(p, t) reactions on ^{75}As and ^{74}Ge and the weak coupling core-excitation model

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$J^{\pi}=\frac{3}{2}^-$ levels to which $L=0$ (p,t) transitions are observed have been identified in ^{73}As at 0 (100%), 396 (2.4%), 656 (3%), and 1595 (1.5%) keV. The shapes of the angular distributions for the ground state and 656 keV level are identical to those corresponding to the two 0^+ levels of ^{72}Ge at 0 (100%) and 690 (27%) keV. Some of these results, the large difference in relative intensities of the pure $L=0$ transitions to the levels at 690 keV in ^{72}Ge (27%) and 656 keV in ^{73}As (3%) and the fact that two other $L=0$ transitions are observed in ^{73}As, significantly differ from those expected for strict weak coupling core excitation. It is shown that weak coupling is indeed a poor approximation for the two 0^+ levels of ^{72}Ge, due to the "blocking" of the proton $p_{3/2}$ orbital.

[NUCLEAR REACTIONS ^{74}Ge(p,t), ^{75}As(p,t), $E=26$ MeV, measured $\sigma(\theta)$; ^{73}As deduced levels, J, π.
NUCLEAR STRUCTURE ^{73}As; weak coupling core-excitation model.]

I. INTRODUCTION

A series of experiments by Seth and co-workers[1] has shown that two $L=0$ transitions are quite generally observed in the (p,t) reaction on odd-A nuclei $(A+3\rightarrow A+1)$ in the s-d and f-p shells. These two transitions have the same angular distributions and about the same relative intensities (within a factor of 3) as those feeding the ground state and first excited 0^+ state in the adjacent even-A nuclei $(A+2\rightarrow A$ or $A+4\rightarrow A+2)$. The absolute intensities for the ground states and the energy differences are, moreover, of the same order. These results have been interpreted as an evidence that the states populated by these transitions in the odd-A final nucleus could be described by weak coupling of the two 0^+ states of the even-A core with the same odd particle (proton or neutron) acting as a spectator in the (p,t) reaction. All the final $A+1$ nuclei in the papers published by Seth were quite naturally chosen to be good weak coupling cases, that is to say, nuclei with one particle outside (or one hole in) an even core consisting of a closed shell or subshell (spectroscopic factor for the one particle g. s.$\rightarrow$g.s. transition: $0.7<S<1$). The question therefore remains open: Does the phenomenon observed in the (p,t) reactions really reflect a weak coupling core excitation structure of the levels of the nucleus $A+1$, or does it occur quite generally even when weak coupling does not dominate?

To help to answer this question it was interesting to see what happens with an even final core *not* consisting of closed shells or subshells. With this in mind, our study of the (p,t) reaction on all the even Ge isotopes[2] has been complemented by the study of the (p,t) reaction on ^{75}As. The final even and odd nuclei, A and $A+1$, are here $^{72}_{32}$Ge and $^{73}_{33}$As. The proton $p_{3/2}$ subshell is neither filled nor empty[3,4] in ^{72}Ge and continue not to be filled in the even Se and Kr nuclei (an evident proof of this is the appearance of $J^{\pi}=\frac{3}{2}^-$ ground states in As, Br, and Rb). As a consequence the $J^{\pi}=\frac{3}{2}^-$ ground state of ^{73}As *cannot* be considered as consisting simply of a $p_{3/2}$ proton weakly coupled to the 0^+ ground state of ^{72}Ge (experimentally[4]: $S_{\text{g.s.}\rightarrow\text{g.s.}}\approx 0.25$). ^{73}As is therefore a good test nucleus where weak coupling is not expected to work, at least for the ground state.

The predictions of a strict weak coupling core-excitation model[1,5] would be the following, for the (p,t) reaction:

(1) The ground states of ^{72}Ge and ^{73}As should be populated both by $L=0$ transfers with identical shapes and intensities.

