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EXOTIC NUCLEAR STRUCTURE AND DECAY: NEW NUCLEAR COLLECTIVE PHENOMENA

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INTRODUCTION

Studies of the properties [illegible] have revealed [illegible] richness [illegible] variety of [illegible] structures, and [illegible] exceeding our understandings and expectations of even a decade ago.[1,2,3] By exotic [illegible] nuclei under extreme conditions not found in nuclei naturally on the earth that is, nuclei far from stability with neutron numbers much larger or much smaller than those of the stable isotopes of a given element, or with Z well beyond 92, or with very high angular momenta even up to [illegible] fission limits. In this same decade, studies of heavy ion collisions as reported at this conference have been extended up to uranium on curium with possible evidence for the formations of giant nuclear molecules with combined Z up to 188, which may exist for periods very long compared to their collision times.

From studies of far-off-stability exotic nuclei have come evidence for the coexistence of different nuclear shapes in the same nucleus, new regions of unusually large deformation, new ground-state phase transitions from one shape to another, new magic numbers but now for deformed shapes, and for the importance of reinforcing shell gaps (see ref. 2). New exotic decay modes include a wide variety of beta delayed particle emission (see ref. 1) and heavy cluster emissions such as ^{14}C and ^{24}Ne (see refs. 4, 5). The new deformed magic numbers of 38 and 40 (refs. 2, 3) seen far off stability clearly support that there are likely other "magic" numbers for protons and neutrons which give stability to different deformed shapes. Perhaps these other new magic shell gap numbers at large deformation could influence the sticking of two very heavy nuclei in collisions such as U on Cm. Finally, another area which could have a bearing on the formation, motions, and structures of giant nuclear systems involves the recent observation of very energetic, light particle (proton, alpha) emission with up to 50% and more of the total incoming energy in a collision, for example in 300 MeV ^{32}S on Ta (refs. 6, 7). This is another completely unexpected new collective phenomenon where a large fraction of the total energy is transferred to a single particle. Examples of the new insights being gained and their promise for the future will be given. The wide variety of new collective modes being observed in nuclei and in nuclear collisions suggests that indeed we may see other new exotic collective motions in the collision of two very heavy nuclei.

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NEW SHAPES AND STRUCTURES

Studies of nuclei far from stability in recent years have brought about major changes in our understandings of the structures of nuclei.[1-3] No longer does a nucleus have to have a single, "permanent" shape which characterizes its low-lying levels. Now throughout the periodic table one finds nuclear shape coexistence where two or more different shapes can coexist with energy levels characteristic of each shape overlapping in energy. These coexisting shapes include small oblate (near spherical)-large prolate; spherical-prolate; triaxial-prolate and other combinations. In these cases sudden ground state phase transitions from one configuration lying lowest to the other being lowest or to even totally different shapes also are observed.

In addition, new "magic" numbers which play an important role in shape coexistence and superdeformations observed in certain regions have been identified. In Fig. 1 are shown the magic numbers (2, 8, 20, 28,...) for the spherical shell model (deformation parameter, $\beta = 0$). Note that 40 is shown as magic for a spherical shape as taken from the review of Baranger and Sorensen.[8] It was the double closed shell structure of $^{90}_{40}$Zr$_{50}$ which originally provided the evidence for the spherical magic character of 40. Subsequently, the double-closed-shell-like structure of $^{96}_{40}$Zr$_{56}$ and more recently well off stability $^{68}_{28}$Ni$_{40}$ provide support for both Z and N of 40 being magic for a spherical shape. Likewise, $^{88}_{38}$Sr$_{50}$ is often taken as the inert double closed shell core in many shell model calculations. Thus, it was quite surprising to discover[9] in $^{74,76}_{36}$Kr$_{38,40}$, where N = 38 and 40, a new region of unusually large deformation with $\beta \sim 0.35$. This new region of very strong deformation is found to be centered around N = Z = 38. It was independently predicted by the calculations of the ground state shapes and masses of over 4000 nuclei by Möller and Nix.[10] Without going through all the experimental evidence, what emerges can be understood by looking at Fig. 2 which shows the single particle levels as a function of deformation, as taken from Bengtsson et al.,[11] and at a summary of the data as given in Table 1. When 40 or the 38 spherical ($\beta = 0$) shell gaps get reinforced by a strong spherical magic number like 28 and 50 and even the weaker subshell gap at 56, then the reinforcing push of the protons and neutrons for the same shape, here spherical, makes nuclei like $^{90,96}_{40}$Zr$_{50,56}$, $^{68}_{28}$Ni$_{40}$ and $^{88}_{38}$Sr$_{50}$ look like spherical double magic nuclei. However, there are competing shell gaps at large prolate deformation (β - 0.35) for N,Z = 38 and 40. These deformed shell gaps are somewhat deeper than their competing spherical gaps at 38 and 40 so that when both N and Z approach 38 and 40, the stronger push for a deformed shape by both the protons and neutrons drives these nuclei to unusually large deformation as first observed in $^{74,76}_{36}$Kr$_{36,40}$ (ref. 9). So, the reinforcing effect of the protons and neutrons can cause a switch in which shell gap is "magic" in this region in stabilizing the nuclear shape to be spherical or deformed.

