, the cross section of the reaction ^{197}Au(^{14}N,^{18}F) does not exceed 8μ b, that of the reaction (^{12}C, ^{16}O) on ^{232}Th and ^{197}Au being smaller than 1 μ b. At the same time the cross section of the alpha pick-up on light nuclei reaches tens of milli - barn [11-13], despite the less favourable Q of the reaction.

In order to explain the small value of the α pick-up cross section on heavy nuclei two assumptions might be made. It is possible, that the reduced α-particle widhts in heavy nuclei are small since the neutrons and protons populate different nuclear shells. In this case the assumption about the significant α-clustering on the heavy nuclei surface [9,10] must be rejected. The α-pick-up cross section decreases sharply if the ^{4}He pick-up occurs to the unbound excited states of the final nucleus-receptor. Such final nuclei will decay on their way to the detector and our attempts to detect the α-particle pick-up will be a failure. As is seen from the energy spectra in fig.5 and 6 the ^{3}He and ^{4}He transfer in the stripping reactions occurs to the levels with the excitation considerably exceeding the binding energy of ^{4}He in the ^{18}F and in ^{16}O nuclei. It should be noted that by bombarding ^{181}Ta with ^{20}Ne ions with an energy 8 MeV per nucleon the cross section of the ^{4}He stripping from ^{181}Ta nucleus reached 10^{-27} cm^{2} /24/. Both factors mentioned seem to have an effect on the value of the α - pick-up cross section and some more experiments are needed to clarify the role of each one.

4.2. Transfer of One Nucleon

a) Neutron Transfer

In the one neutron transfer reaction the energy spectra are of particular interest since they permit to obtain additional information on the reaction mechanism. As is seen from fig.4, in the neutron pick-up a certain accordance of the energy spectrum to the bound levels positions of the nucleus-receptor can be observed. Three bound levels with an energy equal to 3.09, 3.68 and 3.85 MeV are in the ^{13}C nucleus besides the ground state. There are two maxima in the energy spectrum of the reaction ^{232}Th(^{12}C,^{13}C)^{231}Th: the first corresponds to the neutron pick-up into the ground state and the second one to the group of the bound excited levels. The similar situation can be seen in the reaction ^{232}Th(^{15}N,^{16}N)^{231}Th. The final nucleus ^{16}N has three bound levels located very close to the ground state; the excitation energy of the highest level being 332 keV. The energy spectrum of the reaction shows the transfer of one neutron to this level group. Unfortunately, the insufficient resolution does not permit to identify in both cases transfers to separate levels of the group. Nevertheless, by basing on the mutual position of the energy spectra and level schemes of receptor nuclei one can draw a significant conclusion that the neutron transfer from the heavy nucleus is not accompanied by the noticeable excitation of the donor nucleus, that means that the most weakly bound neutrons are transferred. This conclusion is confirmed when comparing the energy spectra of the reactions: $^{197}Au(^{14}N, ^{15}N)^{196}Au$ and $^{232}Th(^{14}N, ^{15}N)^{231}Th$. The nuclei-targets in these reaction differ strongly in the shape (^{197}Au is an almost spherical nucleus and ^{232}Th –a strongly deformed one) as well as in the level density and their position. However, the spectra in the both reactions are practically similar and correspond to the transfer of the neutron to the bound excited levels of the final nucleus-receptor ^{15}N.

When comparing the energy spectra obtained in the neutron stripping reaction, one can see their considerable difference from those of the neutron pick-up /23/. There is practically no transfer to the ground state in stripping, the distribution width reaches 5 MeV, and transfers are observed with a 20 MeV excitation energy of the final nucleus. This difference might be explained in the following way. In the pick-up reaction the most weakly bound nucleons are transferred from the nucleus-target to the impinging nucleus. Only the transfers, when the nucleon is captured to the bound levels of the final nucleus, are detected in the experiment. If there are only a few levels, as it is in the case of ^{13}C and ^{16}N, the energy spectrum shape corresponds to the bound level position.

In the stripping reactions the transfer not only to the bound states of the nucleus-target, but also to the unbound states (including states belonging to the continuous spectrum) are detected. In this case the spectrum shape is determined by the two factors competition. The level density increasing with the excitation energy and the length of the exponential "tails" of the wave functions will promote the nucleon transfer to the high excited levels of the nucleus-receptor. On the contrary, Q of the reaction decreasing with the increase of the excitation energy will act in the opposite direction.

b) Proton Transfer

At present, comparatively few works on the proton transfer are known. One concludes from them that the mechanisms of the proton and neutron transfers are similar in general and might be with good approximation described as quasielastic scattering with one nucleon transfer. In ref./25/ the evidence of the charge independence of transfer reactions on light nuclei has been obtained. Simultaneously, a great effect of the Coulomb field of the nucleus-target on the cross section of the proton pick-up reaction $(^{12}C, ^{13}N)$ has been observed/15/. Therefore a more detailed comparison of the proton and neutron transfer reactions on heavy nuclei is of interest.

