CHARGED-PARTICLE-INDUCED RADIATIVE CAPTURE

PROCEEDINGS
OF A PANEL
VIENNA
9-13 OCTOBER 1972

INTERNATIONAL ATOMIC ENERGY AGENCY, VIENNA, 1974

PANEL PROCEEDINGS SERIES

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ORGANIZED BY THE
INTERNATIONAL ATOMIC ENERGY AGENCY
AND HELD IN VIENNA, 9-13 OCTOBER 1972

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STI/PUB/365

FOREWORD

Charged-particle radiative capture (CPRC) is just one of many nuclear reactions, and reasons should perhaps be given for singling out this particular reaction for discussion at an IAEA-sponsored panel meeting.

CPRC, in particular the capture of protons and alpha particles, is known to be, as the following papers show, a particularly useful reaction for the detailed study of nuclear structure, i.e. for the exhaustive determination of energies, life-times, branching decay ratios, spins, and parities of the many and various excited states of nuclei. The usefulness of CPRC studies is reinforced by the agreeable state of development of the equipment required for the experimental measurements: the accelerators, modest in size, complexity, and cost used to produce the beams of charged particles; the Ge(Li) detectors of adequate detection efficiency and truly remarkable energy resolution used to detect the gamma radiation; and the modern and sophisticated electronics, pulse-height analysers, "on-line" and "mini" computers, used to collect and speed the analysis of the abundant data. And all this equipment is commercially available, relatively inexpensive and often "multiply usable". It was perhaps as much as anything the belief that such equipment could be found in, or obtained by, even the smaller nuclear laboratories of the developing countries – and profitably used there by the rather large number of highly-selected and well-trained nuclear physicists known to be available in these countries – that led to the Agency's decision to convene a panel meeting on "Charged-Particle-Induced Radiative Capture" in Vienna, 9-13 October, 1972.

Although the panel was mainly concerned with applications to the study of low-energy nuclear structure, an attempt was made, in the selection of the panelists, to cover as broadly as possible the full range of applications of CPRC, and to include current work aimed at the understanding of the more highly excited nuclear states and of the nuclear reaction mechanisms, where the capture of deuterons, tritons, and ^{3}He-particles becomes interesting, and where accelerators of the tandem Van-de-Graaff class are often used. A particularly interesting application of great importance to astrophysics is the use of CPRC processes at very low, sub-Coulomb-barrier, projectile energies.

It was natural, in view of the prevailing research climate, that some consideration should be given during the meeting to possible practical applications and developments of CPRC for the future.

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Part I: CHARGED-PARTICLE RADIATIVE CAPTURE FOR THE STUDY OF NUCLEAR STRUCTURE

Capture into ordinary resonances (bound-state levels)

CHARGED-PARTICLE RADIATIVE CAPTURE AS A TOOL IN NUCLEAR-STRUCTURE STUDIES

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Abstract

CHARGED-PARTICLE RADIATIVE CAPTURE AS A TOOL IN NUCLEAR-STRUCTURE STUDIES.

In the introduction charged-particle capture is compared to other spectroscopically useful reactions like direct reactions, neutron capture, and resonance reactions involving a secondary charged particle. The special advantages and disadvantages of (p, γ) and (α, γ) DSA measurements are also discussed. As examples, recent investigations in Utrecht of the $^{23}Na(\alpha,\gamma)^{27}Al$, $^{27}Al(\alpha,\gamma)^{31}P$ and $^{35}Cl(p,\gamma)^{36}Ar$ reactions are quoted.

A survey is given on the strengths of γ-ray transitions between bound states in self-conjugate nuclei. The upper limits derived for, e.g. T-retarded M1-transitions can be used as spectroscopic tools for J^{π}- and T-determinations.

Finally some remarks are made on the theoretical interpretation of energy spectra in the s-d shell, with special emphasis on many-particle shell-model calculations. Calculations of magnetic moments are given as an illustration.

1. HISTORICAL INTRODUCTION

Work on the capture of protons and α-particles has always been closely connected with resonances. Although resonances had been observed well before 1940, the first high-resolution (p, γ)-yield curves have been measured during the war in Trondheim and Oslo by R. Tangen [1]. Previous work had been limited to the p-shell where most resonances are rather broad, and it should be credited to Tangen that, by proceeding to slightly heavier nuclei, he discovered that resonances can be quite narrow (a few keV) and beautifully separated. Of course, we know at present that the weakest detectable resonances are as narrow as a few MeV or even less.

