NUCLEAR SPECTROSCOPY OF NEUTRON RICH A = 147 NUCLEI

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1. Experimental Techniques

Several ISOL systems, using different separation techniques, were used to perform a systematic study of odd-mass neutron rich nuclei in the transitional region around A = 89.

The mass chain A = 147 is, up to now, the most exotic one we could extensively study with the existing equipements.

At the recoil separator for unslowed fission products Lohengrin (ILL/Grenoble), extremely pure gamma single spectra of ^{147}La, ^{147}Ce and ^{147}Pr, were obtained.

The gamma-gamma coïncidences for these nuclei were performed at the recoil separator Josef (K.F.A.- Jülich).

The mass separator Ostis (ILL/Grenoble), equipped with a conventional thermoionisation source, was used to observe the decay of ^{147}Cs and his daughter products ^{147}Ba, ^{147}La and ^{147}Ce. Owing to the extreme complexity of the gamma spectra a high-temperature ion source was also installed at this separator in order to enhance drastically the relative intensities of ^{147}Ba, ^{147}La and their daughter products.

Standard techniques were used to perform γ-single, γ-γ-time and β-γ-time coïncidence measurements. A Si(Li) detector was used for conversion electron measurements, which were necessary for the identification of some mixed gamma transitions. For the most important transitions, K/L ratios could be measured leading to the mixing ratios M1/E2.

All these measurements were performed on line with a more or less rapid evacuation of the collected activity.

2. Discussion

The decay schemes proposed for the different nuclei are shown figure 1 to 4. The ground state beta branchings were determined by the "filiation method" using the thermoionisation source of OSTIS and the absolute intensities of some gamma transitions in the decay of ^{147}Pr [1]. The rather low logft values of these beta branches may possibly result from an underestimation of the Q_β value (Cs and Ba decays) and from possible systematic error in the "filiation method" due to eventual direct extraction of a small amount of Ba and La, even with the thermoionisation source : these two effects would not affect in an appreciable manner the relative beta feedings of the excited states. Another perturbing effect could be a lot of weak unobserved gamma transitions from the region of high density levels, specially in Ba and La were we could not observe levels higher than 1 MeV in spite of the high Q_β values.

It is difficult to identify the huge amount of levels observed below 1 MeV in the nuclei of A =147 with the rather poor arguments we have for definite spin assignments, as up to now no γ-γ angular correlations were performed.

The total amount of levels with spins lower than 9/2 below 1 MeV in the even-odd or odd-even nuclei around N = 89 neutrons shows a maximum value for the nuclei with A = 147 : this maximum is nearby twice the value observed for the neighbouring spherical or well deformed nuclei. This may be considered as an additionnal indication for the transitionnal character of the nuclei studied here.

In spite of these considerations, a temptative identification of some low lying levels may be performed, partly owing to the extended systematics which are now avalaible in that region.

The slow, regular decrease of the first excited 2^+ levels in the even-even nuclei of that transition region around N = 89 suggests that the deformation appears very progressively : a smooth behaviour of some levels in the neighbouring odd nuclei may therefore also be observed.

Spin of ^{147}Cs ground state :
Spin and parity of ^{147}Cs ground state are unknown; nevertheless, $3/2^+[422]$ would be in agreement with the values directly measured by Ekström et al[2] for ^{143}Cs and ^{145}Cs, although a spin $1/2^+[420]$ cannot be totally excluded.

Levels of ^{147}Ba :
Considerations concerning the neutron orbits available in that region, suggest that the retardation of the two M1 transitions at 85 and 110 keV can be explained by assuming h 9/2 character for the two excited states at 85.2 and 109.7 keV and f7/2 character for the ground state. The regular decrease observed for the $3/2^-[532]$ level in ^{155}Gd, ^{153}Sm and ^{151}Nd - extensively studied nuclei which all have 91 neutrons - with decreasing proton number[3)4)], gives a reasonable support for assuming that the ground state of ^{147}Ba is $3/2^-[532]$ from the orbit f7/2 (figure 5).

The positive parity states at 46.2, 75.1, 198.9 and 292.0 keV belong to the i13/2 neutron system. A doublet with about 22 keV energy difference, and identified as the beginning of a strongly perturbed 3/2[651] rotational band, is observed at low energy in the heavier N = 91 isotones mentioned above.

The doublet we observe here at 46.2 and 75.1 keV is possible this one. Another possibility, if the existence of the level at 75.1 keV could not be proved, is to consider that the three well established positive parity states at 46.2, 198.9 and 292.0 keV are the low spin states of a strongly mixed band $1/2^+[660]$ + $3/2^+[651]$ observed in less deformed nuclei in that region, for example ^{149}Nd[5]). One of these positive parity states could also have a non negligable $5/2^+[642]$ state which was only observed in ^{155}Gd and ^{153}Sm.