The angular distributions of the proton transfer reaction $(^{12}C, ^{11}B)$ obtained in our experiment have a maximum typical for the one nucleon transfer. The maxima position corresponds to the grazing collision of two nuclei. Making use of the theoretical models, the characteristic of the reaction region may be obtained in the form of the distribution of amplitudes and phases of partial waves or with the use of classical parameters: the radius of interaction R and the reaction region width d. The results of our data analysis within the framework of Frahn-Wenter/22/ and Strutinsky/26/ models are given in Table 2. including MacIntire et al.'s data on the neutron stripping reaction $^{197}Au(^{14}N, ^{13}N)\,^{198}Au$ 28). The data are given for the energy, when the ^{14}N ion at the moment of its collision with the Au nucleus has velocity equal to that of the ^{12}C ion in our case. It is seen from Table 2 that the value r_0 for both reactions is practically the same. That means that the proton and neutron stripping occurs most probably at the same distance of the closest approach of interacting nuclei. However, the widths of the reaction regions are notably different, that for the proton pick-up being narrower. This difference is due to the large proton binding energy in the ^{12}C (16 MeV) as compared to that of a neutron in the ^{14}N (10.6 MeV). Since the one nucleon transfer occurs at the peripheral collisions, the radial parts of the nucleon wave functions of the initial and the final states may be presented in the form of exponentials. The higher binding energy of a nucleon corresponds to the shorter exponential "tail" and more narrow reaction region/26/.

A definite conclusion about the mechanism of the reaction (^{12}C, ^{11}B) can be drawn from the ^{11}B energy spectra. The ^{11}B may be produced, in principal, in two ways: due to the transfer of one proton to the nucleus-target or as a result of dissociation of the impinging ^{12}C nucleus to ^{11}B and a proton with the latter emitted as a free particle. It follows from the energy spectrum of the reaction (^{12}C, ^{11}B) that the overwhelming majority of ^{11}B nuclei is produced in the proton transfer reaction, since there is an energy lack for free proton emission.

The energy spectra in the proton stripping reaction (^{12}C,^{11}B) turned out to be very similar to those of the neutron stripping reaction (^{14}N,^{13}N)28). Since the ^{13}N nucleus has no bound excited states, its energy spectrum shows the excitation of the ^{198}Au nucleus-receptor. The similarity of the proton and neutron stripping energy spectra allows to make two assumptions concerning the mechanism of the transfer of one nucleon:

a) the majority of neutrons in the stripping reaction ^{197}Au(^{14}N, ^{13}N) is also captured by the nucleus-target. One cannot make this conclusion directly from the ^{13}N energy spectrum, since unlike a free proton the neutron does not "carries away" the energy equal to the Coulomb barrier height.

b) the ^{11}B spectrum reflects, mainly, the excitation spectrum of the final nucleus-receptor.

The comparison of the proton and neutron stripping cross sections is of particular interest for the reactions with final nuclei of similar level structure (^{12}C, ^{11}B); (^{12}C, ^{11}C) . Unfortunately, the elastic scattering makes it extremely difficult to detect ^{11}C for all angles. We managed to compare the cross sections of both reactions only for the angle corresponding to the maximum of the angular distribution of the reaction (^{12}C, ^{11}C) . The cross section of the proton stripping turned out to be by a factor of 20 larger than that of neutron stripping. The result obtained seems to be surprising, since the binding energies of the proton and the neutron are similar: 15.9 MeV and 18.7 MeV, respectively.

The stripping reactions with the transfer of one proton or one neutron from the light to heavy nucleus were discussed above. Let us consider the reactions where the transfer occurs in the opposite direction, i.e. the pick-up reactions. A sharp asymmetry takes place in (^{12}C, ^{13}N) and (^{12}C, ^{13}C) reactions: the cross section of the proton pick-up appeared to be some orders of magnitude smaller than that of the neutron pick-up, despite the similar level structure of the final nuclei ^{13}N and ^{13}C. We could not discriminate between the proton and deuteron pick-up. But even in the comparison of the neutron pick-up cross section with the summed one proton and deuteron pick-up the difference exceeds 3 orders of magnitude. For the first time the effect of cross section decreasing in the reaction (^{12}C, ^{13}N) with the increase of Z of the nucleus-target has been observed in ref. /15/. The authors assumed that it was due to the influence of the Coulomb field of the nucleus-target deforming the wave function of the weakly bound proton in the ^{13}N nucleus (the binding energy is 1.9 MeV). Ref. /15/ deals with the proton transfer reaction only, whereas the present paper contains the information concerning both channels of the reaction. Following the assumption in ref. /15/ one can expect that the deformation of the proton wave function and, subsequently, the decrease of the cross section in the proton pick-up, would depend upon the proton binding energy in the final nucleus. Indeed, in the reaction $^{232}Th(^{15}N, ^{16}O)$ at the proton pick-up to the ground state ^{16}O with the 12.1 MeV binding energy the cross section increases to 3.9 mb.