In this pioneering work, Tangen used a GM counter for the detection of the γ-radiation produced. A great stride forward has been made around 1955 when the first NaI-detectors became commercially available, and another equally important one at about 1966 with the introduction of the Ge(Li) detector. The Ge(Li) era is still in full swing; detectors are still becoming larger and are still getting a better energy resolution. Spectra showing, say, a hundred different γ-ray transitions are no longer an exception nowadays. We are still far away from the stupendous abundance of lines shown in many optical spectra, but we are certainly moving in this direction.

Improvements in charged-particle and γ-ray resolution have been decisive in the development of capture work, but the development of high-speed computing techniques has been hardly less important. The analysis of our complicated spectra (including, e.g. the determination of peak centroid positions, the transition from peak positions to γ-ray energies, the checking of energy sums), and especially the thorough χ^2-analysis of γ-ray angular distributions and γ - γ angular correlations are just about impossible without computers.

2. POSSIBILITIES AND LIMITATIONS OF CHARGED-PARTICLE CAPTURE WORK

One can estimate that charged-particle capture reactions are being or have been investigated in, at least, some 30 different laboratories all over the world. Why are all these people attracted to this sort of work? In the discussion of this point, I want to separate the resonance-type reactions (capture of protons or α-particles) from the reactions which are more of a direct nature (capture of deuterons, tritons, ^{3}He-particles and heavy ions). The requirement that the reaction proceeds through (preferably) separated resonances automatically entails two restrictions:

a) the bombarding energy may not be too high;
b) the initial nucleus may not be too heavy, with the limit, perhaps, at A = 60 or 70.

Restriction a) is decidedly an attractive feature for many people; capture reactions are ideally suited for small (and, consequently, cheap) generators, e.g. for 2-, 3- or 5-MV Van-de-Graaff generators. As to point b), it is true that analogue states appear as resonances also in heavier nuclei, but γ-ray emission is generally quite weak because of the heavy competition with particle emission.

The fact that a reaction proceeds through a single resonance is a tremendous advantage from a spectroscopic viewpoint. Since the compound state has a well-defined angular momentum one may apply single-level Breit-Wigner theory, which is so well understood that one may say that the results of, e.g. angular distribution and correlation measurements are model-independent. This, in turn, makes it possible to apply a thorough χ^2-analysis to such data in which spin possibilities may be rejected at a 0.1% probability limit, such that statistically significant spin determinations result. This model independence of results is shared by all reactions proceeding through the weak interaction, like β-decay, electron scattering and particle-γ coincidence measurements. To physicists used to this strict statistical treatment of data, direct reactions seem to be hopelessly sloopy. Angular distributions generally fit badly beyond the first one or two interference maxima, such that χ^2-values (if calculated) are large even for the best-fitting ℓ- and/or j-value. Consequently, spectroscopic factors often remain without experimental errors, also because too little is known about the influence of possible variations in optical-model parameters.

Capture work is generally performed to obtain information on low-lying bound states in the final nucleus, which are very much more interesting than most resonance states (analogue resonances are exceptions). Low-lying bound states may be accessible to theoretical interpretation, which is generally impossible for the high-lying resonances with complicated wave functions. This possibility of obtaining bound-state information favourably distinguishes the capture reaction from resonance reactions like (p,α_0), (p,p_0) or (α,p_0) which only provide resonance information. In this context, one can regard the latter reactions as useful but rather uninteresting auxiliaries to capture work. They may provide, e.g. resonance spins and parities, necessary data for the interpretation of capture angular distributions and correlations.

It is also useful to compare charged-particle capture with neutron capture. In a certain sense, these reactions are complementary as they excite different final nuclei. Charged-particle capture, however, has the great advantage that one may work through a variety of resonances, with different spins and parities, such that, by suitable resonance selection, one may excite almost any bound state in the final nucleus. This is in contrast to neutron capture where one practically can only work at thermal neutron energy, because resonance capture time-of-flight work suffers from very low intensities. In addition, of course, thermal neutrons can only be captured in an s-state, such that the (isotropic) γ-ray angular distributions provide no information. Still worse, for non-zero spin J_i of the initial nucleus, the neutron capture state may not even have a well-defined angular momentum J_c, because both $J_c = J_i + 1/2$ and $J_c = J_i - 1/2$ are possible.