(2) The same should be true for the 0_2^+ (690 keV) level of ^{72}Ge and one $J^{\pi}=\frac{3}{2}^-$ level of similar energy in ^{73}As.

(3) The first 2^+ level of ^{72}Ge should give rise to a multiplet of levels $|2^+\otimes p_{3/2},J\rangle$ in ^{73}As with similar shapes for the angular distributions. The intensities should be proportional to $(2J+1)$, the total intensity being equal to that observed for the 2^+ level in ^{72}Ge; the energy centroid should be close to the energy of the 2^+ level in ^{72}Ge.

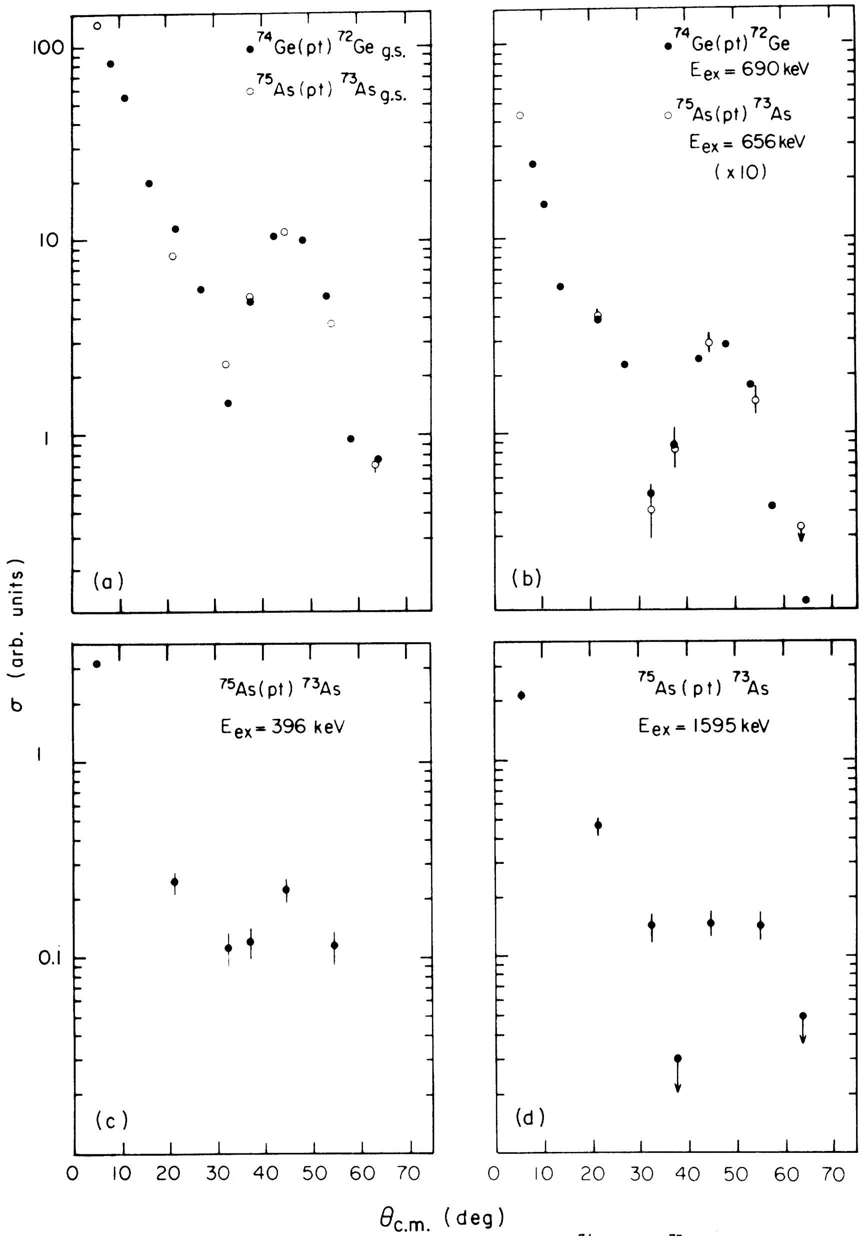

FIG. 1. Angular distributions of the tritons from the (p, t) reaction on ^{74}Ge and ^{75}As targets. The shapes are compared for the ground state transitions in (a) and for the transitions to the 690 keV level of ^{72}Ge and 656 keV level of ^{73}As in (b). Target thickness measurements show that 100 arbitrary units are equal to 3.6 mb/sr. In (b) the intensity of the transition to the 656 keV level of ^{73}As was multiplied by 10 in order to permit a comparison of the shapes. The angular distributions for the 396 and 1595 keV levels are shown in (c) and (d).

II. EXPERIMENTS

The experiments were done using the 26 MeV proton beam ($I \approx 1$ μA) of the Orsay MP tandem accelerator and a split pole spectrometer equipped with solid state position sensitive detectors. The (p, t) reaction was performed on ^{74}Ge (94.5% enrichment) and ^{75}As evaporated targets, with an energy resolution (full width at half maximum) of 12 keV for Ge and 9 keV for As (very thin target).

The results can be summarized as follows:

(1) The (p, t) reaction is very selective and only few of the known levels of ^{73}As are populated. Particularly striking is the fact that well known levels at 67 ($J^\pi = \frac{5}{2}^-$), 84.5 ($J^\pi = \frac{1}{2}^-, \frac{3}{2}^-$), 428 ($J^\pi = \frac{9}{2}^+$) keV strongly populated[4] in the (^{3}He, d) reaction, are not even observed in the (p, t) reaction.

(2) The unambiguous $L = 0$ dominant nature of the transitions feeding the ground state and the levels at 396, 656, and 1595 keV in ^{73}As firmly establish-

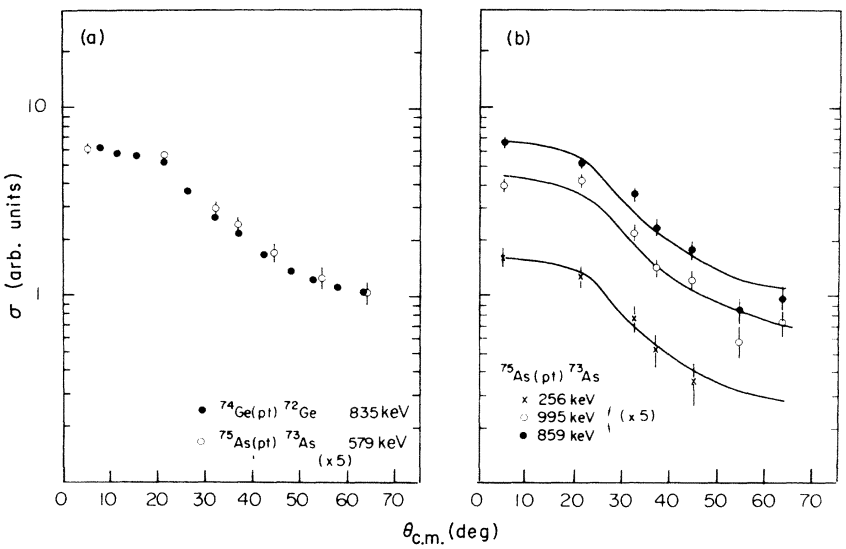

FIG. 2. Angular distributions of the tritons from the (p, t) reactions on ^{74}Ge and ^{75}As. The distribution for the 579 keV level of ^{73}As is compared with the distribution corresponding to the 2_1^+ level of ^{72}Ge in (a) [in order to permit this comparison the intensity of the ^{73}As transition was multiplied by 5, instead of 10 in 1(b)]. The distributions for the 256, 859, and 995 keV levels of ^{73}As are given, also multiplied by 5, in (b). The curves represent the best fit for each distribution with the shape of the distribution for the 2_1^+ level in ^{72}Ge.

es that these levels all have $J^\pi = \frac{3}{2}^-$, as the ^{75}As ground state. This confirms the spins previously proposed for the two former ones, but is in disagreement with the value $J^\pi = \frac{1}{2}^-$ favored[6] for the 656 keV level. The spin of the level at 1595 keV was not known previously. The total $L = 0$ (p, t) intensity for the three excited levels is only 6.9% of the ground state one. Their intensity weighted energy centroid is 780 keV.