4.3. Transfer of Nucleon Groups

The transfers of some nucleons are specific to heavy ion direct reactions. When considering the mechanism of such reactions, the question usually arises, whether the nucleons are transferred independently from each other or as a bound group. Unfortunately, up to now there has been no appropriate theoretical model which would allow to obtain the unambiguous answer on the basis of the quantitative analysis of the experimental data. Therefore, we have to be limited only with the qualitative arguments based, mainly, on the comparison of the cross sections of the one nucleon and nucleon group transfer and on the energy spectrum shape.

The size of the reaction region at the neutron and proton transfer region might be estimated from the angular distribution. For heavy nuclei it is equal to 1 barn approximately. The total cross section of the one nucleon transfer does not exceed some tens of millibarn. Thus, the probability of the one nucleon transfer by the heavy ion flight through the reaction region does not exceed some per cent. It is seen from figs. 2 and 3 that the angular distributions of the transfer of some nucleons have, in general, the shape similar to that in the case of the one nucleon transfer. This means, that the regions of both reactions are similar. At the independent transfer of three (^{12}C, ^{9}Be) or four (^{14}N, ^{10}B) nucleons one might expect the decrease of the cross section by a factor of thousands in comparison with the cross section of the one nucleon transfer. However, the experiment indicates that the cross sections differ insufficiently.

Let us turn to the energy spectra (see figs. 5 and 6). In the reaction (^{12}C, ^{9}Be) the ^{9}Be energy spectrum shows the excitations of the final nuclei ^{200}Tl and ^{235}U , since the ^{9}Be itself has no bound excited states. On the basis of the peak position one can conclude that the majority of the ^{9}Be nuclei is produced in the transfer of ^{3}He to the nucleus-target but not in the dissociation of ^{12}C into ^{9}Be and ^{3}He . The small peak half-widths are remarkable; they turned out to be smaller than these in the proton transfer reaction, though it was possible to expect the inverse ratio at the independent transfer of a few nucleons. There are similar peculiarities in the spectrum of the (^{14}N, ^{10}B) reaction. The only difference is that the accurate estimation of the excitation energy of the final nucleus-receptor is complicated due to the presence of bound excited states of ^{10}B .

Thus, the cross section and the energy spectra in the investigated reactions of a few nucleon transfer may serve as arguments in favour of such a reaction mechanism, when nucleons are transferred as a bound group.

The narrow half width of the energy spectra indicates that the excitation of one or a few neighbouring levels occurs in the reaction. As is seen from figs. 5 and 6, these levels are placed rather high; the excitation energy at the ^{3}He transfer being equal to 14–13 MeV, at the ^{4}He transfer not smaller than 23 MeV.

In ref.[27] when investigating the deuteron transfer reaction (^{11}B, ^{9}Be) on light nuclei it has been found that states are predominantly excited with configuration $(d^{2}_{5/2})_{5}$. This means, that there occurs the capture of a neutron and a proton by the nucleus-target to the near nucleon orbits with the orbital momentum close to the average one in the impinging nucleus at the tangent collision. It is possible to assume the excitation of such a type "cluster" levels with the 3 or 4 nucleon transfer in our case in the reactions (^{12}C, ^{9}Be) and (^{14}N, ^{10}B) . "Cluster" levels are a new type of the nucleus collective excitations obtained in direct reactions with heavy ions. The investigation of these levels may be useful for the nucleus model development, in particular, for those ones which claim to the correct description of the nuclear surface properties.

The nucleon group transfer to the high excited levels permits to understand why the spectrum of the stripping reaction appeared to be richer and the cross sections larger than those in the pick-up. In the stripping reactions all the reaction channels are detected including transfers to the bound and unbound states of the final nuclus-receptor. As for the pick-up reactions, by means of $dE/dx \cdot E$ method the nucleon transfers only to the bound states are detected. In particular, one of the possible reasons for the small ^{4}He pick-up cross section might be the ^{4}He transfer to the levels with the excitation considerably higher than the binding energy of an alpha-particle in the final nuclei-receptors.