One last advantage of charged-particle over thermal-neutron capture is the fact that in the former case the final nucleus, immediately after capture, has a well-defined recoil velocity which entails the possibility of Doppler-shift life-time measurements. It hardly has to be emphasized here how extremely useful the results of this DSA work are, if only because the region of applicability of the method, from about 10^{-14} to 10^{-12} s, coincides closely with the average life-time of excited bound states in light nuclei. At present, the life-times are known of some 570 bound states of nuclei in the $A = 21-44$ region, an increase of about a factor of 8 over the situation in 1967.

It might not be superfluous to remark that the quantities to be compared with theoretical calculations are not the life-times but γ-ray transition probabilities. To evaluate the latter ones, one needs, in addition to life-times,

a) the J^{π}-values of initial and final states,
b) the branchings of the states in question,
c) the mixing ratios of the transitions concerned.

Many levels of which the life-time has been measured have not yet obtained an unambiguous J^{π}-assignment. Still more disturbing, however, is the scarcity of known mixing ratios. In each of the two interesting and easily accessible nuclei, ^{24}Mg and ^{28}Si, which have been the subject of countless experimental and theoretical investigations, the mixing ratios of only two transitions are known (in addition to the unmixed transitions starting or ending on a $J = 0$ state). Apparently, a campaign of γ-ray angular distribution and correlation measurements, aiming at the determination of mixing ratios, would be quite useful.

3. THEORETICAL PROSPECTS

Both the shell model and the collective model have contributed to our understanding of the structure of light nuclei. As to the collective model, although some light nuclei (like those in the A = 20-25 region and in the lower half of the f-p shell) decidedly show collective features, rotational bands are never so nicely developed as, e.g. in the region of the rare-earths. Band mixing seems to play a much more important role such that large deviations from the simple J(J+1) energy rule are observed, with corresponding deviations in γ-ray transition probabilities.

The most satisfactory but seemingly hopeless calculation would be the consistent application of the many-particle shell model, e.g. one might consider even-parity states in the s-d shell as built up by putting particles in the three sub-shells $1d_{5/2}$, $2s_{1/2}$ and $1d_{3/2}$; the shell-model space is limited by neglecting the possibilities of excitation of the inert ^{16}O core and of the population of higher shells. One may form a specific state characterized by the number of active particles A-16 and by its spin and isospin, J and T, by coupling k $d_{5/2}$ particles to J_1T_1, ℓ $s_{1/2}$ particles to J_2T_2 and m $d_{3/2}$ particles to J_3T_3 and then coupling the three groups together. The number of ways this can be done (defined as the number of configurations) increases fast with the number of active particles, until it reaches 6706 for a 3^+ T=1 state in A = 28, the worst case. The energies of these 6706 3^+ states then are obtained by the diagonalization of a 6706 × 6706 matrix. There exists a program (the Rochester-Oak Ridge Shell Model Program [2]) which performs just this, although, at present, computing time limits the maximum matrix size to about 1000 × 1000, corresponding to at most five active particles (or holes). The program may also be used in the middle of the shell, if the shell-model space is truncated further, e.g. for A = 28 one may introduce the additional requirement that at least eight particles occupy the $d_{5/2}$ sub-shell. Once the many-component wave functions have been obtained, the program can calculate, in addition to ground-state binding energies and level schemes, β- and γ-transition probabilities, magnetic dipole and electric quadrupole moments, and spectroscopic factors for all sorts of transfer reactions. It should be kept in mind that all these results depend on the parameters of the specific two-particle effective interaction which is assumed. Wide use has been made of the extremely simple (and quite successful) surface-delta interaction, described with only three parameters.

The program has now been in use for a few years and has been applied to widely different regions of the periodic table and to many different nuclear properties. Examples of applications to the A = 27-29 and 30-34 regions are given in Refs [3] and [4], respectively.

Recently, it has been claimed [5] that suitable abbreviations of the program make it possible to extent the calculation (in full generality) from 5 to 12 active particles such that the whole s-d shell would be covered. It is too early yet to correctly evaluate the impact this new method will have on future shell-model calculations.

4. UTRECHT CHARGED-PARTICLE CAPTURE WORK

In the period 1958-1972 altogether 13 Utrecht Ph.D. theses have been concerned with charged-particle capture investigations. The first five of these were based on work with a 800-kV Cockcroft-Walton generator (now dismantled), and in the last eight our 3-MV Van-de-Graaff generator was utilized. The 3-MV machine has been in operation until 1970 in the old laboratory in Utrecht's medieval inner town, after which it has been updated by HVEC and then transferred to the new campus outside Utrecht.

