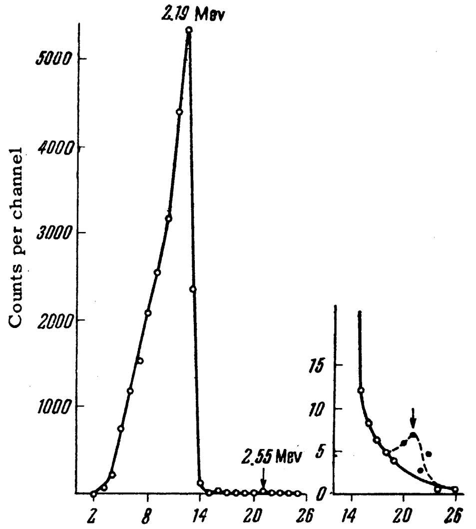

FIG. 2. Spectrum of alpha particles from the natural mixture of samarium isotopes (without collimation). At the right – part of the spectrum on a magnified scale. The observed counts in the energy range for the Sm^{146} alpha particles are indicated by black dots. The areal difference between the solid and dashed curves was employed to estimate the upper limit of the Sm^{146} content.

The number of fixed alpha particles at the decay energy of Sm^{146} does not exceed the background count. Comparing the count of pulses from Sm^{147} alpha particles possessing an energy of 2.19 Mev with the count of pulses which can be triggered by alpha particles having an energy of 2.55 Mev and taking into account the half-lives of these isotopes, viz., $T(Sm^{147}) = 10^{12}$ years and $T(Sm^{146}) = 5 \times 10^{7}$ years, (with allowance for the respective percentage contents in the natural isotopic mixture) we deduce that the natural mixture of samarium isotopes contains not less than $2.5 \times 10^{-6}\%$ of Sm^{146}.

According to the latest data of mass-spectrometric analysis[8] this value has been determined as equal to $8 \times 10^{-5}\%$.

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Translated by J. E. Viscardi
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USE OF THE (d,p) REACTION TO EXCITE STATES WITH LARGE SPINS

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Submitted to JETP editor May 8, 1959

J. Exptl. Theoret. Phys. (U.S.S.R.) **37**, 548-550 (August, 1959)

IT has been proposed to use the inelastic scattering of complex nuclei for the excitation of nuclear states with large spins.[1] We desire to call attention to the fact that (d, p) reactions can be effectively applied to light nuclei for the same purpose. In this case, not only can single-particle levels with large spins be excited, but, thanks to peculiarities of the angular distributions, it is possible to segregate such levels from the rest.

For the ordinary stripping process[2] the angular momentum summation rule has the following form

$$J_i + j_n = J_f, \quad (\Delta J)_{max} = j, \tag{1}$$

where J_i and J_f are the initial and final states, and j_n is the total momentum of the capturing nucleon, determined by the shell structure of the nucleus. Ordinary stripping is forbidden if condition (1) is not fulfilled. In this event the following processes may occur, also characterized by differential cross-section peaks at small angles: stripping with change of spin orientation (spin-flip),[3] and the process of direct ejection of a proton from the nucleus with capture of the deuteron in the bound state ("knockout").[4,6] For the latter process we may write

$$J_i + j_{p_1} + j_{n_1} = J_f + j_{p_2}, \quad (\Delta J)_{max} = 3j; \tag{2}$$

where j_{p_1} and j_{n_1} refer to the proton and neutron in the incident deuteron, and j_{p_2} to the expelled proton. From (1) and (2) it is evident that in a knockout process the difference between the spins of the initial and final states, ΔJ, can attain considerably larger values than in ordinary stripping.

As an example illustrating the general features of the knockout process, we calculated the angular distribution of the neutrons evolved as a result of this process in the reaction $B^{10}(d, p)B^{11*}$ ($E_{exc} = 2.14$ Mev, $J^* = \frac{1}{2}^-$), for which ordinary stripping is forbidden. The calculation was carried out for deuteron energies of 4, 8, and 12 Mev ($R = 4.8 \times 10^{-13}$ cm), using the formula from reference 7. The computed results are exhibited in Fig. 1, wherein Butler's curves are reproduced for comparison. From these graphs it ensues that at all energies the maximum region is narrower for ordinary stripping than for the knockout process. Computed results for angular distributions in the same process were presented recently by Evans and French.[5] The curve obtained for $E_d = 7.7$ Mev, $R = 5 \times 10^{-13}$ cm, is shown in Fig. 1b. Unfortunately, formulas for the cross section are not given in reference 7, so that it is impossible to compare the calculation procedures.

