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EUROPEAN ATOMIC ENERGY COMMUNITY - EURATOM

THE (n,d) REACTION ON Fe^{54}

by

G. BASSANI, L. COLLI,
E. GADOLI, I. IORI,

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Istituto di Fisica dell'Università, Milano and
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THE (n, d) REACTION ON Fe^{54}

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Received 10 April 1962

Abstract: The angular distribution of deuterons from the pick-up reaction Fe^{54}(n, d)Mn^{53} taken at incident neutron energy of 14 MeV is presented; only high energy deuterons have been considered. These deuterons correspond to two levels of the residual nucleus Mn^{53}, that is the ground state and the first excited level at 0.39 MeV, which cannot be separated. The results can be interpreted by means of Satchler's calculation using distorted wave Born approximation, attributing a part of the transition to a pick-up reaction with transferred angular momentum $l = 1$. This shows that the first excited level of Mn^{53} must have spin $\frac{3}{2}$.

1. Introduction

Direct reactions have received an increasing attention in the last few years due to the fact that they may give some information on nuclear structure. This quality of direct effects is connected with the fact that they are single particle processes, and therefore are of relatively simple interpretation.

From this point of view, we have studied some (n, d) reactions [1–4], involving in particular the nuclei [4] between Sc^{45} and Ni^{60}.

All these nuclei have, according to the shell model, a very similar proton configuration. In fact, from Sc to Ni, they fill progressively the orbit $f_{\frac{7}{2}}$, Sc having only one proton in this orbit and Ni eight. For these nuclei, the deuteron spectra emitted forward following bombardment with 14 MeV neutrons were measured. Of particular interest was the comparison of the cross sections of the deuteron peaks of maximum energy, at which the residual nucleus is left in the ground state.

From this comparison we have derived some indications of the validity of the shell model with j-j coupling as was discussed in the work quoted above.

All previous conclusions were based on the hypothesis that the mechanism of the (n, d) reaction is that of pick-up, according to which the incident neutron snatches a proton off the target nucleus without interacting with the nucleus as a whole. This is therefore a typical case of direct interaction, which is well described by Butler theory to the first approximation.

† Work done under the research contract EURATOM-CNEN.

Many recent experimental results have, however, demonstrated that there exist systematic deviations from the predictions of Butler's theory, and some doubt always arises as to the validity of the theory in the particular cases concerned.

A basic check of what has been stated above, both with regard to the hypotheses of the configuration of protons as expected on the basis of the shell model and the validity of Butler's theory, can be made by measuring the angular distribution of the deuterons emitted in the reaction.

According to the above theory, this distribution is in fact determined by the orbit of the shell model on which the proton in the nucleus lies.

With this in mind, we have begun the measurement of the angular distribution of deuterons of maximum energy emitted by the elements examined in the above quoted work. The present work reports the results obtained for Fe^{54}.

2. Experimental Apparatus

The experimental apparatus is the same one used in the previous work [4]). The deuterons are detected by means of a telescopic unit of proportional counters and a scintillator in coincidence. By measuring the energy loss in a proportional counter the separation of particles of different mass is achieved. Therefore, the measurements are not affected by the protons emitted in the (n, p) reaction on the same nucleus. The energy resolution of the system is 5 %.

The measurements are carried out taking the pulse energy spectrum at 10 angles between 7° and 120°, with an average angular opening varying from 10° to 15°. In the spectra thus obtained, the peak corresponding to the deuterons of maximum energy is experimentally identified (fig. 1) and the number of deuterons contained in the peak is calculated.

The result of the angular distribution so obtained is shown in fig. 2.

3. Discussion

The ground state of Mn^{53} has spin $\frac{7}{2}$, as foreseen by the shell model, and the first excited level at 0.38 MeV has unknown spin value [5]). We may note at once that the energy resolution of our measurement is not such as to enabel us to discriminate between these two levels and therefore both levels could contribute to the measured peaks.

In the pick-up theory, the transition obey the angular momentum conservation law expressed by the formula:

$$(\mathbf{J}_{\rm in}+\mathbf{J}_{\rm fin}+\mathbf{S})_{\rm max} \geqq l \geqq (\mathbf{J}_{\rm in}+\mathbf{J}_{\rm fin}+\mathbf{S})_{\rm min} .$$

where $\mathbf{J}_{\rm in}$ and $\mathbf{J}_{\rm fin}$ are the angular momenta of the initial and final states, $\mathbf{S}$ is the proton spin, and l is the transferred angular momentum.

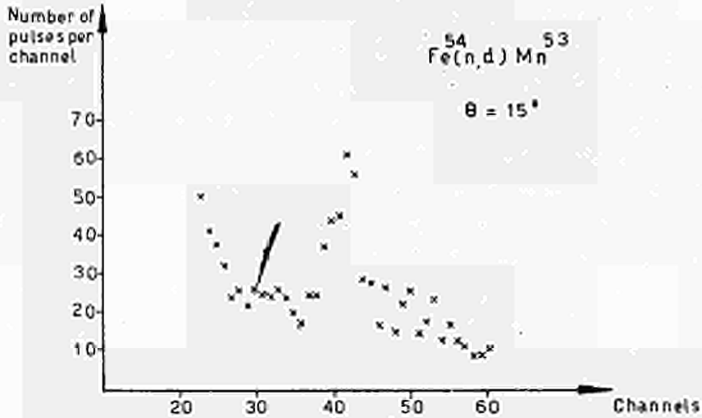

Fig. 1. Energy spectrum of deuterons from the Fe^{54}(n, d)Mn^{53} reaction at 15°. The peak of deuterons of maximum energy is prominent.