(3) The shapes of the angular distributions for the (p, t) transitions feeding the ground state and the level at 656 keV in ^{73}As are the same as those for the transitions corresponding, respectively, to the ground state and the 690 keV, $J^\pi = 0_2^+$, level in ^{72}Ge (see Fig. 1). These transitions are, therefore, pure $L = 0$ transitions. The distributions of the 396 and 1595 keV levels exhibit a dominant $L = 0$ shape but differ somewhat from the preceding ones. This may be due to a different configuration of the transferred neutron pair or/and to a weak $L = 2$ admixture.

(4) The ratio $\sigma(0_{690}^+)/\sigma(0_{g.s.}^+) = 27\%$, determined in the ^{74}Ge$(p, t)^{72}$Ge experiment, is very different from the ratio $\sigma(\frac{3}{2}^-, 656)/\sigma(\frac{3}{2}^-, \text{g.s.}) \approx 3\%$ determined in the ^{75}As$(p, t)^{73}$As experiment.

(5) The intensities of the transitions ^{74}Ge$_{g.s.}$ $\to$ ^{72}Ge$_{g.s.}$ and ^{75}As$_{g.s.} \to$ ^{73}As$_{g.s.}$ are equal.

(6) Transitions are observed to levels at 256, 579, 859, and 995 keV with relative intensities: 5/20/22/13.4. Their angular distributions are the same as the one measured for the first 2^+ level at 835 keV in ^{72}Ge (see Fig. 2). This is particularly striking because this distribution in ^{72}Ge has a peculiar shape, observed[2] for all the 2_1^+ levels of the Ge isotopes, and different from that of a standard $L = 2$ transfer as seen for other known 2^+ levels. The intensity weighted energy centroid is 748 keV and the ratio of the total (p, t) intensity for these levels to the (p, t) intensity for the 2^+ level in ^{72}Ge is 60%. These levels, with the exception of the 256 keV level, are very weakly populated, if at all, in the $(^3\text{He}, d)$ reaction.[4]

III. DISCUSSION

The experimental results given above are summarized in Fig. 3. In many aspects they seem to be in agreement with the predictions of the weak coupling core-excitation model, using as core states the ground state and first 2^+ level of ^{72}Ge. The agreement would be even better if we assumed that the even core is intermediate[7] between ^{72}Ge and ^{74}Se, the 2^+ mean energy of 735 keV being very close to the 748 keV, $L = 2$, centroid in ^{73}As. Spins suggested on the basis of the relative (p, t) intensities as giving reasonably constant values of $\sigma/(2J+1) = 2.5\text{-}3.3\text{-}2.8\text{-}3.3$, would be as follows: 256, $J^\pi = \frac{1}{2}^-$; 579, $J^\pi = \frac{5}{2}^-$; 859, $J^\pi = \frac{7}{2}^-$; and 995, $J^\pi = \frac{3}{2}^-$. These spins, except for the level at 995 keV, are in agreement with the values proposed in Ref. 6.