For some work to be described below the measurements were performed before and in 1970 but the analysis of the results has extended over the last two years.

4.1. The $^{23}Na(\alpha,\gamma)^{27}Al$ and $^{27}Al(\alpha,\gamma)^{31}P$ reactions

The investigation by de Voigt et al. [6] on the $^{23}Na(\alpha,\gamma)^{27}Al$ and $^{27}Al(\alpha,\gamma)^{31}P$ reactions has now been published and should only be mentioned briefly.

This work has shown, first, that it is possible to use with advantage a Ge(Li)-detector for (α,γ)-measurements, notwithstanding the high background of $^{13}C(\alpha,n)$-neutrons which had prevented the detection of γ-radiation up to about $E_\gamma = 8$ MeV in previous NaI-work. Both the smaller neutron cross-section for Ge as compared to that for I and the higher energy resolution make the peaks due to capture radiation stand out clearly all the way down to, say, $E_\gamma = 0.51$ MeV, such that not only the high-energy primary transitions but also the low-energy secondaries can be observed.

This work has also shown that one can investigate the γ-ray decay of compound states situated in an energy region in which the channel for proton decay is wide open; the Q-values for the $^{23}Na(\alpha,p)^{26}Mg$ and $^{27}Al(\alpha,p)^{30}Si$ reactions are 1.82 and 2.37 MeV, respectively. This competition between γ-ray and proton emission turns out to be a blessing in disguise. For low-spin compound states the copious proton production effectively suppresses γ-ray emission; such states may have a width of many keV. For high-spin ($J = 7/2 - 11/2$) compound states, however, the high orbital momentum barrier prevents proton decay, such that the (α,γ)-reaction proceeding through narrow well-separated resonances dominates. In turn, the high-spin resonances decay to high-spin relatively high-lying bound states. The reaction thus operates as a sieve for the selective excitation of high-spin states, which are not (or very weakly) excited in "normal" transfer reactions as, e.g. (τ,d).

Of course, the (α,γ)-reaction is ideal for DSA measurements because of the high recoil velocity imparted by the heavy α-particle whereas, in addition, the recoil direction is fixed.

Finally, it turned out that many resonance and bound-state spins could be determined unambiguously from γ-ray angular distribution measurements alone. This has to do with the fact that the angular distribution is almost independent of the z-component of the resonance spin. If, e.g. a $11/2^+$-resonance is formed in the $^{23}Na(\alpha,\gamma)^{27}Al$ reaction by $\ell_\alpha = 4$ capture, the resonance z-component may be $m = \pm 1/2$ and $m = \pm 3/2$ (because the ^{23}Na spin is 3/2). In both cases, however, the resonance spin is almost perpendicular to the beam axis (because of the large value of J), such that the γ-ray angular distribution is insensitive to the actual value of m. This elimination of a bothersome parameter leads to considerable simplification. A necessary condition for the determination of bound-state spins is the knowledge of the life-times and branchings of the states in question.

4.2. The $^{35}Cl(p,\gamma)^{36}Ar$ reaction

A great amount of information on ^{36}Ar has been obtained by means of the $^{35}Cl(p,\gamma)^{36}Ar$ reaction [7]. This reaction had previously been investigated [8] with the use of NaI-γ-ray detection but the great level density had precluded work on bound states above about 5.5 MeV.

There are some 60 resonances in the E_p = 0.4 - 3.0 MeV region. At 20 selected resonances showing a promising decay to high-lying bound states Ge(Li) spectra were measured and DSA-measurements performed. Finally, γ-ray angular distributions have been measured at eight resonances. The analysis of these measurements has resulted in:

a) a reaction Q-value of 8506.9 ± 0.3 keV;
b) accurate excitation energies (errors ranging from 0.05 to 1.8 keV) and branchings for 29 bound states; two previously known states proved to be narrow doublets;
c) life-times (or life-time limits) for 22 bound states;
d) unambiguous J^π-determinations for 13 bound states (and J^π-restrictions for several more). This latter part of the work has been aided by a previous high-resolution (15-keV) investigation [9] of the $^{35}Cl(\tau,d)^{36}Ar$ reaction.