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Positive parity states were also observed in ^{143}Ba and ^{145}Ba [6][7]. The systematic of some odd Baryum isotopes shown figure 5, where some results of our recent conversion electron and life-time measurements are included, shows the regular lowering of these levels with increasing neutron number. Such an effect, which is also observed in odd Neodynium isotopes[8], is attributed to the crossing of the i13/2 and f7/2 neutron orbits when the deformation increases.

As shown in ref.[6] and [9], the doublet 1/2$^-$ 5/2$^-$ near the ground state in ^{143}Ba, is identified in all N = 87 isotones by a strong E2 transition and probably comes from the orbit h9/2 which crosses the orbit f7/2 - responsible for most of the other observed negative parity states - when the deformation increases ; it is possible that we observe the same E2 transition in ^{145}Ba and that the level at 85 keV is the favoured 5/2$^-$ level of a strongly perturbed band built on the orbit 1/2$^-$ [530] coming from h9/2.

Levels of ^{147}Ce

The most striking feature in this nucleus is the existence of two-clearly evidenced by their K/L ratios - E2 transitions of 186 and 215 keV feeding the ground state, the second one being faster than the first one. A spin 5/2$^-$ for the ground state of ^{147}Ce, in agreement with the systematic of N = 89 neutrons shown figure 6, would lead to 1/2$^-$ for the spins of the levels at 186 and 215 keV ; but then we would have no observed candidate for the 7/2$^-$ level which is expected at low energy in ^{147}Ce (as it is in ^{149}Nd) and which has to be fed by beta decay from ^{147}La(5/2$^+$).

Therefore, we cannot exclude that the ground state of ^{147}Ce has a spin 7/2$^-$, the spins of the two levels at 186 and 215 keV being then 3/2$^-$; ^{147}Ce would then be only a weakly deformed nucleus, as it is also suggested by the absence of positive parity states at low energy.

Concerning the ground state and the first excited state at 64 keV observed in ^{145}Ce[10] spin sequences 7/2$^-$ 3/2$^-$ or 5/2$^-$ 1/2$^-$ are equally possible on ground of experimental arguments.

Levels of ^{147}La :

The spin assignment of 5/2$^+$ for the ground state of ^{147}La and 1/2$^+$ for the first excited state at 74.9 keV is in agreement with the E2 transition observed between them and with the beta feeding of both levels from the 3/2$^-$ ground state of ^{147}Ba ; spin 1/2 is excluded for the ground state of ^{147}La since levels up to 5/2 are fed in ^{147}Ce.

The delayed M1 transition of 105 keV probably connects levels belonging to the two different proton orbits g7/2 and d5/2.

In ^{145}La, the existence of two M1 and one E2 transitions, as shown figure 7b leeds to a spin 5/2$^+$ for the ground state of this nucleus. A systematic of some odd Lanthanum isotopes is shown figure 7 b, which includes also our recent results concerning conversion electron measurements on ^{145}La. Also included is the level structure of ^{151}Pm[11] which has the some neutron number as ^{147}La.

The lowering of negative parity states with increasing neutron number was already observed in odd Pm and Eu nuclei and is regarded as a characteristic feature of the levels originating from the h11/2 proton state. By assuming the structures 5/2$^+$ [413], 1/2$^+$ [420] and 3/2$^+$ [411] for the ground state and the levels at 75 and 105 keV, respectively the observed retardations of the ground state transitions could be explained by the d5/2 and g7/2 character of these levels.

Levels of ^{147}Pr :

According to reference[1], where the beta decay of ^{147}Pr was studied, the most probable spin for the ground state of this nucleus is 5/2$^+$.

A spin 3/2$^+$ can therefore be deduced for the level at 93 keV, due to the weakness of the beta feeding to this level from the 7/2$^-$ ground state of ^{147}Ce and in agreement with the observed M1 transition of 93 keV. Owing to the gamma branching ratios the level at 2.6 keV could be 5/2$^+$.

A spin 7/2 is also probable for the level at 218 keV since no gamma transition to the low spin state at 93 keV is observed.

The systematic shown figure 7a suggests that the levels at 0, 93 and 218 keV may belong to a strongly perturbed rotational band built on the proton orbit d5/2, whereas the level at 2.6 keV could be the lowest level of an equally perturbed band built on the orbit g7/2, as observed in ^{149}Pm[12].

