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Investigation of the Energy Levels of the F^{20} Nucleus by Magnetic Analysis

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The products of the reaction $F^{19}(d,p)F^{20}$ were studied by applying the magnetic analysis method. In the investigated excitation energy range (up to 6.75 mev) 24 proton groups were recorded which determine the ground state and 23 excitation levels of the F^{20} nucleus. Six of these levels, with excitation energies 4.55, 4.86, 5.41, 5.54, 6.07 and 6.36 mev, have not been observed previously. The $E^* = 6.74$ mev level in the (d,p) reaction has likewise been observed previously, but the relatively close F^{20} level has been detected in investigations on resonance scattering of neutrons.

ONE of the most effective means of investigating the levels of the nucleus F^{20} is analysis of the products of the reaction $F^{19}(d,p)F^{20}$. This reaction has been investigated in a series of experiments.[1–6] The results of the most recent of these can be summarized as follows.

Burrows, Powell and Rotblat investigated the energy spectrum of protons from the indicated reaction by measuring their range in photo plates. Notwithstanding the comparatively high energy of the bombarding deuterons (8 mev), the authors studied only a relatively narrow band of excitation energies of the F^{20} nucleus, up to 4.73 mev. In this interval the authors observed ten levels of the F^{20} nucleus. 8 proton groups with excitation energy less than 4.01 mev were reported by Allen and Rall[4] In their work, the proton energy was determined by range in aluminum, that is, under circumstances giving poor accuracy and resolution.

In a subsequent short communication of Shull,[5] the proton energy was studied by a more exact method, with the aid of magnetic analysis. However, notwithstanding the bombardment by deuterons of energy greater than 10 mev in this work, the author investigated an energy range of excitation only to 4.4 mev and observed only seven levels of the F^{20} nucleus.

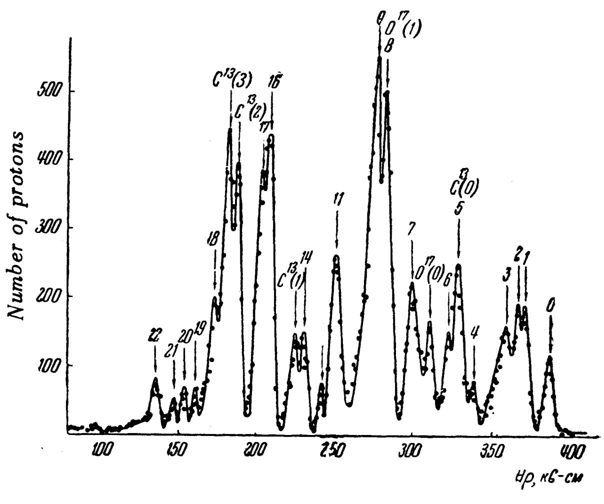
In 1952 Watson and Buchner[6] gave more exact and complete information about the energy levels of the F^{20} nucleus in the excitation interval up to 4.3 mev. The target was bombarded by deuterons of comparatively small energy (up to 2.1 mev) and the authors were able to observe, with the aid of a magnetic spectrometer, 19 proton groups characterizing the ground state of the F^{20} nucleus and 18 excited levels.

At the beginning of the present work (May, 1955) a collection of the data on the levels of the F^{20} nucleus given in the survey of Ajzenberg and Lauritsen[7] gave an incomplete picture. There was an excitation energy region up to 4.3 mev which had been sufficiently thoroughly studied by analysis of the reaction $F^{19}(d,p)F^{20}$. There were also data in the region of higher excitation energy (6.6 to 8.5 mev) obtained by study of the resonance scattering of neutrons by F^{19}. The interval between these two regions remained practically uninvestigated.

The present work had the aim of investigating the levels of F^{20} in the region of higher excitation energy and a filling of the uninvestigated gap between two series of data which existed till then.

METHOD AND CONDITIONS OF THE EXPERIMENT

The levels of the F^{20} nucleus were determined in the present work by analysis of the reaction F^{19} (d, p) F^{20}. Proton groups of various energies were separated with the aid of a magnetic field. The analyzer was the magnetic field of the same cyclotron which served as the source of the accelerated deuterons which bombarded the target. Forthis purpose, a specially constructed box described by us in Refs. 8,9 was put into the cyclotron vacuum in the space between the dees. The target which was located inside the box was hit by a beam of deuterons passing through a system of two collimating slits. Because of this a comparatively monoenergetic part of the initial deuteron beam was selected. Outgoing particles arising from the target as the result of nuclear reactions described a part of their circular trajectory inside the box, and passing through a narrow slit fell upon a photographic plate which was coated with a thin layer of nuclear emulsion.