At first glance, the $J^\pi = \frac{3}{2}^-$ level at 656 keV in ^{73}As is a good candidate for the level corresponding to weak coupling of a $p_{3/2}$ proton to the 690 keV, 0_2^+, level of ^{72}Ge. However, its (p, t) intensity is

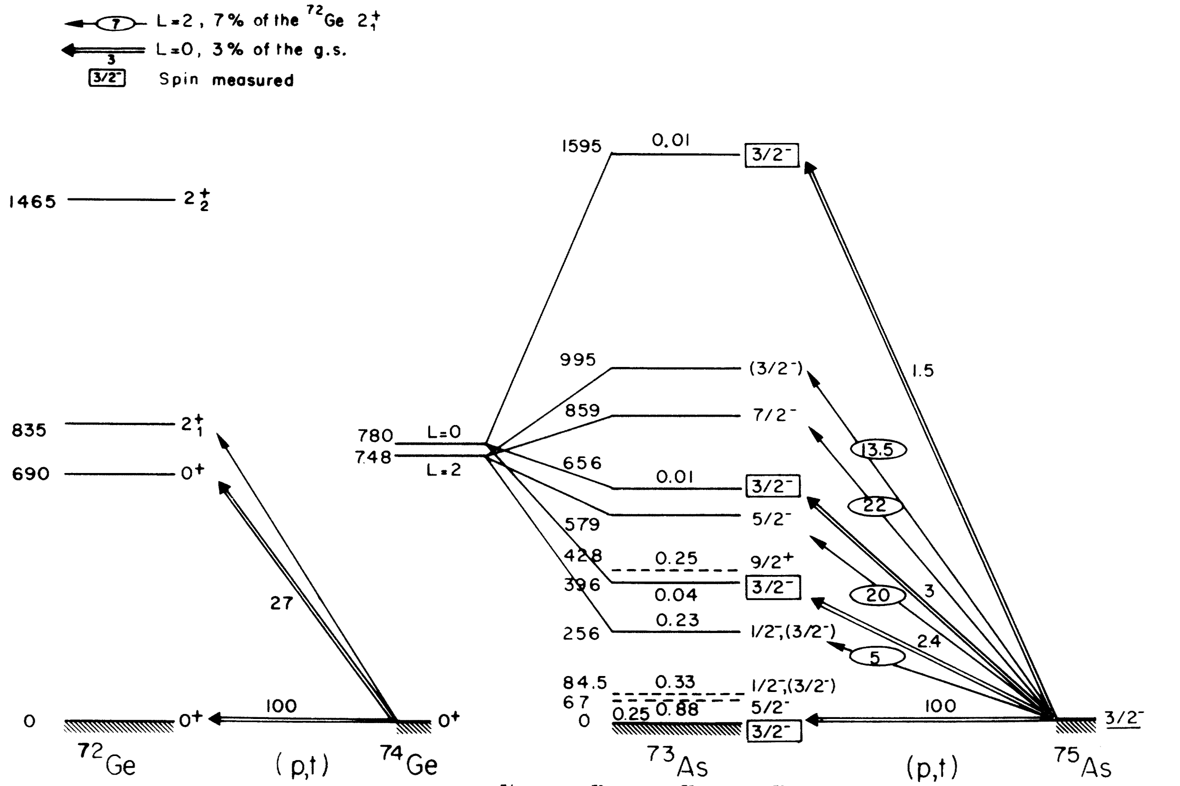

FIG. 3. Comparison of the results of the reactions ^{74}Ge(p, t)^{72}Ge and ^{75}As(p, t)^{73}As. The numbers just above the levels in ^{73}As are the values of the spectroscopic factors for the ^{72}Ge(^{3}He, d)^{73}As reaction (Ref. 4). Dotted levels are not seen in the (p, t) reaction.

only 3% compared with 27% observed for the 0_2^+ level in ^{72}Ge and, furthermore, we observe two more $L=0$ transitions in ^{73}As whose equivalents do not exist in ^{72}Ge. Even using a core intermediate[7] between ^{72}Ge and ^{74}Se, we would predict a single $L=0$ transition, with an intensity intermediate between 27% (^{72}Ge) and ≈4% (^{74}Se, Ref. 8), that is of the order of 10 to 15% of the ground state one. It is to be remarked, however, that the energy centroid of the $L=0$ excitation in ^{73}As, 780 keV, is very close to the energy of the 0^+ level of the intermediate core, 768 keV.