3. Conclusion

The need of more refined measurements, such as angular correlations, in order to have a chance to understand these nuclei, is obvious.

Nevertheless, our work seems to show that in the mass chain A = 147, Baryum is the most deformed nucleus, and that the most propable spin sequence for the ground states is 3/2$^+$ for ^{147}Cs, 3/2$^-$ for ^{147}Ba, 5/2$^+$ for ^{147}La, 7/2$^-$ for ^{147}Ce and 5/2$^+$ for ^{147}Pr.

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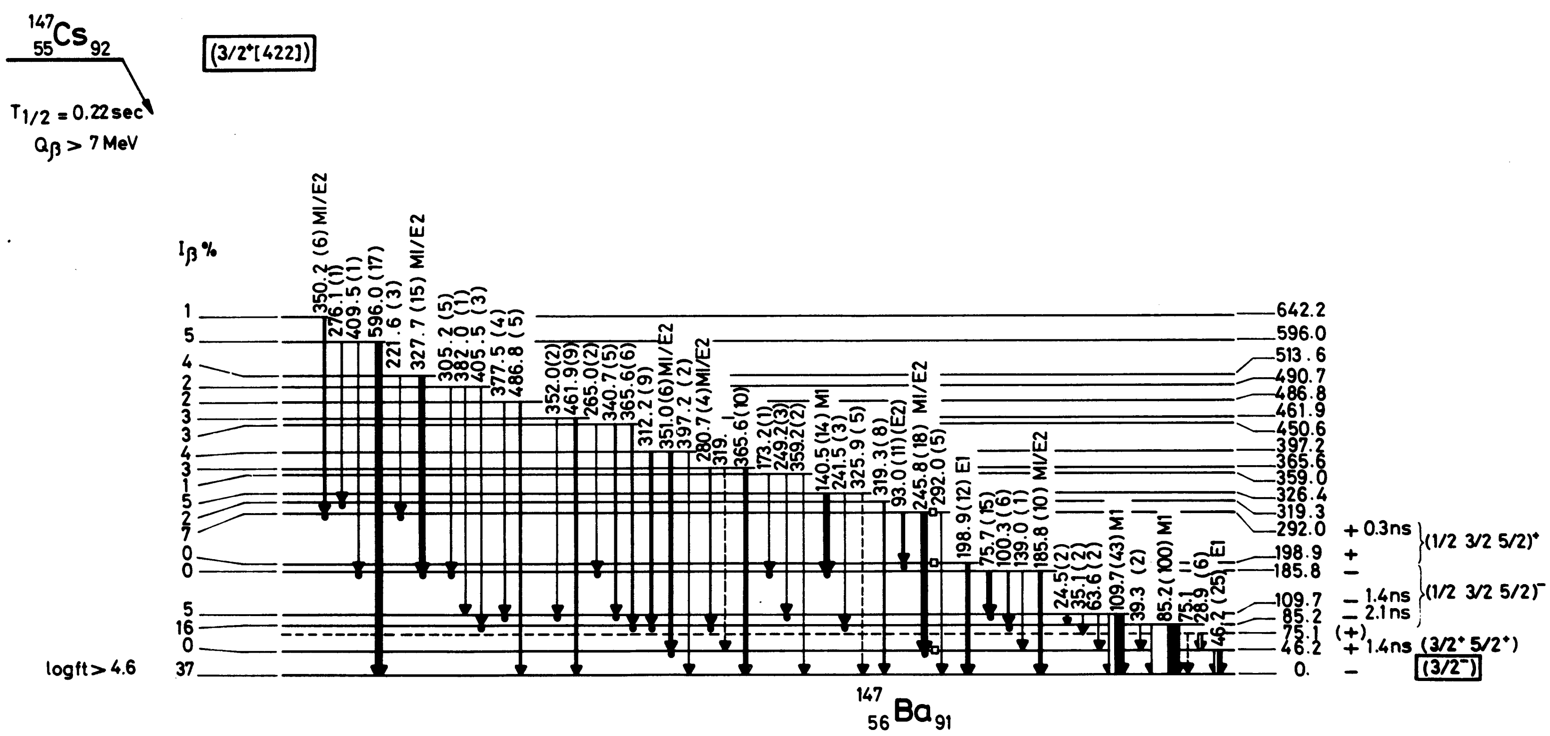

Figure 1 - Proposed level scheme for ^{147}Ba.