The odd-parity states in ^{36}Ar deserve a special discussion. The shell model predicts a set of states with the configuration $d^3_{3/2}f_{7/2}$; there should be 20 T=0 states in this set, with J^π-values ranging from 0^- to 7^-. Of these there are three 5^-, two 6^- and one 7^- state. Three of these (presumably the three lowest), i.e. two 5^- states and a 6^- state, have been found in the present work. The lowest 5^- state, at 5.17 MeV, is excited in the (τ,d) reaction with a very strong pure $\ell_p = 3$ transition and thus predominantly should have the $(d^3_{3/2})_{3/2}f_{7/2}$ configuration, with the three $d_{3/2}$ particles coupled to J = 3/2 (like in the ^{35}Cl ground state). The next lowest 5^-, at 6.22 MeV, and the lowest 6^- state, at 7.35 MeV, are not excited in the (τ,d) reaction and thus presumably have the $(d^3_{3/2})_{5/2}f_{7/2}$ configuration as predicted by a simple shell-model calculation. In the (p,γ) reaction the latter two states are excited at the E_p = 2136 and 2231 keV resonances (corresponding to E_x = 10.58 and 10.67 MeV, respectively) both with $J^\pi = 5^-$, T=1. The shell-model calculation predicts that these are strongly mixed states, both with appreciable $(d^3)_{3/2}f$ and $(d^3)_{5/2}f$ components. This nicely agrees with their formation and decay properties. The states act as doorway states; the formation through proton capture should proceed through the $(d^3)_{3/2}f$ component, the γ-ray decay to $(d^3)_{5/2}f_{7/2}$ states through the $(d^3)_{5/2}f$ component. The M1-γ-ray transitions in question are quite strong, ~0.25 W.u., whereas a simple calculation shows that a $(d^3)_{3/2}f \to (d^3)_{5/2}f$ M1-transition, requiring recoupling of the $d_{3/2}$ particles, is quite weak.

4.3. Statistics on γ-ray strengths

A new edition [10] of the 1967 review paper on Z = 11-21 nuclei [11] is in an advanced stage of preparation (the writing has proceeded up to A = 40). Such reviews can be used with advantage for statistical considerations on all sorts of nuclear properties. Although such considerations

TABLE I. GAMMA-RAY STRENGTHS OF TRANSITIONS BETWEEN BOUND STATES IN SELF-CONJUGATED NUCLEI IN THE A = 6-42 REGION

Character			Number	Strength (W.u.) Logarithmic average	Strongest transition
E1	allowed	$\Delta T = 1$	2	5×10^{-5}	1.7×10^{-4}
	forbidden	$\Delta T = 0$	20	5×10^{-5}	2.2×10^{-3}
M1	allowed	$\Delta T = 1$	23	0.29	7
	retarded	$\Delta T = 0$	31	7×10^{-4}	1.2×10^{-2}
E2	allowed	$\Delta T = 0$	63	2.1	60
	retarded	$\Delta T = 1$	2	0.09	0.16
M2	allowed	$\Delta T = 1$	2	0.7	0.7
	retarded	$\Delta T = 0$	2	2.5×10^{-3}	2.6×10^{-3}
E3	allowed	$\Delta T = 0$	6	13	30

do not specifically relate to capture work, it was thought appropriate to include an example in the present paper, because the analysis of capture data has to rely heavily on statistical data.

The example given here regards the strengths of γ-ray transitions between bound states in self-conjugated nuclei in the A = 6-42 region. The restriction to self-conjugated nuclei was prompted by the wish to learn something about isobaric spin selection rules. The restriction to bound states follows from the same wish; highly-excited unbound states in a region of high level density may be isospin impure. Only transitions were taken (in accordance with the rules stated in section 2) with known mixing ratios and proceeding between states with known spin and parity. The results are given in Table I.

Apparently we can learn very little about the groups with poor statistics, like the allowed E1's, the retarded E2's and the M2's. To increase our knowledge of these rarities it would certainly be remunerative to start a special search for them, e.g. through (p,γ)-work.

Most informative are the M1-groups. Let us recall that for retarded transitions the (generally large) isovector component in the matrix element is zero, such that only the (generally small) isoscalar component remains. The logarithmic averages of the allowed and retarded groups differ by more than three orders of magnitude. Especially useful, however, is the knowledge of the maximum strength in the retarded group. It leads to the statement that if an M1-strength exceeds, say, 0.05 W.u. the transition must be of allowed character. This rule has been applied with advantage for isobaric spin assignments in the investigation of the $^{35}Cl(p,\gamma)^{36}Ar$ reaction discussed in section 4.2. The T-1 levels at 10.6 MeV in ^{36}Ar correspond to levels at 4.0 MeV in ^{36}Cl, a region with a high density of levels, all with unknown J^{π}-value.