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References

1. A.Zucker. Ann. Rev. Nucl. Sci., 10, 183 (1960).
2. G.N.Flerov and V.A.Karnaukov. Congres International de Physique Nucleaire, Paris, 1964 (Editions du Centre National de la Recherche Scientifique, Paris, 1964). p.373.
3. D.A.Bromley. Proceedings of the Summer Study Group on the Physics of the Emperor Van de Graaff Region, (Brookhaven National Laboratory Report BNL 948 (C-46), 1965), vol.III, p.1045.
4. K.R.Greide. Ann. Rev. Nucl. Sci., 15, 291 (1965).
5. A.Dar. Recent Progress in Nuclear Physics with Tandems. Heidelberg, Germany, July 18-21, 1966. Invited papers, (edited W.Hering). Session IV.
6. G.Bereit. Encyclopedia of Physics. vol 41/1 (Springer-Verlag, Berlin, 1959) sect. 48, p.367.
7. V.V.Volkov. Proceedings of the Problem Symposium on Nuclear Physics, Tbilisi, 1967 (Academy of Science USSR, Moscow, 1967) vol. 1, p.226.
8. D.A.Bromley. A series of Lectures Prepared for Presentation at the Enrico Fermi Summer School on Nuclear Structure and

Nuclear Reactions, Varenna-Italy, June 26- July 15, 1967. Preprint YALE-3223-84.

9. D.H.Wilkinson. Proceedings of International Conference on Nuclear Structure. Kingston, Canada. (D.A.Bromley and E.W.Vogt, University of Toronto Press, 1960) p.20.

10. D.H.Wilkinson. Proceedings of Rutherford Jubilee International Conference, Manchester, 1961; ed. by T.B.Birks (London Heywood Co. LTD 1961) p.339.

11. I.M.Ladenbauer- Bellis, I.L.Preiss and G.E.Anderson. Phys. Rev., 125, 606 (1962).

12. R.M.Caedke, K.S.Toth and I.R.Williams. Phys. Rev., 140, 296 (1965).

13. J.Wilczynski, V.V.Volkov and P.Decovski. Sov. J.Nucl. Phys., 5, 942 (1967).

14. K.S.Toth and E.Newman. Proceedings of the Third Conference on Reactions between Complex Nuclei, edited by A.Ghiorso, R.M.Diamond and H.E.Conzett. (University of California Press, Los Angelos, 1963) p.114.

15. V.V.Volkov and J.Wilchynski. Nucl. Phys., 92, 495 (1967).

16. A.G.Artjuch, V.V.Volkov, T.Kwiecinska. Sov . J.Nucl. Phys., 4 , 1165 (1966).

17. E.Goldberg and H.L.Reynolds. Phys. Rev., 112, 1981 (1958).

18. H.L.Reynolds, E.Goldberg and D.D.Kerlee. Phys. Rev., 119, 2009 (1960).

19. J.Alster and H.E.Conzett. Proceedings of the Second Conference on Reactions between Complex Nuclei, edited by Zucker, Halbert and Howard (John Wiley and Sons, New York, 1960) p. 175.

20. D.D.Kerlee, H.L.Reynolds and E.Goldberg. Phys. Rev., 127, 1224 (1962).

21. S.A.Karamjan, I.V.Kuznetcov, Ju.A.Muzitchka, Ju.C.Oganesjan, Ju.Peniongekevitch, B.I.Pustilnik. Preprint P7-3105, Dubna, 1967.

22. W.E.Frahn and R.H.Venter. Nuclear Physics, 59, 651 (1964).

23. J.A.McIntyre, T.L.Watts and F.C.Jobes. Phys. Rev., 119, 1331 (1960).

24. V.V.Volkov. Preprint E7-3155, Dubna, 1967.

25. J.Birnbaum, J.C.Overley and D.A.Bromley. Phys. Rev., 157, 787 (1957).

26. V.M.Strutinski. Sov. J.JETF, 46, 2078 (1964).

27. M.W. Sachs, C.Chasman and D.A.Bromley. Phys. Rev., 139, 92 (1965).

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Table 1

Total cross section of the Transfer Reactions

Target and projectile	Ion energy (MeV)	Cross section in mb.						
		^{4}+He	+d	-d	-^{3}He	-^{4}He	+n	-P
^{197}Au+ ^{14}N	110	8×10^{-3}	2.6	100		26	25	
^{232}Th+ ^{12}C	82	$<1\times10^{-3}$	5×10^{-3}		31		37	37
^{197}Au+ ^{12}C	82	$<1\times10^{-3}$	$<5\times10^{-3}$		27			41

The sign + corresponds to the pick-up reactions, the sign - corresponds to the stripping reaction.