The reinforcing of the proton and neutron shape driving forces, as seen by the gaps in the single particle spectrum in Fig. 2, also explains the sudden appearance of another new region of equally strong deformation ($\beta \sim 0.35$) in $^{100,102}_{40}$Zr$_{60,62}$ and $^{98,100}_{38}$Sr$_{60,62}$ (as described in detail in ref. 2). As discussed there[2] and seen by looking at the 2$^+$ energies in Fig. 3, it is the reinforcing of the neutron shell gap at N = 60 at large deformation (β - 0.35) by the proton shell gaps at 38, 40 at the same large deformation (β - 0.35) that leads to this region of very strong deformation and not simply the N = 60 shell gap at large deformation as first proposed. For the N = 60, 62 nuclei as Z increases from 38, the large and suddenness of the onset of deformation (as indicated in Fig. 3 by the 2$^+$ level energies) are both gone by Z = 42 and clearly by

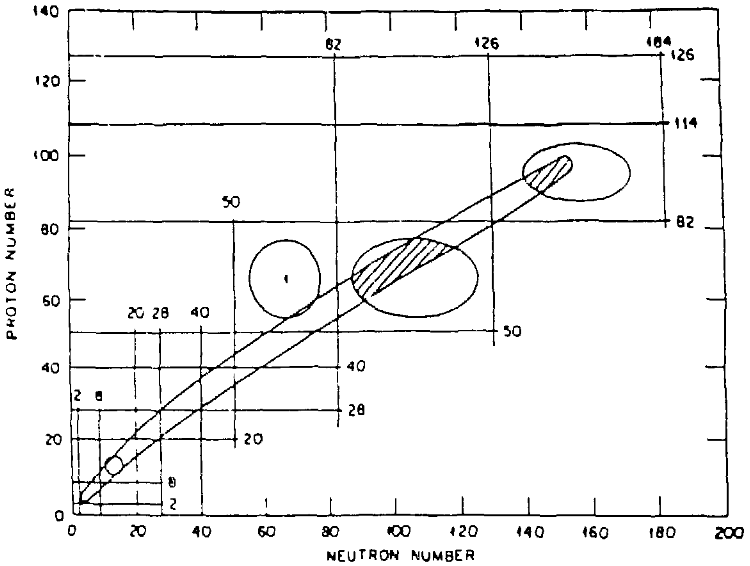

Fig. 1. Chart of the nuclides as a function of N and Z from ref. 8 with the spherical closed-shell magic numbers shown by verical and horizontal lines and deformed regions by ovals.

Z = 44. The suddenness of the onset of deformation in the ${}_{40}$Zr and ${}_{38}$Sr nuclei between N = 58 and 60 is also explained by the reinforcing proton and neutron shell gaps. The N = 56 spherical shell gap reinforces the spherical gaps at Z = 38 and 40 to keep these nuclei spherical further out from N = 50 than they would otherwise be. The double-closed-shell-like level structure seen in ${}^{96}_{40}$Zr$_{56}$ but not ${}^{94}_{38}$Sr$_{56}$ indicates that the Z = 40 and N = 56 spherical shell gap reinforcement is stronger than for 38-58. However, the Z = 38 and N = 60, 62 deformed shell gap reinforcement is stronger to drive the N = 60,62 ${}_{38}$Sr nuclei to have even larger deformation than the N = 60,62 ${}_{40}$Zr nuclei. Thus, we have clear evidence for new "magic" numbers, 38 for N and Z, (and perhaps 40 for N and Z) and 60 for N but now for deformed shapes. These "deformed magic" numbers or shell gaps confirm the longstanding prediction of Brack et al.[12] that there should be such magic numbers for different deformations which play the same role at large deformation as the well-known spherical magic number derived by Mayer and Jensen from the spherical shell model. The importance of reinforcing shell gaps on nuclear deformation and of the new "deformed magic numbers" are additional examples of new phenomena which could only be obtained by studying nuclei far from stabilty.