It has already been stressed that in ^{73}As the weak coupling condition, $S_p(\mathrm{Ge_{g.s.}} \leftrightarrow \mathrm{As_{g.s.}}) = \langle {}^{73}\mathrm{As_{g.s.}} | {}^{72}\mathrm{Ge_{g.s.}} \otimes p_{3/2} \rangle \approx 1$, appears experimentally not to be fulfilled for the ground state. This result is easily understood if we remember that in a strict shell model description the proton $p_{3/2}$ subshell should be completely filled in ^{72}Ge. Pairing interaction does, in fact, introduce configuration mixing and the following proton wave functions have already been proposed by us[3] for the two 0^+ levels of ^{72}Ge, to interpret the results of the ^{71}Ga(^{3}He, d)^{72}Ge reaction,

$$\psi_{0_1^+} = \alpha'(p_{3/2})^4{}_0 + \beta'(f_{5/2})^2{}_0(p_{3/2})^2{}_0 ,$$
$$\psi_{0_2^+} = \beta'(p_{3/2})^4{}_0 - \alpha'(f_{5/2})^2{}_0(p_{3/2})^2{}_0 , \qquad (1)$$

with $\alpha' = (0.28)^{1/2}$ and $\beta' = (0.72)^{1/2}$, the neutron wave function being a mixture[9]

$$\alpha(p_{1/2})^2{}_0 + \beta(g_{9/2})^2{}_0 \qquad (2)$$

(α and β are supposed[3] to be the same for the two 0^+ levels). We see that the "blocking" of the $p_{3/2}$ orbital in the ground state of ^{72}Ge reduces the weak coupling overlap integral $S_p(\mathrm{Ge_{g.s.}} \leftrightarrow \mathrm{As_{g.s.}})$ to a maximum value of 0.36 [$S_p(\mathrm{exp}) \approx 0.25$]. With the proposed wave functions, the blocking is even more effective for the 0_2^+ level (86% filling of the $p_{3/2}$ orbital compared with 64% in the g.s.). A maximum calculated value of the overlap of this 0_2^+ level, weakly coupled to a $p_{3/2}$ proton, and any of the $J^\pi = \frac{3}{2}^-$ levels in ^{73}As is $S_p(\mathrm{Ge}_{0_2^+} \leftrightarrow \mathrm{As}_{3/2^-}) < 0.14$. In fact this maximum value represents the sum of all the overlap integrals for $J^\pi = \frac{3}{2}^-$ levels. Much smaller individual values ($0.004 \leq S_p(\mathrm{Ge}_{0_2^+} \leftrightarrow \mathrm{As}^*_{3/2^-}) \leq 0.02$) would result for the excited levels from an estimate using the present proton wave functions for the 0^+ levels and the very small[4] experimental population of the levels at 396, 656, and 1595 keV in the (^{3}He, d) reaction.

No wave function is available for the first 2^+ level of ^{72}Ge, but the fact[10] that the $E2$ transition $2_1^+ \to 0_{\mathrm{g.s.}}^+$ is accelerated (20 single particle units) suggests a collective nature, with many particles involved. No significant blocking of the $p_{3/2}$ orbital is therefore expected, in agreement with the experimental observation of states whose characteristics correspond quite well to the $|2^+ \otimes p_{3/2}\rangle$ multiplet.

