spectra; the similarity of the spectra at different incident energies and different angles of observation; the approximate agreement between an average temperature derived from these spectra and temperatures found in comparable experiments; the symmetries observed in the angular distributions; and the agreement between observed and predicted proton yields.

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Seniority of the $f_{7/2}{}^4$ Levels in Cr^{52}†

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The seniorities of recently observed levels in Cr^{52} are considered. The energies as well as $M1$ transition rates agree rather well with a $f_{7/2}{}^4$ assignment. On the other hand, there is not enough experimental information about the possible operation of the $E2$ selection rule ($\Delta v=2$ but no $\Delta v=0$) for this configuration.

In a recent paper[1] the level structure of Cr^{52} has been experimentally investigated. The following levels were assigned the $f_{7/2}{}^4$ proton configuration (the neutrons are in the closed shell of 28): ground state ($J=0$), 1.434 Mev ($J=2$), 2.369 Mev ($J=4$), 2.766 Mev ($J=4$), 2.965 Mev ($J=2$), and 3.112 Mev ($J=6$). The positions of the lower 2^+ level and the 6^+ level agree very well with those found in $f_{7/2}{}^4$ configurations.[2,3] The existence of two 4^+ levels as well as another 2^+ level can be simply interpreted. In the $f_{7/2}{}^n$ configurations with two-body forces between the protons, the seniority is a good quantum number, and the pairing property holds. Therefore, in the $f_{7/2}{}^4$ configuration the positions above the $J=0$, $v=0$ ground state of the $J=2$, 4, 6 levels with seniority $v=2$ should be the same as in the $f_{7/2}{}^2$ configuration. The other possible levels of the $f_{7/2}{}^4$ configuration have seniority $v=4$ and spins $J=2$, 4, 5, 8.

The validity of the description in terms of a pure jj-coupling $f_{7/2}{}^4$ configuration can be checked by considering the rate of $M1$ transitions between the levels.[4] The $M1$ operator is proportional in this case (j^n configuration of identical particles) to **J**. It has therefore vanishing matrix elements between *any* two orthogonal states (even if they have the same spin and parity). In V^{51}, for example, there is a very slow $M1$ transition between the first excited $\frac{5}{2}$ state (at 0.32 Mev) and the $\frac{7}{2}$-ground state. In Cr^{52}, no transition was detected between the two 4^+ states (at 2.369 and 2.766 Mev). This shows that the $M1$ transition between these two levels is considerably attenuated (as compared to the $E2$ transition between the 4^+ level at 2.766 Mev and the 2^+ level at 1.434 Mev). It would be of interest to have more accurate limits on the rate of this transition so that the attenuation factor could be obtained. This attenuation, however, does not indicate at all whether the seniority is or is not a good quantum number. This question is irrelevant in the V^{51} case where there is only one state with a given spin of the $f_{7/2}{}^3$ configuration. In Cr^{52}, however, there are two states with $J=4$, as well as two states with $J=2$, and the validity of the seniority quantum number could be investigated. Since the $M1$ selection rule does not give any information about this problem, other effects should be considered.

Another selection rule that can be checked in the Cr^{52} case concerns $E2$ transition probabilities. The matrix elements of even tensor operators taken between states with the same seniority, vanish in the middle of a shell, i.e., in the $j^{(2j+1)/2}$ configuration of identical particles. A special case of this is the vanishing of the quadrupole moment in such configurations. Thus, in this case, in any transition the seniority must change by 2 (this is the maximum possible change for single-particle jumps). As well known, most $E2$ transition probabilities are largely enhanced compared to "single-particle rates". Still, we may be able to approximate the effective $E2$ operator to be used with shell model wave functions by a sum of equally enhanced single-particle operators each of which is a tensor of degree 2. Every such tensor is proportional, within the given configuration, to $r^2Y_{2m}(\vartheta,\varphi)$ with a factor that

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2 I. Talmi, in *Proceedings of the Rehovoth Conference on Nuclear Structure*, edited by H. J. Lipkin (North Holland Publishing Company, Amsterdam, 1958), pp. 31–45, where other references are given.

3 J. D. McCullen and J. J. Kraushaar, Phys. Rev. **122**, 555 (1961).

4 I. Talmi and I. Unna, Ann. Rev. Nuclear Sci. **10**, 383 (1960).

could be interpreted in terms of the square of an effective charge for this transition. There is some recent evidence from electron scattering on V^{51} that this approach can correctly predict branching ratios.[5] We can try and see whether it gives sensible results also for Cr^{52}.