As one looks at Fig 2, one sees that in addition to 38 and 60 there are other shell gaps at different deformations. Theorists have emphasized that the shell gaps at equally large deformation but for an oblate shape ($\beta \sim -0.35$) at Z = N = 36 should be as important as the Z = N = 38 shell gaps. Thus, a new region of the strongest oblate deformation ever observed should exist around N = Z = 36 or 35. The Vanderbilt group initiated studies to seek to identify this new region of very strong oblate deformation and the phase transition from very strong prolate to very strong oblate deformation. All ground state oblate shapes previously observed have had small deformation ($\beta \lesssim -0.15$). Good candidates to observe the sudden transition are the bromine isotopes

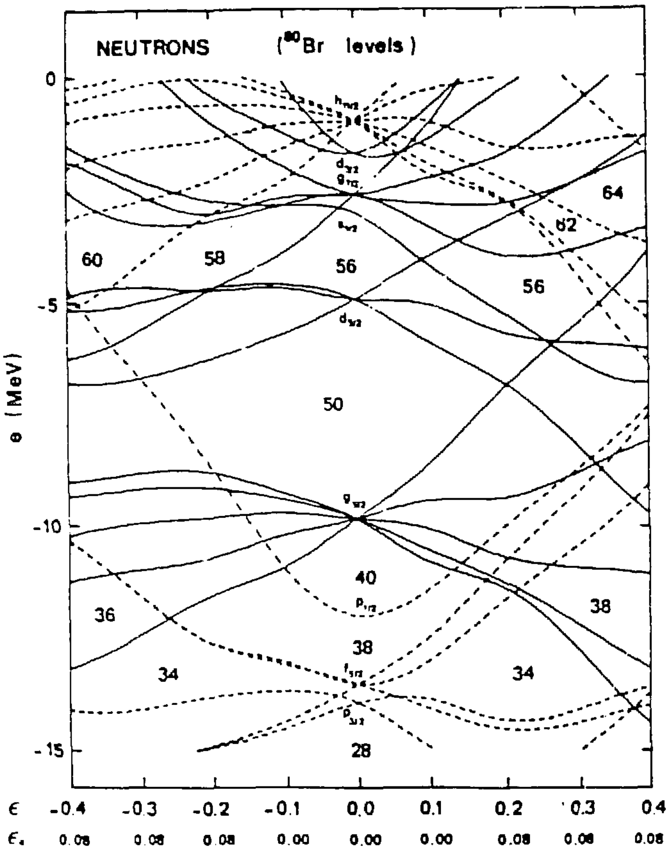

Fig. 2. Single particle levels (ref. 11).

Table 1. Summary of Experimental Data for N = 38 and 40 Nuclei

$^{66,68}_{28}Ni_{38,40}$	- ^{68}Ni spherical double magic energy levels ^{66}Ni spherical, large $E_{2_1^+} = 1.42$	
$^{70,72}_{32}Ge_{38,40}$	- near-spherical ground states and low-lying deformed 0_2^+ states	N=42-50 no deformed bands seen
$^{72,74}_{34}Se_{38,40}$	- near-spherical ground states and low-lying well deformed 0_2^+ states and deformed bands, clear shape coexistence	N=42-50 no deformed bands seen
$^{74,76}_{36}Kr_{38,40}$	- strongly deformed ground states and near spherical 0_2^+ states	N=42,44 γ-soft to N=50 spherical
$^{76,78}_{38}Sr_{38,40}$	- strongly deformed ground states, but no near spherical 0_2^+ states observed	Smooth decrease in deformation as N increases toward 50

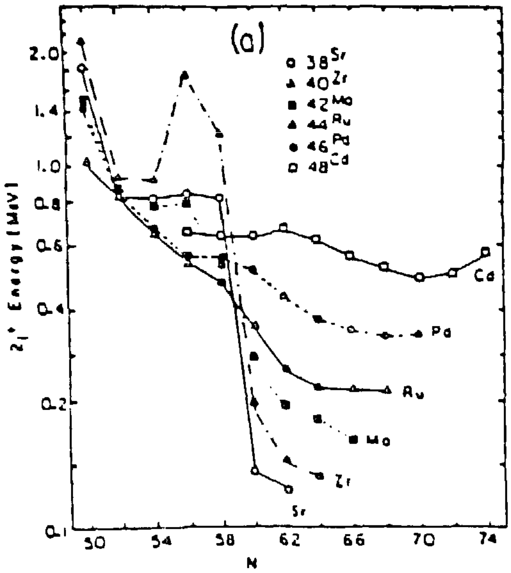

Fig. 3. The 2_1^+ energies for Sr to Cd nuclei with
A = 50-70.