Table 2

The analysis of the proton transfer reaction (^{12}C, ^{11}B) in the framework of Frahn-Venter[22)] and Strutinski [26)] models

Reaction	E_{cm} (MeV)	Frahn-Venter model parameters				Classical parameters			Part. wave numb. in react. region	Trans-fer nucle-on binding energy (MeV)
		T'	Δ'	τ	$\tau/4\Delta'$	R	r_o	d		
^{197}Au(^{12}C,^{11}B)^{198}Hg	77	45	1.77	2.54	0.36	12.5	1.55	0.23	5.0	15.96
^{232}Th(^{12}C,^{11}B) ^{233}Pa	78	42	1.89	2.45	0.33	13.0	1.55	0.23	4.6	15.96
^{197}Au(^{14}N,^{13}N) ^{198}Au	87	51	2.95	1.63	0.14	12.9	1.57	0.32	8.0	10.55

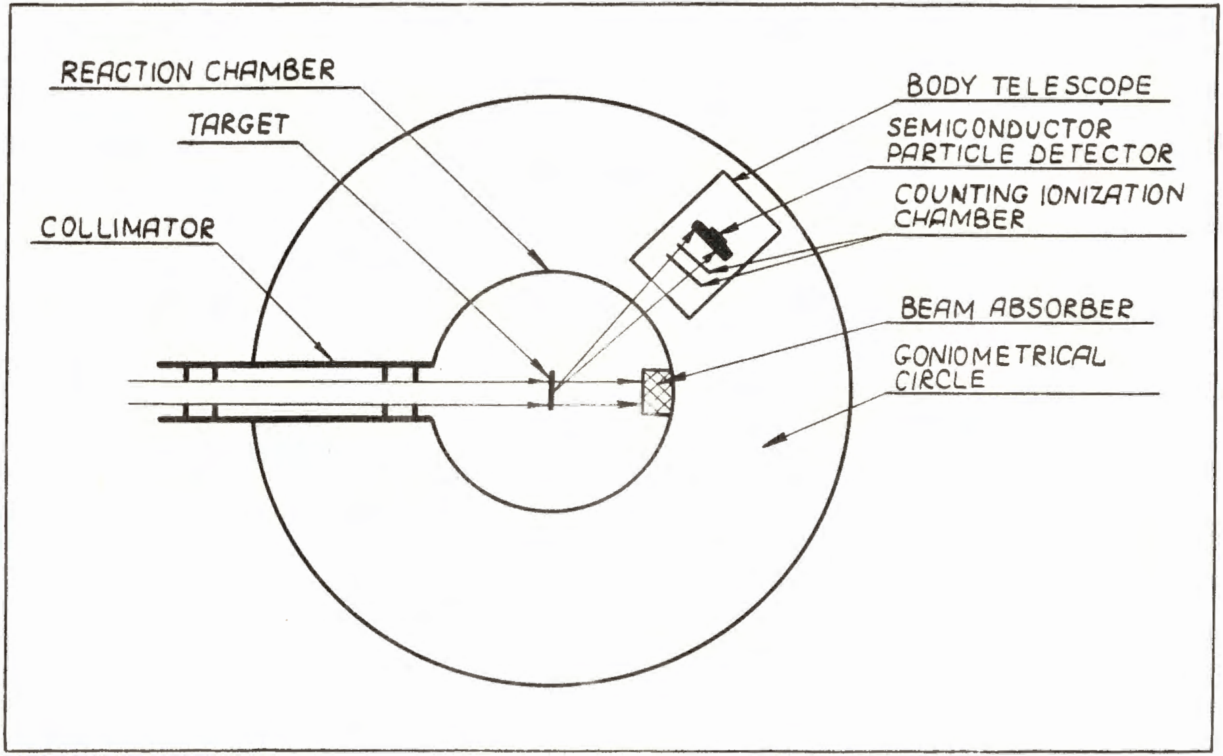

Fig. 1. The experimental scheme.