As in previous experiments involving the (d, p) reaction, an aluminum filter lay along the entire photographic plate, covering half its width. The filter increased in thickness with distance from the target in such a way that at any point deuterons and particles of still shorter range were filtered out and only protons were able to reach the plate. The plate half without the filter showed visible lines from deuterons elastically scattered from the target material. These lines were investigated with the aid of a microphotometer; the energy of the incident deuterons bombarding the target was thus determined.

The half plate which was covered by the filter contained mainly protons from the reaction (d,p) and was investigated under a microscope. A count of proton tracks was made with intervals of 200 μ along the entire length of the plate. Thus the energy of a group was determined by its position on the plate, and its intensity by the number of tracks in the group. These measurements were repeated at 10 locations across the width of the plate. For each plate the proton energy spectrum was obtained by summing these 10 measurements.

The target in our experiments was a thin silver foil on which a thin layer of finely powdered CeF_3 was deposited. This fluorine compound was selected because of its temperature stability and also because the second component (cerium) is a sufficiently heavy element to prevent a (d,p) reaction. The latter, incidentally, was checked by a special control experiment. A proton spectrum was investigated from a target of BaF_2. The identity of these spectra made completely sure the identification of protons from the F^{19} (d, p) F^{20} reaction.

In addition, another type of check was performed. The proton spectrum from the deuteron bombardment of a silver foil was investigated. This showed the presence of two contaminations which were unavoidable under the conditions of the experiment: carbon and oxygen. The CeF_3 target was bombarded by deuterons of various energies in the interval 3.0 to 4.0 mev. This also served as the control on the identification of the proton groups.

To determine the levels of the F^{20} nucleus, we investigated six plates. The results presented here are weighted averages of these six determinations.

DISCUSSION OF THE RESULTS

Study of the $F^{19}(d,p)$ F^{20} reaction under the experimental conditions described above allowed us to register 24 proton groups in the excitation energy up to 6.75 mev. These characterize the ground state of the F^{20} nucleus and 23 excited levels.

The figure shows a proton spectrum obtained with bombarding deuteron energy 3.7 mev. The successsive numbers indicate the proton groups from the F^{19} (d, p) F^{20} reaction. These same indices have corresponding levels of the F^{20} nucleus. Proton groups from (d,p) reactions with carbon and oxygen are indicated in the curve by the symbol of the final nucleus and number of the group. Two proton groups on this curve have double indices: C^{13} (0) and 5, and also O^{17} (1) and 8. In these cases, there is a superposition of the proton groups from the impurities and the fluorine itself. This conclusion is reached by comparison of the relative intensities of proton groups from control spectra (only carbon and oxygen) with spectra from a fluorine target.

Excited levels of the F^{20} nucleus, in mev

Group number	present work	data of other authors [3]	[4]	[5]	[6]	[7]	[10]
1	0.66	0,63	0,64	0.69	0.652	—	—
2	0.81	0.83	—	—	0.828	—	—
3	1.08	1.0	0.97	0.98	{ 0.988 1.059	— —	—
4	1,34	1.37	1,31	—	1.309	—	—
—	—	—	1,91	—	1.970	—	—
5	2.15	—	—	2.20	{ 2.048 2,195	— —	—
(6)	(2.54)	2.55	2,52	—	—	—	—
—	$O^{17}(0)$	2.91	2.83	2.70	2.870	—	—
—	—	—	—	—	2,966	—	—
7	3.11	—	—	3.12	—	—	—
8	3.58	3,49	3,45	—	{ 3,491 3,528 3.586	— — —	—
—	—	—	—	—	3,681	—	
9	3.77	—	—	3.74	—	—	—
—	—	—	—	—	3,961	—	—
10	4.09	4,06	4.01	—	4,079	—	—
11	4.37	4.31	—	4.41	{ 4,275 4,310	— —	—
12	4,55	—	—	—	—	—	—
(13)	(4.73)	4,73	—	—	—	—	—
14	4.86	—	—	—	—	—	—
—	$C^{13}(1)$	—	—	—	(5,063)	—	5.04
15	5.16	—	—	—	—	—	5,19
—	—	—	—	—	—	—	5,27
16	5,41	—	—	—	—	—	—
17	5,54	—	—	—	—	—	—
—	$C^{13}(2)$	—	—	—	—	—	5.72
—	—	—	—	—	—	—	5.87
—	$C^{13}(3)$	—	—	—	—	—	5,95
18	6,07	—	—	—	—	—	—
19	6,17	—	—	—	—	—	6,25
20	6,36	—	—	—	—	—	—
21	6,47	—	—	—	—	—	6,52
22	6,65	—	—	—	— —	{ 6,63 6,65	6,63
23	6,74	—	—	—	—	6.70	—
—	—	—	—	—	—	6.86	6,81
—	—	—	—	—	—	6.92	6,98
—	—	—	—	—	—	7,0	—
—	—	—	—	—	—	7,08	—
—	—	—	—	—	—	7.17	7.20
—	—	—	—	—	—	7,50	—
—	—	—	—	—	—	8,18	—
—	—	—	—	—	—	8,54	—