The first task is to determine the seniorities of the two experimentally observed 4^+ states. If we consider the position of the 4^+ level in known $f_{7/2}{}^2$ configurations,[2,3] we conclude that the 4^+ level with seniority $v=2$ in Cr^{52} should be about 2.75 Mev above the ground state. This agrees very well with the position of the *higher* 4^+ level in Cr^{52} (2.766 Mev). If we accept this assignment, it turns out that the 4^+ level with $v=4$ is lower than the 4^+ level with $v=2$. If the interaction energy is due to effective two-body forces only, we can calculate the positions of the $v=4$ levels in the $f_{7/2}{}^4$ configuration from any given set of levels of the $f_{7/2}{}^2$ configuration. If we start from the Ca^{42} levels (0^+ at 1.5, 4^+ at 2.75, 6^+ at 3.2 Mev), we obtain, using the appropriate coefficients of fractional parentage[6] (c.f.p.), the 4^+ level with $v=4$ at 2.47 Mev. This is actually lower than the 4^+ level with $v=2$ and rather close to the experimental value (2.37 Mev of the *lower* 4^+ level in Cr^{52}). If we take the two particle energies from the $v=2$ levels of Cr^{52} itself (2^+ at 1.434, 4^+ at 2.766, and 6^+ at 3.112 Mev), we obtain the 4^+ level with $v=4$ at 2.32 Mev which is even in better agreement with the experiment.

As long as there are only effective two-body interactions between nucleons, the seniority is a good quantum number in the $f_{7/2}{}^n$ configurations. Effective three-body and four-body forces, however, can admix the two 4^+ states. The experimental positions of the $f_{7/2}{}^3$ states in V^{51} agree rather well with the values calculated from the $f_{7/2}{}^2$ energies.[7] There are some deviations which can be attributed to a slight amount of configuration interaction. It may be possible that these deviations can be considered as due to effective three body forces that may be operative also in Cr^{52}. If this is the case, we can see whether these possible three body interactions give rise to admixtures of the two 4^+ states, with $v=2$ and $v=4$, in Cr^{52}. Using the appropriate c.f.p.[6] and the observed V^{51} levels,[7] we obtain for the nondiagonal matrix element between the two 4^+ states the value of 0.07 Mev. This is rather small, as compared to the 0.4 separation between the two levels. The calculated shift of the levels due to this interaction is only about 0.01 Mev and the admixture of different seniorities in the actual states would be about 3%.

If we adopt the seniority assignments made above (4^+ level at 2.766 Mev $v=2$, and the 4^+ level at 2.369 Mev $v=4$), we conclude that the reduced matrix element of the $E2$ transition between the two 4^+ levels ($\Delta v=2$) should be considerably bigger than that of the $E2$ transition between the upper 4^+ level (at 2.766 Mev) and the 2^+ level (at 1.434 Mev) ($\Delta v=0$). However, the energy ratio between these two transitions taken to the fifth power is 1/360, and, therefore, it is hard to draw any definite conclusion from the fact that the $4^+ \rightarrow 4^+$ transition was not detected. Another check on our assignment could be obtained from the branching ratio of the decay of the 6^+ level (at 3.112 Mev). This level decays primarily to the lower 4^+ level (81.9%) and only a small branch goes to the upper 4^+ level (0.9%). However, the transition to the lower level is energetically favored by a factor $(0.744/0.346)^5 \sim 45$. Therefore, the transition strength to the upper 4^+ level ($\Delta v=0$) seems to be smaller by only a factor of 2 from that to the lower 4^+ level ($\Delta v=2$). Although this is in the right direction, a factor 2 would indicate large admixtures of seniorities $v=2$ and $v=4$ in the two observed states. Alternatively it could indicate that the description of the $E2$ operator as a sum of single nucleon operators is far from exact. It is therefore highly desirable to establish rather accurately this branching ratio, as well as the other ones in this nucleus.

Starting from the levels of the $f_{7/2}{}^2$ configurations, we can calculate the positions of other $v=4$ levels in Cr^{52}. Using the Ca^{42} levels or the $v=2$ levels in Cr^{52}, we obtain the calculated position of the $J=2$, $v=4$ level in Cr^{52} at 3.5 Mev above the ground state. The observed position of the state in Cr^{52}, tentatively given a 2^+ assignment, is 2.965 Mev. The branching ratios in the decay of this level are of interest. If it is actually the $J=2$, $v=4$ level, its transition strength to $v=2$ levels should be much bigger than that to the $v=4$ levels, or $v=0$ level. The available information on the decay of this level indicates that it decays primarily to the first excited 2^+ level (at 1.434 Mev) with a crossover to cascade smaller than 0.03.[8] This is in good agreement with the seniority selection rules. The crossover transition involves $\Delta v=4$ and should be forbidden; whereas, even in the absence of the $M1$ transition, the $E2$ $2^+ \rightarrow 2^+$ transition has $\Delta v=2$ and is, therefore, not inhibited. However, it may be too hasty to attribute this branching ratio to the seniority-selection rules. Such crossover to cascade ratios are known in other cases in which the states considered do not even belong to the same configuration. Only if the configuration assignment is definitely established will it be possible to decide on the validity of the seniority as a good quantum number.