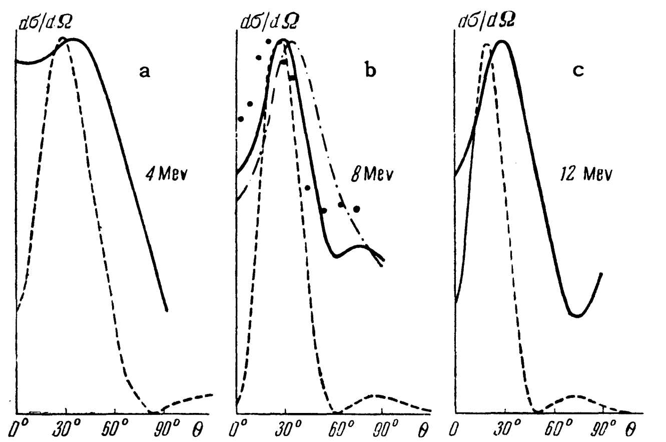


FIG. 1. Angular distribution of protons in the $B^{10}(d, p)B^{11*}$ reaction (the cross section is expressed in relative units). The solid curve was calculated in the present work, the dot-dash curve was calculated in reference 5, the dash curve is by Butler, and the experimental points are from reference 6. The Mev values on the charts correspond to the incident deuteron energy.

In Fig. 1b the dots represent the experimental data of Evans and Parkinson.[8] It is evident from the plot that the curve calculated for the knockout process agrees approximately with the experimental results, especially if we add some isotopic background, which can be due to a mechanism connected with the formation of a compound nucleus and with the "stripping of heavy particles."[4,9,10] At the same time it must be borne in mind that good accord between the calculated and experimental angular distributions should not be expected, since flip-spin is possible in this reaction. For the latter process the angular-momentum summation rule can be written in the form

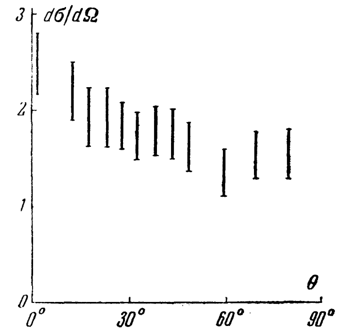
$$\mathbf{J}_i + \mathbf{j}_n + \mathbf{s}_p + \mathbf{s}_p = \mathbf{J}_f, \quad (\Delta J)_{max} = j + 1, \tag{3}$$

where s_p is the proton spin. According to estimates by Bowcock,[3] the angular distribution for this process also differs from that for ordinary stripping and agrees well with the experimental data.

Thus the task of detecting states with large spins (more precisely, states for which $\Delta J > j$) resolves itself into the most accurate possible determination of the differential cross-section peak and the segregation of the large-spin levels in relation to the location and width of the peak. At sufficiently high deuteron energies it is still possible to study such peaks experimentally in angular distributions which are several tenfolds smaller than for ordinary stripping and only a few times larger than the isotopic background level.

The knockout process, like stripping with change of spin orientation in the (d, p) reaction, is considerably more sensitive to the Coulomb field than the ordinary stripping process, since in the latter case the proton remains outside the limits of the nucleus. Furthermore, the orbital momenta of the deuteron, different from zero, play a substantial role in the excitation of states with large spins. For these reasons, in order to excite levels with large spins it is necessary to use deuterons with energies several times greater than the Coulomb-barrier height ($E_d \gtrsim 15$ Mev for $Z \sim 12$, $E_d \gtrsim 8$ Mev for $Z \sim 5$). At lower energies the forward peak will be suppressed. The reaction $Mg^{24}(d, p)Mg^{25*}$ ($E_{exc} = 1.61$ Mev, $J^* = {}^7\!/_2{}^+$),[11] for which Fig. 2 shows the experimental results at 8 Mev, can serve as an example of this.