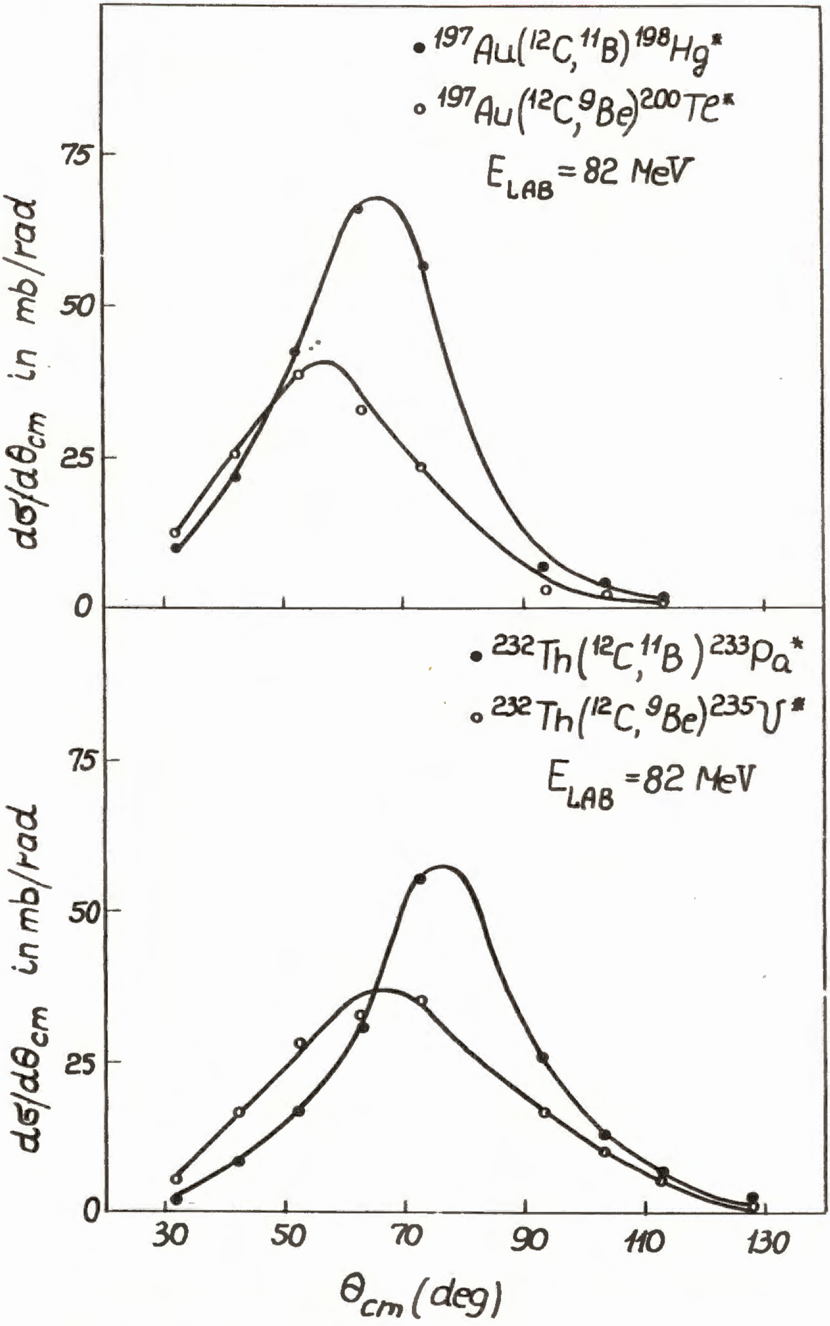

Fig.2. The differential cross sections of the proton and ^{3}He stripping.

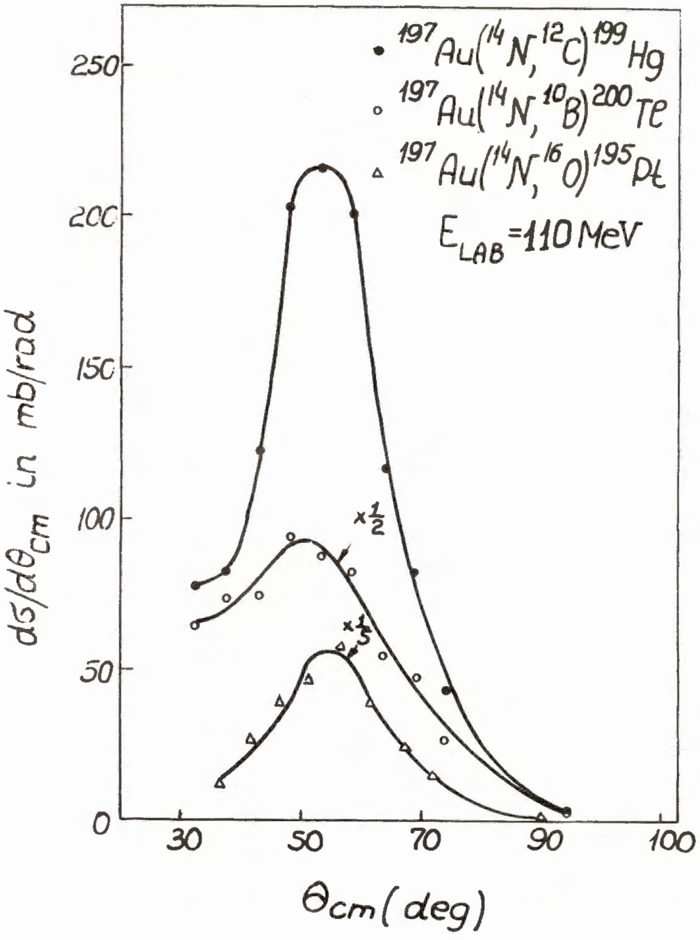

Fig.3. The differential cross sections of the deuteron and ^{4}He stripping and deuteron pick-up.