The next high state with $v=4$ in Cr^{52} has $J=5$ and is similarly calculated to lie at 3.8 Mev above the ground state. (The other state with $v=4$ has $J=8$ and should lie at 5.2 Mev). Each of the possible (5^+,6^+) states at 3.614 and 3.832 Mev can be given this assignment. None of them seems to decay to the 6^+ state which is in agreement with the absence of any $M1$ transitions. The $E2$ transitions from the (5^+,6^+) states to the 4^+ states are energetically favored over the transition to the 6^+ state

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[6] See, e.g., A. R. Edmonds and B. H. Flowers, Proc Roy. Soc. (London) **A214**, 515 (1952).

[7] J. E. Schwäger, Phys. Rev. **121**, 569 (1961).

[8] D. M. Van Patter, Bull. Am. Phys. Soc. **6**, 47 (1961).

and were actually observed. If the 5^+ $v=4$ state is the 3.614 Mev state, the observed branching ratio of its decay to the two 4^+ levels would indicate that the upper 4^+ state is primarily a $v=2$ state, whereas, the lower 4^+ state has primarily $v=4$. However, the ratio of the observed transition strengths is only 3. This would indicate rather considerable admixtures or else the impossibility of an exact description of the effective $E2$ operator as a sum of single particle operators. The corresponding ratio of transition strengths from the 3.832 Mev level seems to be about 50, but the data here are only rough values. It is clear that no further conclusions can be reached before the experimental situation is clarified.

From the experimental evidence, it seems that the $f_{7/2}{}^n$ configurations of either protons or neutrons (while the other group is in closed shells) are rather pure. The level scheme of Cr^{52} with the seniority assignments made above agrees rather well with a $f_{7/2}{}^4$ configuration assignment. This nucleus may be very useful in testing the validity of the seniority as a good quantum number. The answer to this question will tell us whether the effective mutual interactions between nucleons can be really represented by two body forces, or that effective three and four body forces are also important. At the same time the transitions in Cr^{52} may furnish a sensitive test of the idea that the effective $E2$ operator is actually a sum of effective operators of the independent individual nucleons. In order to find out more about these problems more accurate experimental information must be available.

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Delayed Neutron Yields in the Photofission of U^{238} and Th^{232}†

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The delayed neutron yield per fission in the photofission of U^{238} and Th^{232} was measured with a 22-Mev betatron. The results are 0.036 and 0.030, respectively, and substantiate previous empirical predictions for these isotopes. No evidence was found of a dependence of this ratio as a function of energy.

THE absolute delayed neutron yield of several isotopes of Th, U, Pu and Cf has been known for some time and recent additional data were published by Cox[1]; in this paper, a systematic of the yield/fission is suggested.

Two additional nuclei, U^{238} and Th^{232}, were measured by us using the 22 Mev betatron of the University of São Paulo; photofission in these isotopes cannot be produced by particle-induced fission. In neutron-induced fission, the fissioning nucleus has one additional neutron over the target neutron number.

Measurements of delayed neutron yields are easy to carry out with betatrons which are pulsed machines with short x-ray pulses and high repetition rates. The fissionable target is irradiated inside a paraffin box in which are embedded two BF_3 counters.[2] The prompt neutrons are counted by the same system and decay with a half-life of 125 μsec characteristic of the paraffin moderator. After 3000 μsec, only the delayed neutrons are left, and the prompt neutron tail and background are negligible. No correction for the decay of the various periods of the delayed neutrons is necessary because counting is made after equilibrium is reached.

The ratio of delayed to prompt neutrons is obtained without any corrections due to counting of activities and absolute calibration of counters.

Measurements were made at maximum bremsstrahlung energies of 12 and 20 Mev.

TABLE I. Experimental results. The errors in columns 3 and 4 are statistical. The errors in column 5 represent extreme values using plausible estimates for $\sigma(\gamma,n)$ and $\sigma(\gamma,2n)$, and $\bar{\nu}$ from Gindler *et al.*[3] and Leachman.[4]

Element	Energy (Mev)	(Relative counts/pulse)/ monitor unit Prompt	Delayed	Delayed neutrons/fission
U^{238}	12	620±25	3.2 ±0.2	$0.036^{+0.008}_{-0.007}$
	20	2545±100	13.6 ±0.5	$0.036^{+0.010}_{-0.009}$
Th^{232}	12	223±12	0.55±0.04	$0.027^{+0.008}_{-0.007}$
	20	995±40	2.2 ±0.1	$0.030^{+0.012}_{-0.006}$

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