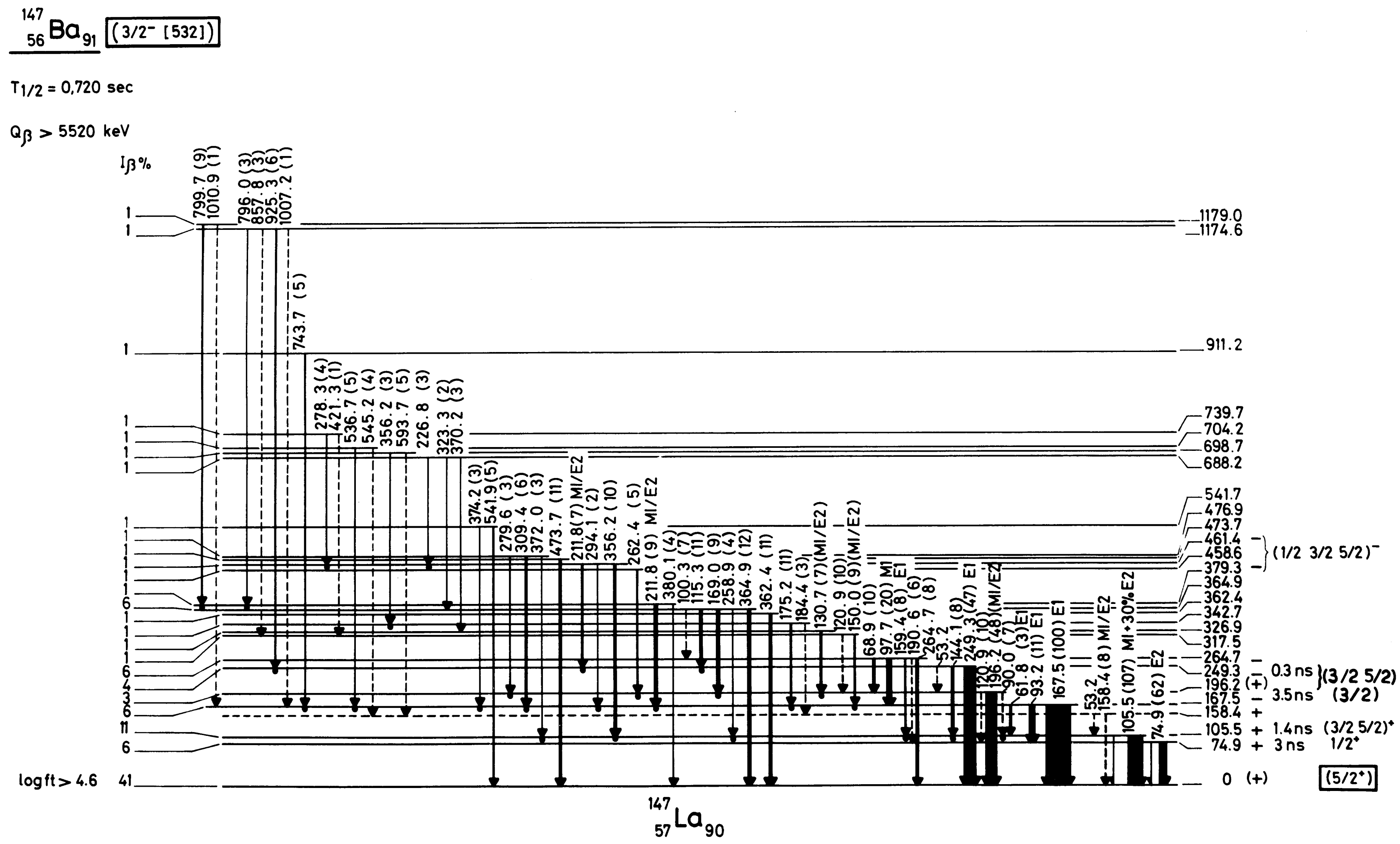

Figure 2 - Proposed level scheme for ^{147}La.