FIG. 2. Angular distribution of protons in the reaction $Mg^{24}(d, p)Mg^{25*}$.



The following reactions may be cited as examples of the possible utilization of the proposed method: a) $Li^6(d, p)Li^{7*}$, $J^* = {}^7\!/_2{}^-$, $E_{exc} \sim 4$ Mev;[12,13] b) $C^{12}(p, d)C^{11*}$, $J^* = {}^5\!/_2{}^-$, ${}^7\!/_2{}^-$, and ${}^9\!/_2{}^-$ in the excitation energy range 3 to 10 Mev;[13] c) $B^{11}(p, d)B^{10*}$, $J^* = 4^-$, $E_{exc} \sim 6$ Mev;[13] d) $C^{13}(p, d)C^{12*}$, $J^* = 4^+$, $E_{exc} \sim 8$ Mev.[13]

In conclusion we emphasize the fact that the investigation of states with large spins by the proposed method possesses advantages over other means [reactions with complex nuclei, (α, p) reactions, and others], since the angular distribution features of the (d, p) reactions are revealed with significantly greater clarity.

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Translated by J. E. Viscardi
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THE PROTON SUBSHELL Z = 100

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Submitted to JETP editor April 1, 1959

J. Exptl. Theoret. Phys. (U.S.S.R.) **37**, 550-553 (August, 1959)

INVESTIGATIONS undertaken for the purpose of finding the new 102nd element were recently crowned with success. Groups headed by Flerov in the U.S.S.R. and by Seaborg and Ghiorso in the U.S.A. have synthesized the short-lived isotopes 102^{253} and 102^{254}, of which the first decays via emission of an 8.8-Mev alpha particle with a period from 2 to 30 seconds,[1,2] and second decays both via fission (30%) and via emission of alpha particles with energy close to 8.3 Mev with a period of approximately 3 seconds.[3] In addition, it was shown that the activity with a period of approximately 10 minutes, observed previously by the Swedish scientists,[3] was in all appearance not connected with the element 102.

We wish to call attention to the anomalous properties of the isotopes of the 102nd element, observed even on a simple graph showing the dependence of the alpha-decay energy on N (analogous to the graphs cited in reference 4). However, the observed slight excess of the alpha-decay energy of isotopes of the 102nd element over those of the neighboring even elements can be the consequence of the fact that these isotopes, which are quite far from the beta-stability curve[5] (as are, in general, all the lighter isotopes of the heavy elements), have excessive alpha-decay energies, other conditions being equal. To exclude the extraneous effect of the increase of the alpha-decay energy upon deviation from the beta-stability curve, we used the empirical dependence of the alpha-decay energy Q_α on Z, for nuclei with identical N but different Z (see reference 5):

$$Q^*_\alpha(N,Z) = Q_\alpha(N) - 0.8(Z - Z^*), \qquad (1)$$

where Z^* is the value of Z corresponding to the most beta-stable nucleus for a given A, and $Q^*_\alpha(N, Z)$ is the alpha-decay energy of the nucleus (N, Z^*) in Mev. One can put (see references 5 and 6)

$$Z^* = 0.356\,A + 9.1.$$

It follows from (1) that the $Q^*_\alpha(N)$ found from the experimental values of Q_α should coincide at each value of N, even in the presence of neutron shells and subshells; only in the case of proton subshells will the corresponding points deviate. Figure 1 shows the dependence of Q^*_α on N. For each of the values of N it was found here that the values of Q^*_α, calculated from different experimental values of Q_α (taken from reference 7), were almost the same. Nevertheless, to exclude the spread (which reaches ±0.15 Mev), we have drawn the curve $Q^*_\alpha = Q^*_\alpha(N)$ only through the averaged points. As can be seen from Fig. 1, in this region only two isotopes of the 102nd element lie without any doubt above the curve $Q^*_\alpha = Q^*_\alpha(N)$. Inasmuch as the isotopes of the 102nd element are converted into Fm by alpha decay, this is evidence of a reduced binding energy past Z = 100.