In summary, for the ground state of ^{73}As, the weak coupling overlap integral is only equal to 0.25 and the experimental results conform to the predictions given in the Introduction; for all the other $J^\pi = \frac{3}{2}^-$ levels the weak coupling overlap integrals are very small and the results do not conform to the predictions. It seems therefore that the success of the weak coupling model (p, t) predictions is indeed—as was previously proposed[1]—related to the value of the overlap integral between the final level and the core state coupled to a particle. The fact, however, that most of the weak coupling criteria are experimentally satisfied in a (p, t) experiment for a given observed transition does not necessarily mean that this integral is larger than 0.25. In our case, the experimental data are explained, at least qualitatively, as due to the peculiar pairing nature of the 0^+ levels of the Ge nuclei, leading to a blocking of the $p_{3/2}$ proton orbital, particularly important for the 0_2^+ level. It appears, in fact, that the excited $J^\pi = \frac{3}{2}^-$ levels of ^{73}As cannot be described as resulting from the weak coupling of the 0_2^+ level of ^{72}Ge and a $p_{3/2}$ particle. To verify if the explanation proposed is correct, a (p, t) experiment populating the levels of an $A+1$ nucleus consisting of the same ^{72}Ge core *coupled to a* $g_{9/2}$ *neutron* would be interesting: the neutron wave function (2) of ^{72}Ge shows indeed a very small occupation of the $g_{9/2}$ orbital and no blocking should occur.

This ^{75}Ge$(p, t)^{73}$Ge experiment is not feasible, ^{73}Ge being the only stable odd isotope, but the experiment ^{73}Ge$(p, t)^{71}$Ge has been done.[11] The ground state of ^{73}Ge has $J^\pi = \frac{9}{2}^+$ and two $J^\pi = \frac{9}{2}^+$ levels are known in ^{71}Ge at 198 and 1038 keV. The occupation of the $g_{9/2}$ orbital in ^{70}Ge is small[9] and the spectroscopic factor for the reaction $^{70}\text{Ge}_{\text{g.s.}} \to {}^{71}\text{Ge}_{198}$ is equal[12] to 0.73, showing that indeed the weak coupling condition is fulfilled between the 198 keV level of ^{71}Ge and a $^{70}\text{Ge}_{\text{g.s.}}$ core (this is also true for the $^{73}\text{Ge}_{\text{g.s.}}$ and a $^{72}\text{Ge}_{\text{g.s.}}$ core). Two, and only two, strong $L=0$ transitions are observed[11] in the (p, t) reaction, to the $J^\pi = \frac{9}{2}^+$ levels at 198 and 1038 keV, the shapes and intensities being very comparable to those observed in the ^{72}Ge$(p, t)^{70}$Ge reaction. [$\sigma_{198}(71)/\sigma_{\text{g.s.}}(70) \approx 0.72$; $\sigma_{1038}(71)/\sigma_{0_2^+}(70) \approx 1.5$.] The energy differences are 840 keV in ^{71}Ge and 1220 keV in ^{70}Ge. [The agreement both for relative intensities and excitation energies would also be somewhat better here using a core intermediate between ^{70}Ge and ^{72}Ge: $\sigma_{198}(71)/\bar{\sigma}_{\text{g.s.}} \approx 0.8$; $\sigma_{1038}(71)/\bar{\sigma}_{0_2^+} \approx 0.66$; mean energy 955 keV compared with 840 keV in ^{71}Ge.]

IV. CONCLUSION

The results discussed in the present paper suggest that the relationship observed[1] by the (p, t) reaction between two levels of an odd-A nucleus and the two 0^+ levels of the even core is a rather general consequence of weak coupling. In the Ge-Se region the reaction ^{73}Ge$(p, t)^{71}$Ge shows[11] the same general features as observed in other "good weak coupling nuclei" in the s-d and f-p shells. In the special case of the reaction ^{75}As$(p, t)^{73}$As, weak coupling is not a good approximation as a consequence of the blocking of the $p_{3/2}$ proton orbital in the Ge 0^+ core states and some of the features observed are at variance with the general rules. It is important to notice that shape identity of the angular distributions (pure $L=0$ transitions), similar g.s. → g.s. intensities and identical excitation energies are observed here, where weak coupling is clearly a poor approximation; they appear to be therefore necessary but not sufficient criteria. It would seem that a more specific signature of weak coupling core excitation is the appearance of *only one* excited level populated by an $L=0$ enhanced transition, the intensity being of the same order as that corresponding to the excited 0^+ level of the even core.

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