(n,He^3) Reactions of Medium Weight Nuclei Induced by 14.8-Mev Neutrons*

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Activation of the following pure monoisotopic elements with 14.8-Mev neutrons gives rise to (n,He^3) reactions as observed by measuring the radioactive products having the following measured half-lives and formation cross sections: $Mn^{55}(n,He^3)V^{53}$, 2±0.3 min, 2–6 mb; $Co^{59}(n,He^3)Mn^{57}$, 1.75±0.2 min, 1–3 mb; $As^{75}(n,He^3)Ga^{73}$, 5.1±0.3 hours, 3–7 mb; and $Rh^{103}(n,He^3)Tc^{101}$, 15±3 min, 1.5–3.5 mb. A qualitative discussion is presented concerning the possible mechanisms for these reactions. Work is being continued to observe other (n,He^3) reactions.

INTRODUCTION

ONE of the authors[1] has measured the angular and energy distribution of alpha particles arising from 14.8-Mev neutron bombardments of medium weight nuclei. Fulmer et al.[2] have measured the energy and angular distribution from (p,α) reactions at energies from 9.5 to 23 Mev. In both cases the energy distributions observed indicated that many more alpha particles, with energies below that of the Coulomb barrier, were emitted than was normally anticipated.

Except for light nuclei[3] and 22-Mev proton reactions on medium nuclei, no other reactions involving He^3 particle[4] emission have been reported. However, if He^3 particle emission exhibits the same anomolous energy distribution behavior as reported for alpha particles, then it should be possible, in certain cases, to observe the products of (n,He^3) reactions.

From a consideration of reaction Q values and ease of identification of products, a number of isotopes were chosen to be bombarded with 14.8-Mev neutrons from the $T(d,n)He^4$ reaction at 400 Kev on the University of Arkansas Cockcroft-Walton Accelerator. Table I lists the target nuclei, preliminary measurements of the cross sections and other pertinent information.

EXPERIMENTAL

The target materials, in all but one case, were in the form of metals with a purity of 99.9% (as supplied by A. D. Mackay, Company, New York). Phosphorus was irradiated as analytical reagent grade phosphorus pentoxide. The gross-beta decay was followed with a $2-\pi$ end-window methane flow proportional counter and the data was corrected for the usual sources of error.[5]

Identification of the products was accomplished by comparison with the well established half-lives[6] of the nuclides formed in the irradiation. The cross-section values for the (n,He^3) reactions are reported as the limits found in analyzing the gross beta-decay curves, and are relative to the internal flux-monitor cross sections. These monitor cross sections were chosen from values reported in the literature (Table II) and the $Mn^{55}(n,\alpha)+(n,p)$ and $Co^{59}(n,\alpha)$ values have been confirmed in this laboratory. For the cases of Al, P, and V an external Cu monitor foil was used to determine the incident neutron flux. The cross-section value of 556 mb as reported by Yasumi[7] for the $Cu^{63}(n,2n)Cu^{62}$ reaction was used here.

In the case of Mn^{55}, samples were counted using an 82.7 mg/cm² aluminum absorber to eliminate the possibility of detecting any activity arising from the highly uncertain 2 minute excited state of Mn^{54} that may have been produced during the irradiation.

The products of the Co^{59} irradiation were separated chemically by precipitating the MnO_2 fraction after addition of iron carrier to the solution made from Co^{59} target material. It was found that the 1.75 min activity assigned to Mn^{57} followed the 2.6 hour Mn^{56}, producing

TABLE I. Observed cross sections of the (n,He^3) reaction with various target nuclei.

Target nucleus	Residual nucleus	Half-life Measured	Half-life Literature[a]	Measured cross section (millibarns)	Q value (Mev)
$_{25}Mn^{55}$	V^{53}	2±0.3 min	2.0	2–6	−12.650
$_{27}Co^{59}$	Mn^{57}	1.75±0.2 min	1.7 min	1.0–3.0	−12.410
$_{33}As^{75}$	Ga^{73}	5.1±0.3 hours	5.0 hours	3–7	−9.822
$_{45}Rh^{103}$	Tc^{101}	15±3 min	15 min	1.5–3.5	−8.459
$_{13}Al^{27}$	Na^{25}	···	1 min	<0.5	−14.617
$_{15}P^{31}$	Al^{29}	···	6.6 min	<0.7	−13.375
$_{23}V^{51}$	Sc^{49}	···	57 min	<0.8	−14.341

[a] See reference 6.

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[4] The notation, He^3, is by no means a conclusion that He^3 particles are emitted as such, but refers rather to the product arising from the emission of two protons and one neutron in any combination.

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TABLE II. (n,He^3) reactions and relative monitor reactions and cross sections.

Reaction	Monitor Reaction	Cross section (mb)	Reference
$As^{75}(n,He^3)Ga^{73}$	$As^{75}(n,p)Ge^{75}$	11.8±1.2	a
$Co^{59}(n,He^3)Mn^{57}$	$Co^{59}(n,\alpha)Mn^{56}$	30±3	b, c
$Mn^{55}(n,He^3)V^{53}$	$Mn^{55}(n,p)+(n,\alpha)$	149±37	b
$Rh^{103}(n,He^3)Tc^{101}$	$Rh^{103}(n,p)Ru^{103}$	11±3	d

[a] E. B. Paul and R. L. Clarke, Can. J. Phys. 31, 267 (1953).
[b] See reference 1.
[c] I. L. Preiss and R. W. Fink (to be published).
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the same relative counting rate in the chemically separated and untreated samples.

In the cases where the (n,He^3) products were observed, the possibility that activity arising from the activation of sample impurities influenced the gross-decay was eliminated by considering the cross sections involved. The minimum impurity cross sections required to produce the observed activity would have to be of the order of one to two barns. In all instances this value is at least one order of magnitude larger than the known or anticipated values of other sample impurities.

DISCUSSION

If the Q values[8] are correct, the He^3 particles would be emitted with very low energies. In the case of cobalt for example, He^3 particles would have energies less than 2.3 Mev. Alpha particles arising from the $Co^{59}(n,\alpha)$ reaction having energies less than 3 Mev have never been observed.[1] Kikuchi[9] and Evans[10] have explained the energy distribution of the alpha particles from the $Al^{27}(n,\alpha)Na^{24}$ and (γ,p) reaction, respectively, by introducing a diffuse nuclear potential. This consideration would enhance the penetration of He^3 particles through the potential barrier of an excited compound nucleus and may be a significant point in explaining the observed cross sections. An alternate approach is that the (n,He^3) process may arise through a mechanism other than compound nucleus formation. For example, a direct process, such as a pick-up reaction involving a proton pair may be involved. Another description of this process may be a direct interaction between the incident neutron and a "preformed" He^3 existing as a "cluster" at or near the nuclear surface, since there is evidence that the nuclear surface is rich in clusters in dynamic equilibrium.[11]

Additional experimental results must be obtained before conclusions on the extent of the contribution of compound nucleus formation or direct interaction processes can be reached. A further study of this problem and a search for other (n,He^3) reactions is in progress at this laboratory.

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