The proton group number 23, corresponding to an excitation energy of 6.74 mev is not seen in the Figure. It appears on plates obtained from deuteron bombardment of the target at higher energies. The energy levels of F^{20} obtained in our experiments are given below in the Table. Our results are compared with those of four other authors which were also based on a study of the F^{19} (d, p) F^{20} reaction. Besides this the table shows levels of the F^{20} nucleus at higher excitation energies taken from work which investigated the F^{19} (n, n) F^{20} reaction. The last column gives data from the work of El Bedewi [10]. In that article which was delivered to us as we were submitting for publication, the author describes experiments on the magnetic analysis of the F^{19} (d, p) F^{20} reaction. These were carried out with deuterons of 8.9 mev. The author investigated the levels of F^{20} up to an excitation energy of 7.2 mev. For a majority of the groups the angular distribution of the protons was also studied. Since in the region previously studied by Watson and Buchner, El Bedewi used their values for the energy levels of F^{20}, we have included only the data for higher levels which the author determined independently.

For the reaction $F^{19}(d, p)F^{20}$ we obtained the value for the reaction energy $Q_0 = 4.383 \pm 0.015$ mev. Watson and Buchner give for this quantity $Q_0 = 4.373 \pm 0.10$ mev. The energy of the reaction obtained from the mass difference is $Q_0 = 4.375$ mev. All three values are in sufficiently close agreement.

For the majority of levels our experimental uncertainty was 20–25 kev. Only some values were determined with greater accuracy. Comparison of our results with those of other authors shows a good degree of agreement for the values of most excited levels of F^{20}. There are however some differences which are outside the limit of error in our measurements. We will discuss these.

In our experiment we did not observe the F^{20} level with $E^* = 1.970$ mev which was shown by Watson and Buchner and earlier by Allen and Rall ($E^* = 1.91$ mev).

The energy level with $E^* = 2.54$ mev was observed in our experiments only in three out of six plates. The corresponding value is less certain and is shown in parentheses in the table. The level of F^{20} analogous to this was observed in Refs. 3 and 4, but not in Refs. 6 and 10. In the experiment of El Bedewi it is true that the group could have been masked by a proton group from the $O^{16}(d, p)O^{17}$ reaction.

In our experiment there is no level with $E^* = 2.966$ mev, as was found by Watson and Buchner. The closest level to this which we observed was $E^* = 3.11$ mev. These can probably not be compared because they fall outside the errors of both measurements. A value close to ours $E^* = 3.12$ mev. was observed by Shull.

We did not observe two weak levels at $E^* = 3.681$ and $E^* = 3.961$ mev which were observed by Watson and Buchner. Our curves however show a strong group 9 with $E^* = 3.77$ mev, that is an excitation energy lying between the indicated two levels. A level similar to ours is reported by Shull ($E^* = 3.74$ mev).

Although we have identified the 6.17 mev level which we have observed with the 6.25 mev level observed by El Bedewi this identification is not definite since the spread of data is too large. In a number of cases we did not observe levels determined by the work of El Bedewi and registered others which did not appear in his experiments.

As can be seen from the Table, seven levels of the F^{20} nucleus with indices 12, 14, 16, 17, 18 20 and 23 have not been observed in any of the preceding work. Level 23 can, however, be identified with the relatively close value $E^* = 6.70$ mev which was observed in a study of resonance scattering of neutrons.

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