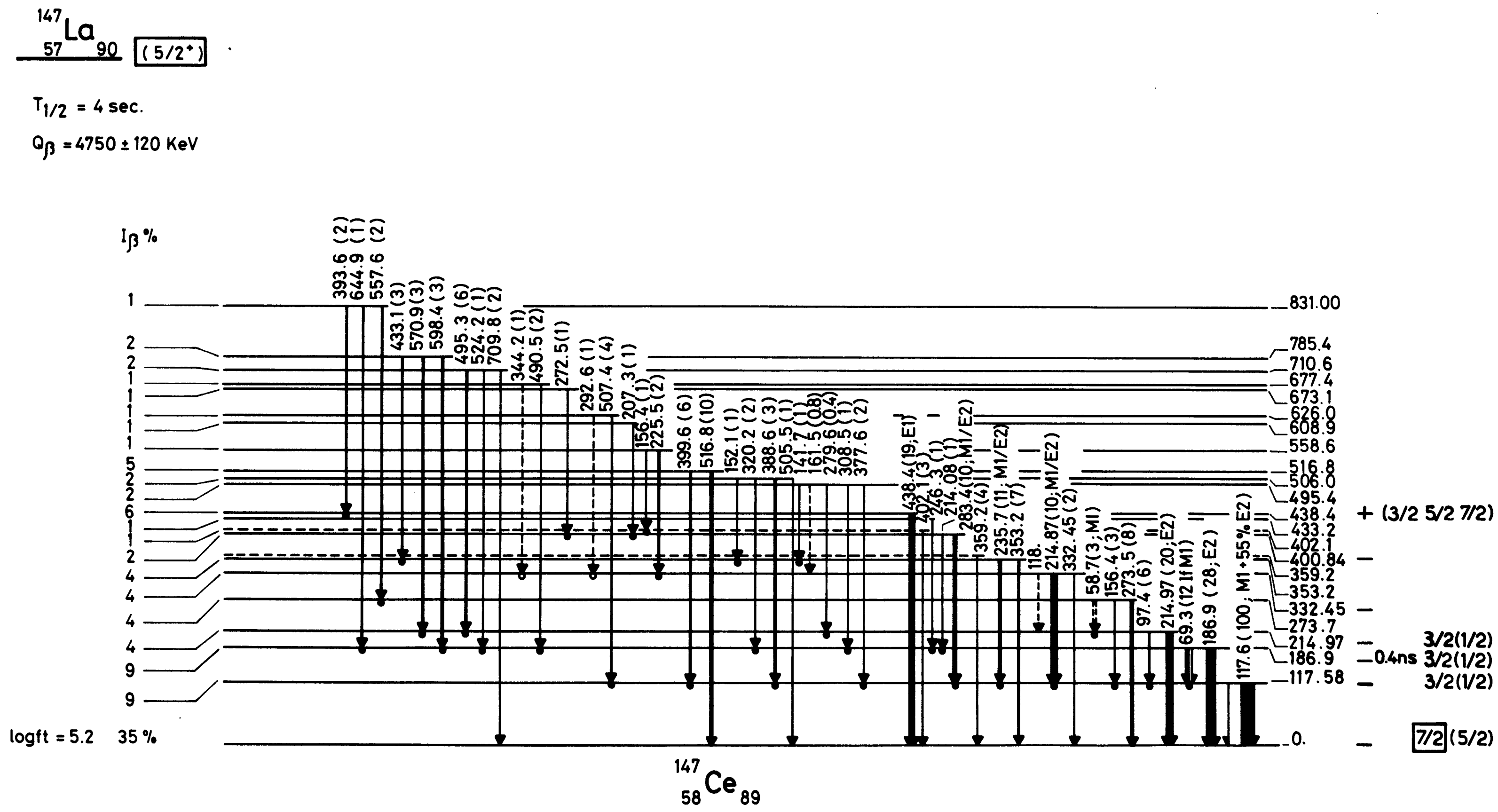

Figure 3 - Proposed level scheme for ^{147}Ce.