$^{75,73,71}_{35}Br_{40,38,36}$ since its Z = 35 is in the center of the expected new region and the N values span the prolate-oblate phase transition region. Unfortunately, the lightest of these isotopes has less than 1% of the total cross section in a heavy ion reaction. Thus, special techniques had to be employed in order to identify the very low cross section products in a heavy ion reaction.

First a five sector neutron detector[13] was built for in-beam n-γ, n-n-γ, and n-γ-γ coincidence studies which have been carried out at the Holifield Heavy Ion Research Facility and the University of Notre Dame. Then this detector was used with the recoil mass spectrometer at the University of Rochester for recoil-mass-n-γ studies. By combining these data, the energy levels in ^{73}Br were identified for the first time (see Fig. 4) and new high spin states in ^{75}Br (ref. 14). The strongest band seen to high spin in both ^{73}Br (Fig. 4) and ^{75}Br is the one built on the $g_{9/2}$ orbital. The transition energies in this band in ^{75}Br, beginning with the $13/2^+ \rightarrow 9/2^+$ transition are 563, 830, 1045, 1209, and 1325, respectively. By comparing these with Fig. 4 one sees that these two bands are nearly identical. (Recently some additional very low energy transitions have been placed[15] below the $9/2^+$ band in ^{73}Br compared to Fig. 4, but the $9/2^+$ bands are identical). The $\Delta I = 2$ sequence of levels in the $9/2^+$ bands in $^{73,75}Br$ are characteristic of a prolate rotor with very large deformation ($\beta \sim 0.35$).

A new five separated sector neutron detector and four large solid angle NaI detectors for light charged particles[6] were built. These detectors were used with the Rochester recoil mass spectrometer in the reaction $^{16}_{8}O + ^{58}_{28}Ni \rightarrow (^{74}Kr)^*$ to search for $^{71}_{35}Br_{36}$. From a comparison of recoil-mass-n-γ and recoil-mass-p-γ coincidences, we identified several transitions as belonging to ^{71}Br (ref. 16). All have energies in the range of 200-400 keV. Since the strongest cascade transitions in $^{73,75}Br$ are in the $9/2^+$ band, we assume this will be the case for ^{71}Br. If this is so, then the low energy of the transitions observed there would indicate a $\Delta I = 1$ sequence in contrast to the $\Delta I = 2$ sequence

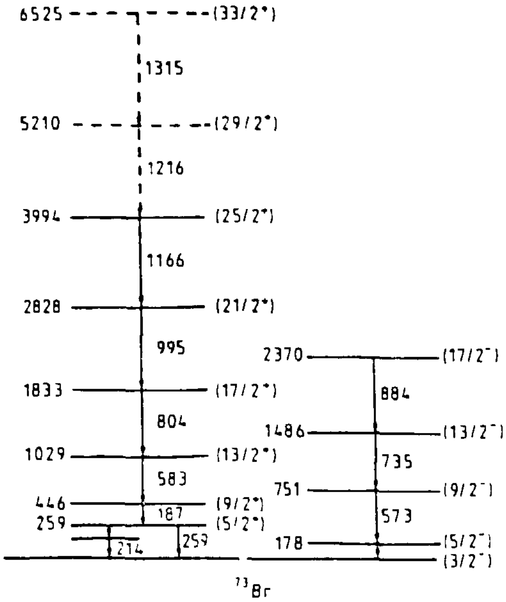

Fig. 4. Energy levels in ^{73}Br from n-γ and recoil mass-n-γ coincidence data[14]. Additional transitions have been placed below the 9/2$^+$ level.[15]

in ^{73,75}Br. Based on the single particle orbitals available, a ΔI = 1 sequence is expected for an oblate shape. Thus, these data may be an indication of a sudden phase shift from a very large prolate ground state in ^{73,75}Br to a very large oblate shape for the ground state of ^{71}Br. Analysis of n-n-γ and n-γ-γ data are in progress to establish the bands and spin sequence in ^{71}Br.