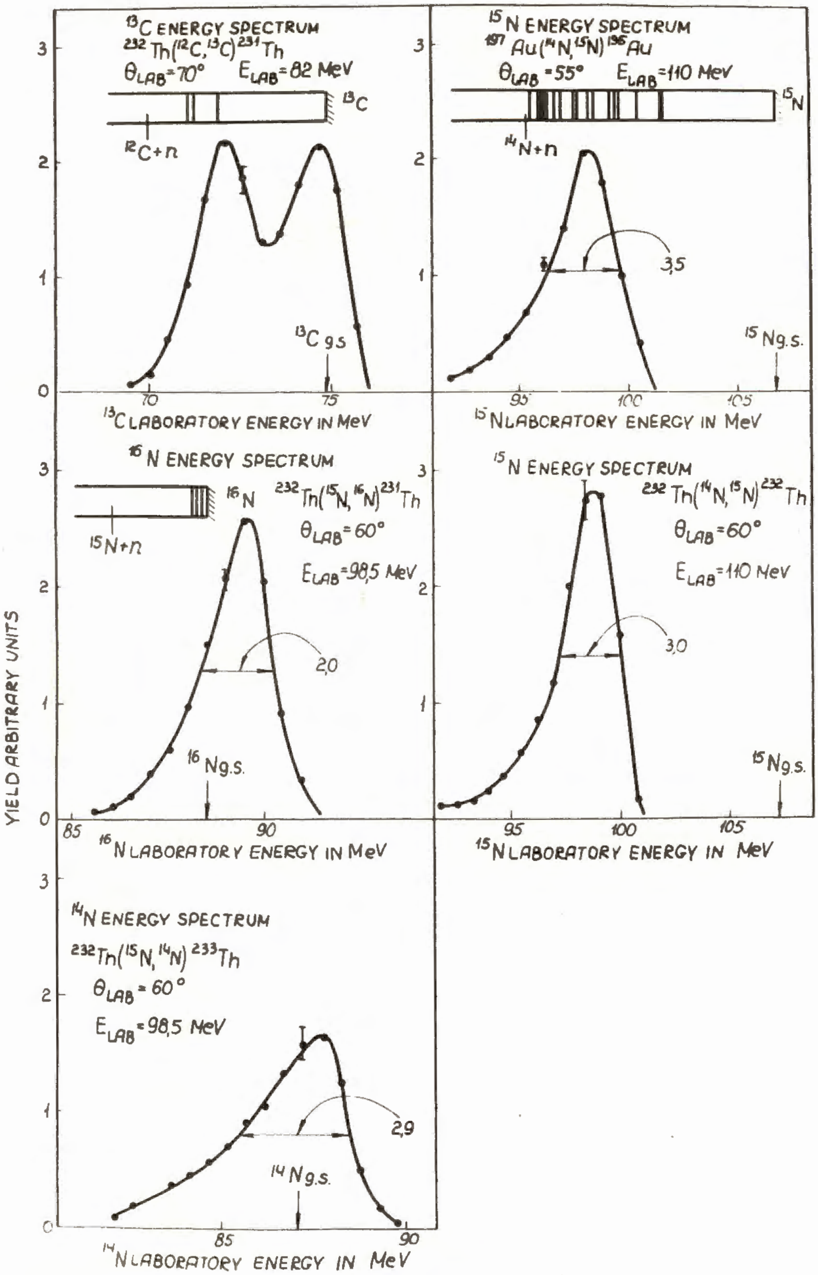

Fig.4. The energy spectra of the neutron transfer reactions.