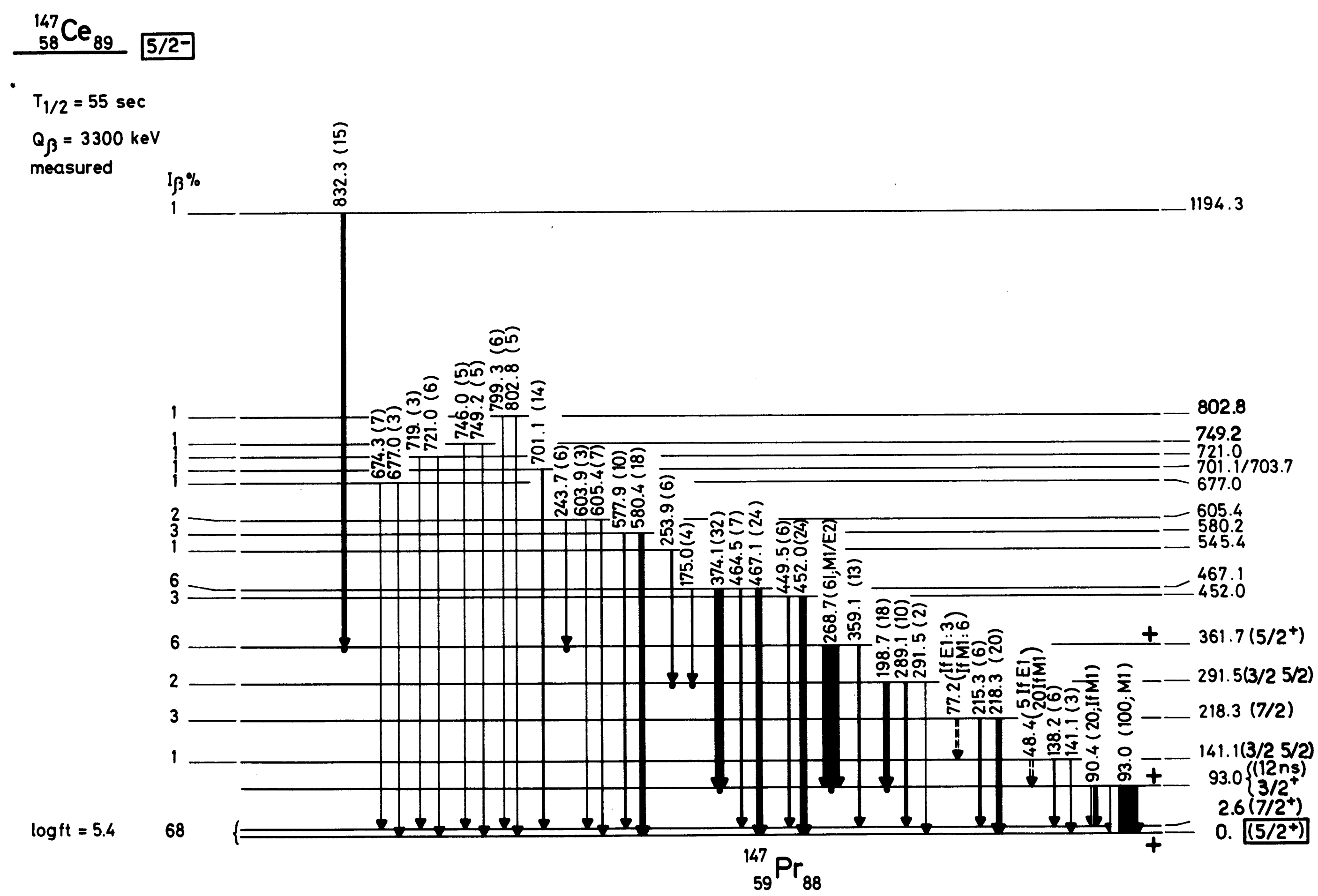

Figure 4 - Proposed level scheme for ^{147}Pr.