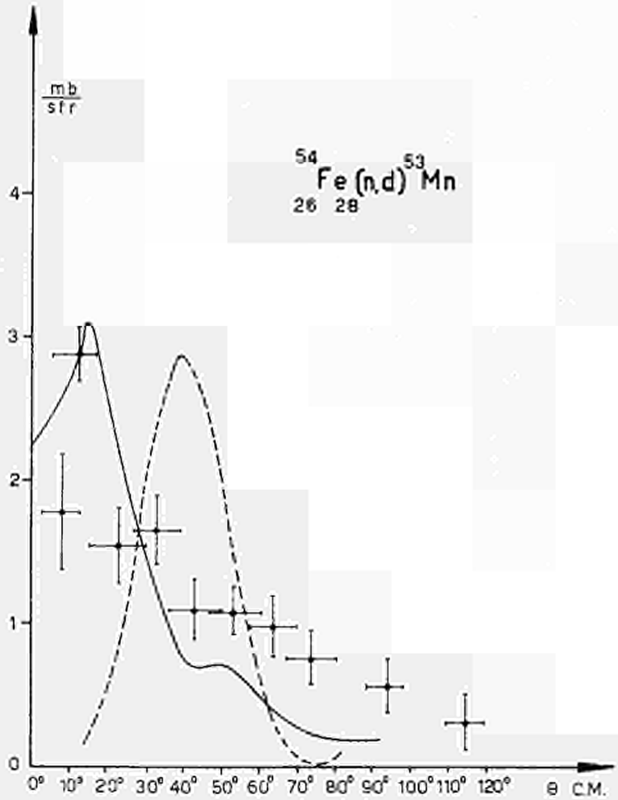

Fig. 2. Angular distributions of deuterons of maximum energy from the Fe^{54}(n, d)Mn^{53} reaction. Points are experimental results. Bars on each point show the statistical errors. The dotted curve is calculated by Satchler using a distorted wave-Born approximation and assuming transferred angular momentum $l = 3$. The curve drawn in full is obtained taking 68 % of $l = 1$ transition plus 32 % of $l = 3$.

Due to this limitation, the $l = 3$ value is the only one permitted for the transition to the Mn^{53} ground state, because $\mathbf{J}_{in} = 0$ and $\mathbf{J}_{fin} = \frac{7}{2}$.

The angular distribution proposed by Butler's theory for the transition to the ground state is a curve with a maximum at 40° and therefore in complete disagreement with the experimental results.

Satchler [6]) has recently calculated the angular distribution expected on the basis of the distorted wave Born approximation for a reaction very similar to the one studied by us, *viz.* the Fe^{56}(n, d)Mn^{55} reaction.

Using these calculations, we find for the transition with $l = 3$, the dotted curve shown in fig. 2, which presents a maximum at 32°. The curve is arbitrarily normalized.

Comparing the part of the angular distribution at small angles with the curve calculated for other values of l, one finds that the maximum at $\approx$15° coincides rather well with the calculations for a transition with a transferred angular momentum $l = 1$.

In fact, taking 68 % of the $l = 1$ transition, and 32 % of the $l = 3$ transition, we obtain the full curve of fig. 2.

The agreement of this curve with the experimental points seems to verify the presence of the $l = 1$ transition.

Considering now the restrictions given by the angular momentum conservation laws, one can see that the only possibility of having an $l = 1$ transition is that the J value of the final nucleus is $\frac{3}{2}$. So, given the ground state spin of $\frac{7}{2}$, we must attribute the value $\frac{3}{2}$ to the first excited level at 0.38 MeV.

There seems to be no other possibility for explaining the presence of the value $l = 1$, if we want to keep the hypothesis of a pure pick-up mechanism.

As for the possibility that the first excited level has $J = \frac{3}{2}$ the following may be observed: examining the level spectra of nuclei with the proton and neutron configuration similar to the one of Mn^{53}, we find that the first excited level above the $\frac{7}{2}$ ground state has in some cases $J = \frac{5}{2}$ and in others $J = \frac{3}{2}$.

Therefore, the assignment does not seem to be unlikely at all. It may be noted that even a small part of the $p_{\frac{3}{2}}$ configuration mixing is easily detectable, because a transition with $l = 1$, is, in absolute value, an order of magnitude higher than the one with $l = 3$.

Finally, following this measurement, we should re-examine some of the conclusions drawn from the above-quoted work, in which the transition probabilities were discussed for deuterons of maximum energy in the case of nuclei from Sc^{45} to Ni^{60} made on the simple $l = 3$ hypothesis.

It is quite clear from the present measurement that the presence of the transition with $l = 1$ changes the value of the specroscopic factor calculated on the basis of the hypothesis that the transition has purely $l = 3$.

But this fact does not substantially alter the agreement between the theoretical predictions and the experimental results, since that agreement was qualitative within a factor of 2, and therefore remains such; it shows, however, that the study of the angular distribution of deuterons emitted in these reactions would be necessary in order to obtain more detailed information concerning the nuclear structure of the residual nuclei.

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