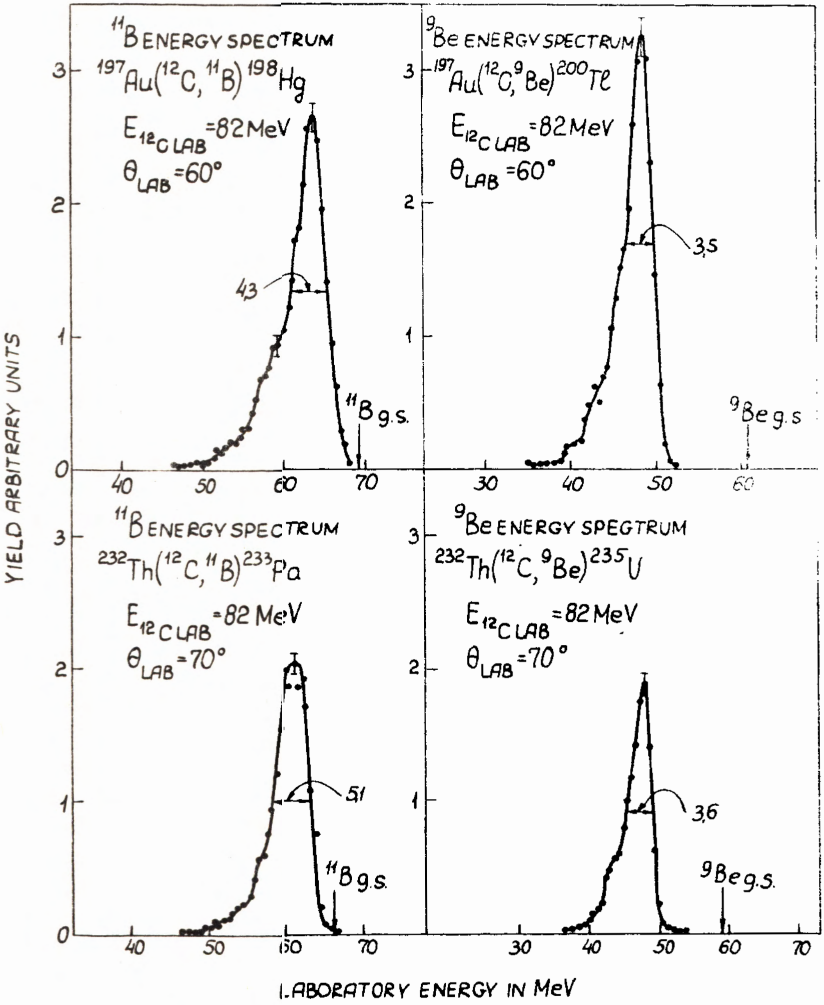

Fig.5. The energy spectra of the proton and ^{3}He transfer reactions.

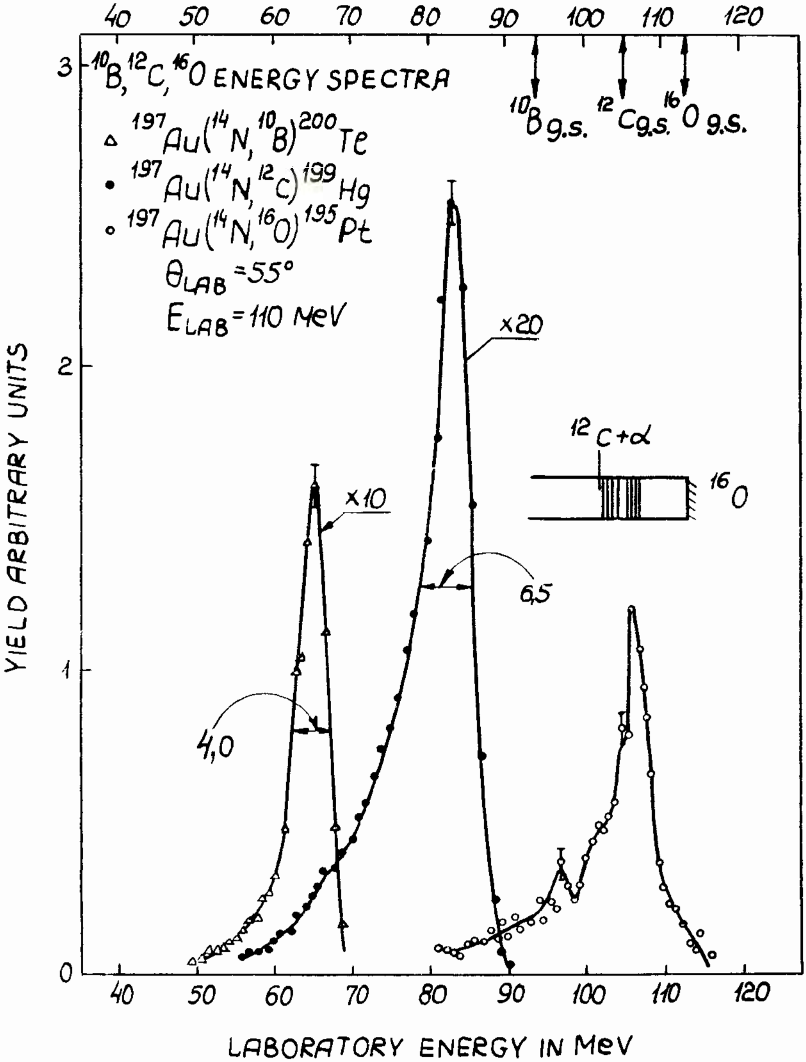

Fig.6. The energy spectra of the deuteron and ^{4}He transfer reactions.