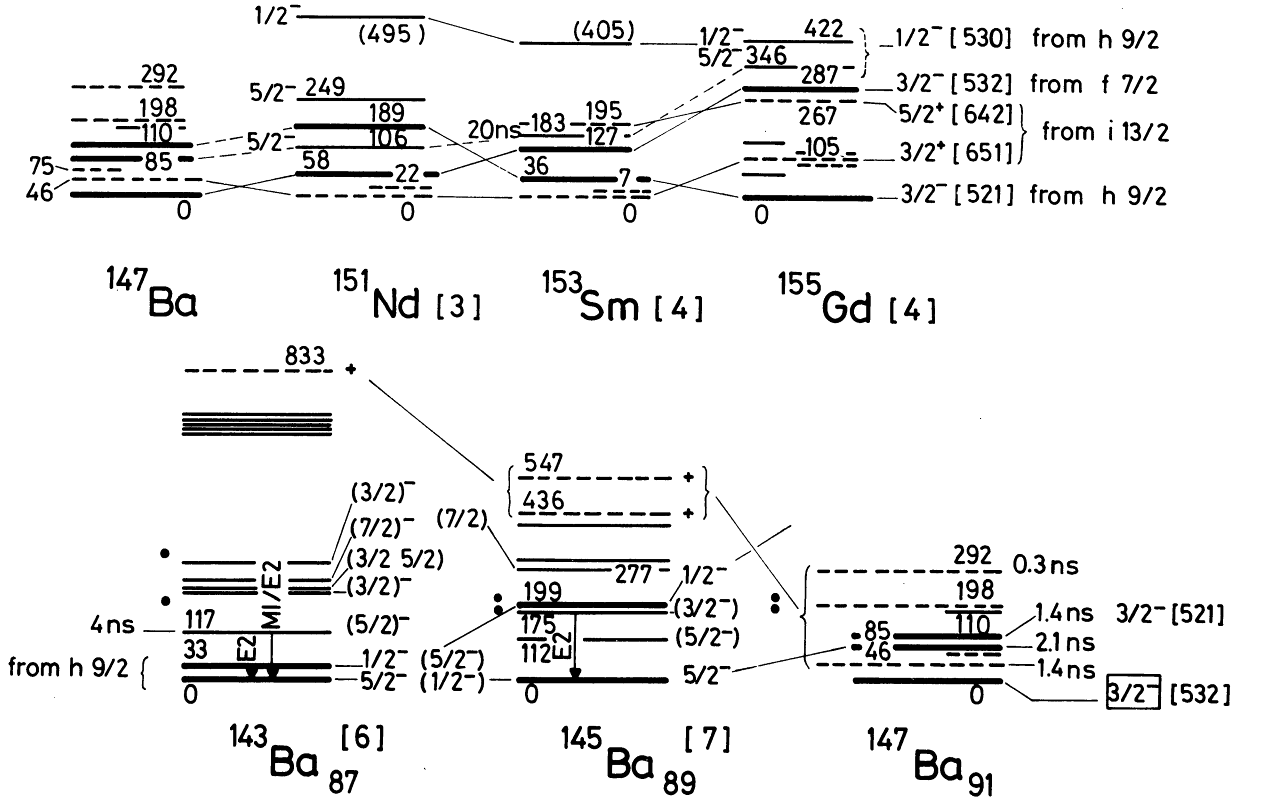

Figure 5 - Level systematic for N = 91 nuclei and for some odd Baryum isotopes. Position of the 2^+ states of neighbouring even-even nuclei are shown by black dots.

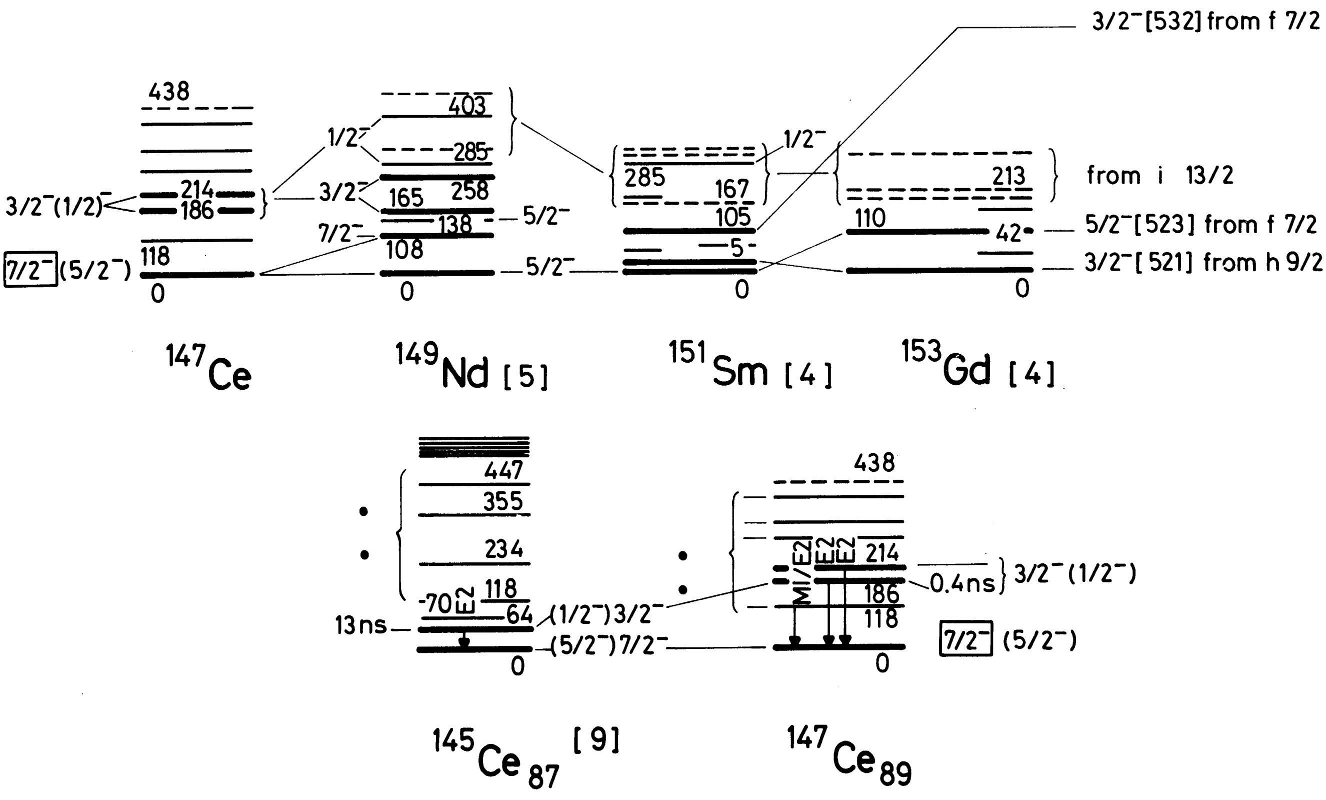

Figure 6 - Level systematic for N = 89 nuclei and for some odd Cerium isotopes.