4.4. Magnetic moments

A brief survey shows that the magnetic moments have been measured of practically all stable nuclei, of some radioactive nuclei, and of very few excited states. Many more can be measured, also by means of charged-particle capture, and we should like to plead here for more effort to be directed towards such measurements. Magnetic moments, like electric quadrupole moments, are very informative quantities because they relate to the wave function of only one state, in contrast to transition probabilities in which the wave functions of both the initial and the final state occur. States with life-times above, say, 1 ns are accessible to perturbed angular correlation measurements, and we are on the verge of shifting this limit down to 1 ps with methods based on transient fields and atomic fields (e.g. the field of a single electron around a naked nucleus).

The best theoretical description of magnetic moments in light nuclei is given by many-particle shell-model calculations (section 3). Recently, however, also a very simple approximate expression [12] has been derived, valid for the isoscalar component μ_0 of the magnetic moment. The approximation made is that all active particles are in the same sub-shell (ℓ, j). The expression can be compared with experiment a) in self-conjugated nuclei, b) for the average magnetic moment of mirror states; in both cases the isovector component is zero. The expression in question reads:

$$g_0 = \tfrac{1}{2} \pm \frac{0.38}{2\ell+1} \text{ for } j = \ell \pm 1/2, \quad \text{with } \mu_0 = g_0 J$$

The numerical factor 0.38 is given by $\frac{1}{2}(g_p + g_n - 1)$ where g_p and g_n are the proton and neutron g-factors, respectively.

This simple relation agrees with experiment to within a few percent, but for the following exceptions:

a) The 1^+ ^6Li ground state has $g_0 = 0.82$ whereas, on the basis of a $s_{1/2}^4 p_{3/2}^2$ configuration, it should have $g_0 = 0.63$. The correct value can be obtained by mixing in an $s_{1/2}^4 p_{3/2} p_{1/2}$ component.

b) The average of the ^{19}F and ^{19}Ne ground-state g-factors is 0.74 whereas, on the basis of a $d_{5/2}^3$ configuration, it should be 0.58. The difference is explained by a $d_{5/2}^2 s_{1/2}$ admixture.

c) The average of the ^{29}Si and ^{29}P ground-state g-factors is 0.68 whereas, for $s_{1/2}$, one would expect 0.88, which can only be understood by invoking holes in the $d_{5/2}$ sub-shell.

From these samples, it is clear that comparison with the single-shell expression offers a simple indication as to the purity of the states involved and even can point to the main admixtures.

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DISCUSSION

S.S. HANNA: This very nice paper leads to a few questions and remarks. First I would like to ask who has performed the calculation on the magnetic moment of ^{6}Li.

P.M. ENDT: It was done by Sven Maripu (East Lansing, Mich.) and will be communicated at the coming Symposium on the Structure of Low-Medium Mass Nuclei at Lexington (Kentucky).

S.S. HANNA: Then I would like to make a remark regarding the transient-field method. It is an interesting possibility but there still are some problems connected with it. One is that measured transient fields apparently are about a factor of 2 larger than predicted by the theory, such that one should be very careful.

P.M. ENDT: I would certainly agree that calculated transient fields are still not very reliable. However, one could think of two possibilities to calibrate transient fields. First one could look for an excited state of which the magnetic moment could be measured both by means of transient fields and by means of the ionic-field method (at present called deorientation method). Then one also could say that, e.g. for the first excited states of ^{20}Ne and ^{24}Mg, the magnetic moments can be calculated quite accurately. One always finds $g = 0.50$, within a few percent, whatever the size of the shell-model space in which the calculation is performed.

S.S. HANNA: Well, I would rather see a few good measurements confirming this prediction, before it can be used to calibrate transient fields. To return to the deorientation method, I guess one could use any number of electrons around the nucleus, not just one?

P.M. ENDT: For two electrons one would have zero field, but three electrons would be a possibility, although the field then is quite somewhat smaller.

S.S. HANNA: I also have a question about the three 5^- resonance states in ^{36}Ar. Are these levels pure $T = 1$ analogue states or would you consider them as mixed $T = 1$ and $T = 0$?

P.M. ENDT: No, they should be pure $T = 1$, as shown by the strong M1-transitions to $T = 0$ bound states. Correspondingly, there should be three 5^- parent states in ^{36}Cl. The lowest of these is probably the 2.52 MeV ^{36}Cl level, but up to now this region has been very little