As described in more detail in refs. 1, 2, the concept of reinforcing proton and neutron shell gaps illuminates a variety of other regions such as the reinforcing of the spherical subshell gaps at Z = 64 by the strong spherical shell gap at 82 to make $^{146}_{64}$Gd$_{82}$ a double closed shell nucleus. Indeed, the spherical subshell gap at Z = 64 plays the same role that the N = 56 spherical gap does in the Sr-Zr region in the sudden onset of deformation as discussed above. It is the influence of the spherical Z = 64 gap that keeps the $_{62}$Sm, $_{64}$Gd and $_{66}$Dy nuclei spherical further out from N = 82 than they would otherwise be, so there is a sudden onset of deformation between N = 88 and 90 for these three elements. However, the suddenness of the onset of deformation between N = 88 and 90 disappears for 62 > Z > 66.

New regions and types of nuclear shape coexistence are continuely being found throughout the periodic table. For example, a new and different type of shape coexistence was found this year in the very light Pt nuclei ^{176,178}Pt (refs. 17, 18). Dracoulis et al.[17] studied the yrast cascades in $^{176,178}_{78}$Pt. In Fig. 5 (from ref. 18) their data are compared with similar data for $^{172,174}_{74}$W and $^{174,176}_{76}$Os (refs. 19, 20). The behaviors of the high spins ($\gtrsim 6^+$) states in ^{172}W, ^{174}Os, and ^{176}Pt, as shown in Fig. 5, are remarkably smilar and characteristic of a well-deformed rotor. However, there is a strong deviation in the 2$^+$ level of ^{176}Pt. Quite similar behavior is seen for the yrast energy levels in the N = 100 isotones except only a small perturbation is seen at 2$^+$ in ^{178}Pt. Dracoulis et al.[17] interpreted the ^{176}Pt low spin difference to the coexistence of two shapes with quite different deformations. Independently and simultaneously, potential energy surface

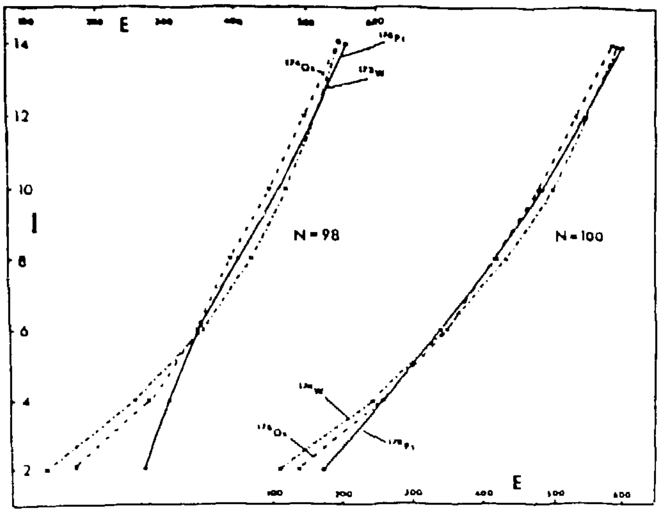

Fig. 5. Yrast level energies vs. nuclear spin in ^{176,178}Pt, ^{174,176}W and ^{172,174}Os.

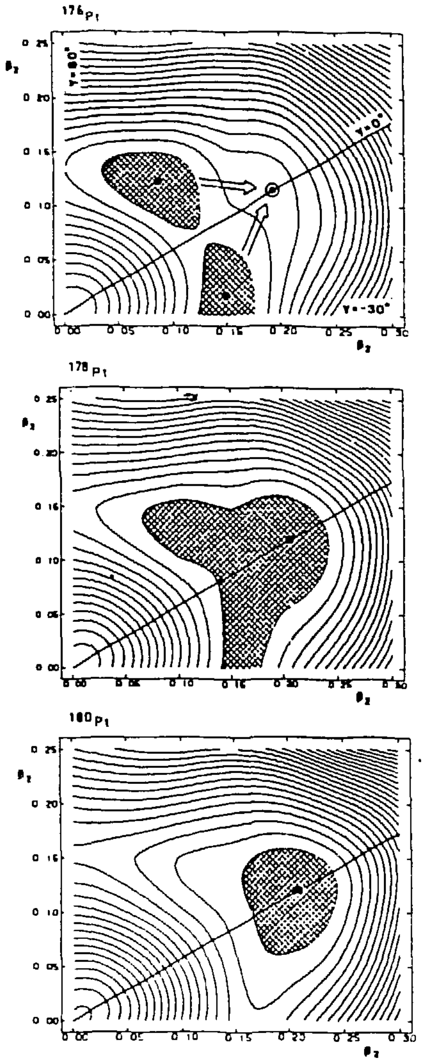

Fig. 6. Potential energy surfaces for $^{176-180}$Pt (ref. 18).