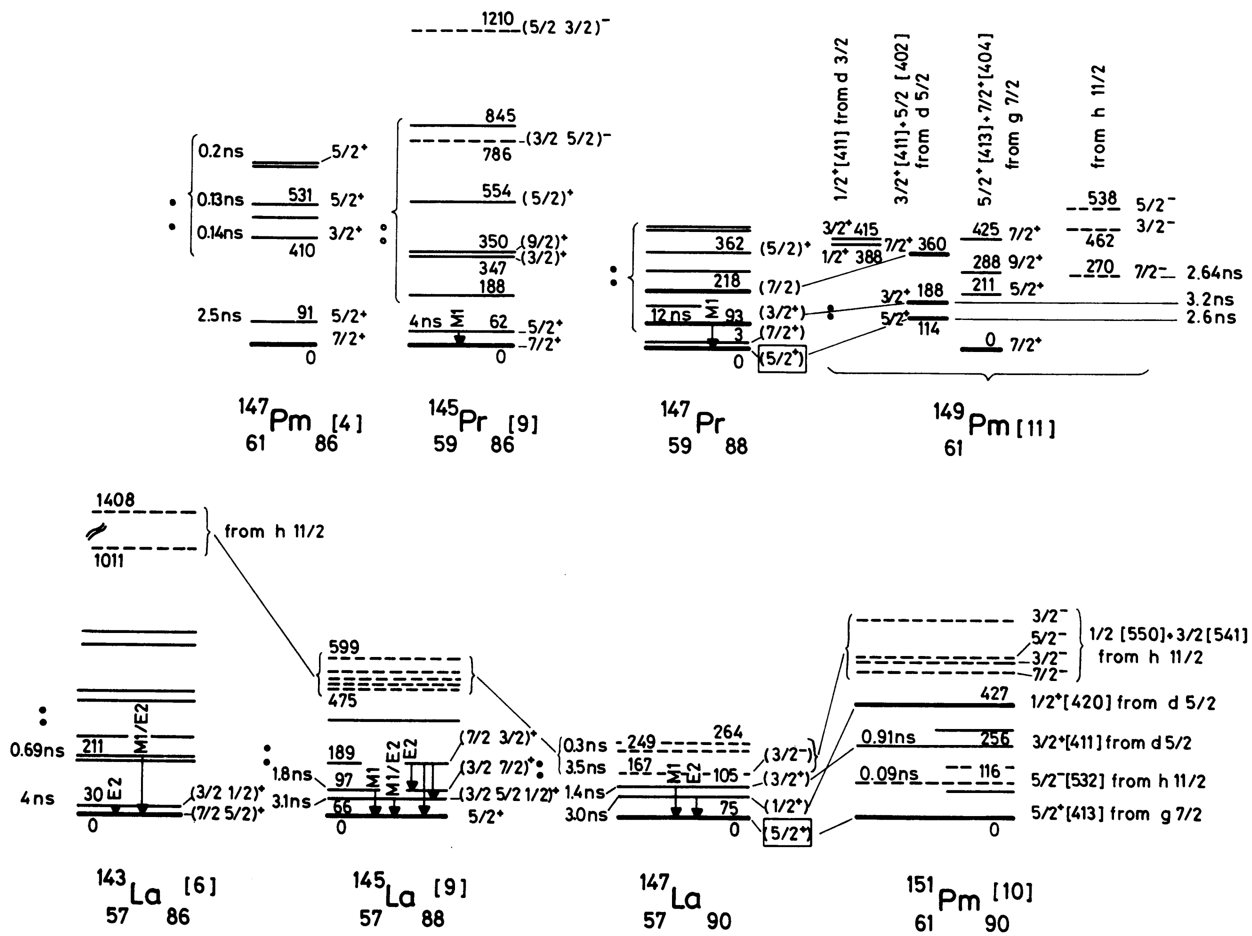

Figure 7 a and 7 b - Level systematic for some odd-proton nuclei around A = 147 and N = 89.