calculations were being carried out for the Pt isotopes.[18] These surfaces (Fig. 6) independently predicted the coexistence of two shapes in ^{178,176}Pt and predicted a sudden ground state phase transition from a strong prolate ground state ($\beta \sim 0.23$) in ^{178}Pt to a weakly deformed ($\beta \sim 0.12$) ground state for ^{176}Pt with a coexisting, nearby, excited prolate deformed shape which had been the ground state of ^{178}Pt. As ^{176}Pt begins to rotate, the minima in the potential energy quickly goes to the prolate shape (flate space in Fig. 6). The weakly deformed band is the excited band in ^{178}Pt and slightly perturbs the 2^+ energy there. Dracoulis et al.[17] noted the similarity of the shape coexistence in ^{176}Pt to that in ^{184}Hg. However, the potential enrgy surface calculations point to a significant difference; the ground state of ^{184}Hg has a small oblate deformation while for ^{176}Pt the ground state has a small, triaxial deformation.

In summary, varieties of nuclear shape coexistence are seen throughout the periodic table (see refs. 1,2 for other examples). In addition, we have firm evidence for new "deformed" magic numbers, 38 for N and Z and 60 for N, which manifest themselves when the proton and neutrons have shell gaps at the same deformation so both the protons and neutrons drive the nucleus toward the same large, prolate deformation and tentative evidence for the N = Z = 36 shell gaps at large, oblate deformation. As seen in Fig. 2, there are numbers of other shell gaps at different deformations. The importance of many of these gaps will undoubtedly be seen when nuclei far off stability with the right reinforcement of proton and neutron shell gaps at the same deformation are studied. These data all clearly suggest that in the collision of U on U or U on Cm one could expect to see the stabilizing influence of other new shell gaps, and certainly we expect to see a much wider range of collective phenomena associated with these collisions than we have seen.

EXOTIC DECAY MODES

In 1980 Sandulescu et al.[4] predicted from their calculations a new type of radioactivity for heavy nuclei intermediate between fission and alpha decay. They predicted that a heavy nucleus could emit a heavy cluster such as ^{14}C or ^{24}Ne when such emissions yielded a daughter nucleus at or near double magic $^{208}_{82}$Pb$_{126}$. Heavy cluster emission is a new collective type of decay mode which is an additional manifestation of the strong nuclear shell structure associated with spherical double magic ^{208}Pb. The first heavy cluster radioactivity, the ^{14}C radioactivity of ^{223}Ra, was discovered by Rose and Jones[21] who were apparently unaware of the predictions of Sandulescu et al.,[4] as noted in ref. 22. As shown in Fig. 7, ^{223}Ra was predicted by Sandulescu et al.[20] to have the largest ratio of ^{14}C to α decay of any isotope. An earlier review of this process is found in ref. 23 and more extensive theoretical analysis and predictions in the recent paper of Poenaru et al.[5]

Basically, the conditions for the splitting of nucleus A_Z into A_{Z_1} + $A2_{Z_2}$ are shown in Fig. 8. Heavy cluster radioactivity occurs when the potential is like curve 2 with a positive Q value and $E_i > 0$. For a potential like curve 1, the nucleus is stable and for curve 3 completely unstable.

Now ^{14}C radioactivities have been observed for $^{222-226}$Ra (refs. 21, 24-28). The expected lifetimes and the ^{14}C/α branching ratios are compared with the original theoretical calculations of Sandulescu et al.[4] and recent calculations from Frankfurt[29] in Fig. 9. While the original calculations do not reproduce the ^{222,224}Ra results, by increasing

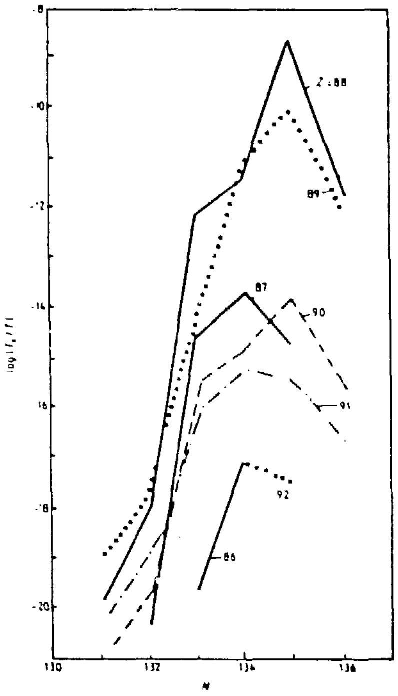

Fig. 7. The $^{14}C/\alpha$ ratios and α partial lifetimes from ref. 4.

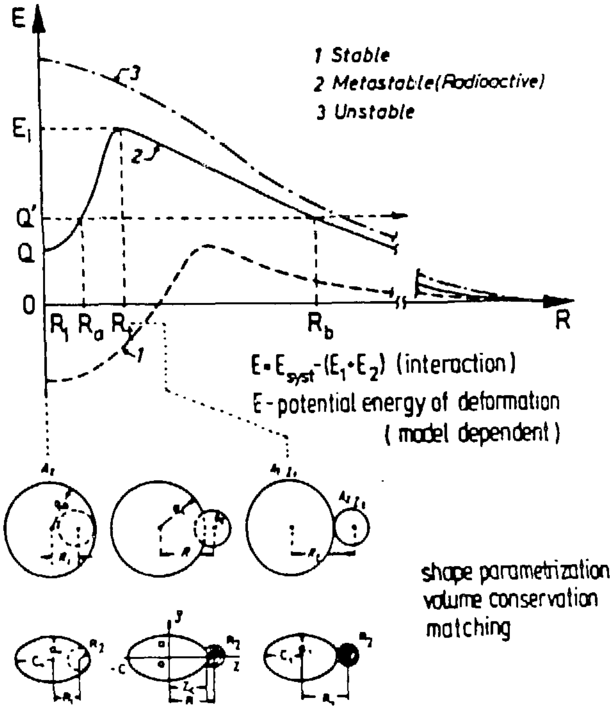

Fig. 8. Possible potential energies for a heavy nucleus. Curve 1 would give a stable nucleus; curve 2 where the Q value is greater than zero would give a radioactive nucleus, and; curve 3 is an unstable nucleus.

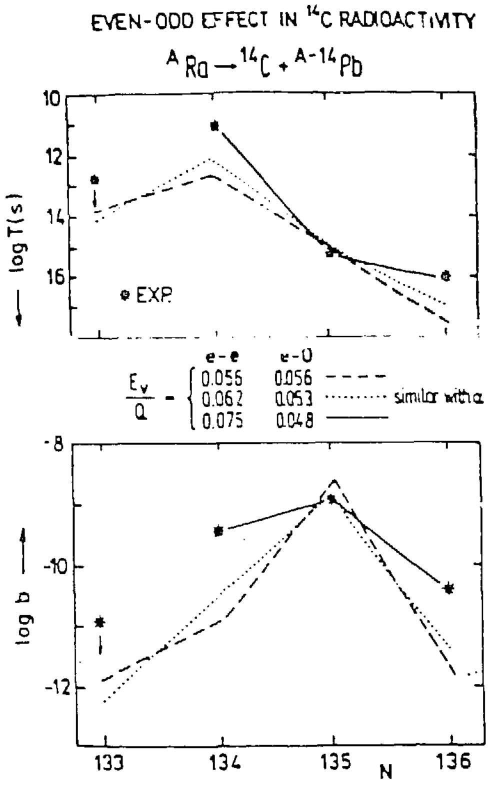

Fig. 9. The experimental ^{14}C/α ratios (b) for the decays of ^{222,223}and^{224}Ra are compared with the recent calculations of the Frankfurt-Bucharest group.[29] Note by allowing the zero vibrational point energy to increase for the e-e and decrease for the e-o cases, excellent agreement between theory and experiment is obtained.

the zero point vibrational energy for the even-even and reducing it for the even-odd cases, excellent agreement with experiment is achieved.[29]

Since the largest Q values occur when one daughter product is ^{208}Pb, as the mass of the heavy elment increase the mass and Z of the heavy cluster radioactivity must also increase as illustrated in Fig. 10. Now ^{24}Ne radioactivity has been reported for ^{231}Pa, ^{232}U, ^{233}U and ^{230}Th (refs. 30-33, respectively). The theoretical calculations[5] of the lifetimes are up to an order of magnitude faster than observed experimentally for these ^{24}Ne decays.

Barwick et al.[31] also have point out that the reported spontaneous fission half-lives[34-40] for the eight isotopes in Table 2 are in reasonable agreement with the theoretically calculated half lives[4,5] for heavy cluster radioactivities. They note that it is very likely that what were called spontaneous fission (into two more equal size fragments) in these eight cases are heavy cluster decays.

In the first calculations, decays to excited states of the heavy daughter were neglected[4,5] and this could introduce a serious correction. Very recently Greiner and Scheid[41] have calculated the corrections to the partial half lives for heavy cluster decays to the ground states[4,5] by calculating the total transition rates including those to excited states of the heavy daughter fragments. They find that this increases

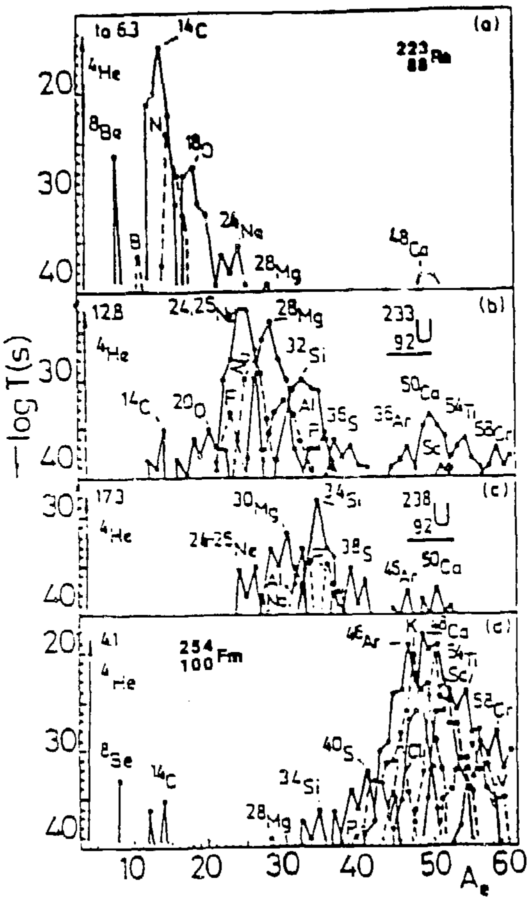

Fig. 10. The heavy cluster radioactivities predicted[5] for heavy elements are shown.

Table 2. Half-Lives Predicted[4,5] for Heavy Ion Emission Compared With Measured Spontaneous Fission Half-Lives[36-42].

Decay Mode	Predicted τ_X	Measured τ_{SF}	Ref.
$^{232}U \rightarrow {}^{24}Ne$	1×10^{13}	6×10^{13}	36
$^{232}Th \rightarrow {}^{26}Ne$	1×10^{22}	$> 1 \times 10^{21}$	37
$^{231}Pa \rightarrow {}^{24}Ne$	4×10^{14}	$\geq 1.1 \times 10^{16}$	38
$^{230}Th \rightarrow {}^{24}Ne$	3×10^{17}	$\geq 1.5 \times 10^{17}$	38
$^{233}U \rightarrow {}^{25}Ne$	9×10^{15}	1.2×10^{17}	39
$^{234}U \rightarrow {}^{28}Mg$	2×10^{17}	1.6×10^{16}	40
$^{237}Np \rightarrow {}^{30}Mg$	3×10^{18}	$\geq 1 \times 10^{18}$	41
$^{241}Am \rightarrow {}^{34}Si$	2×10^{15}	2.3×10^{14}	42

the decay rates even in unfavorable cases by at most not more than half an order of magnitude and so is not a serious correction to the original calculations.[4,5] This amount is within the overall accuracy of the calculations. The effect is essentially zero when one daughter is ^{208}Pb whose excited states are very high in energy.

Poenaru et al.[42] have now calculated the possibility of heavy cluster emission from lighter nuclei. They find that all stable nuclei with $Z \gtrsim 40$ are radioactive with respect to heavy cluster emission but with lifetimes in the range $\sim 10^{40}$ to 10^{50}s.

A NEW NUCLEAR COLLECTIVE PHENOMENA: VERY ENERGETIC PROTON AND ALPHA EMISSION IN HEAVY ION REACTION

Recently Maguire (at Vanderbilt) as part of a collaboration with Argonne, Michigan, Kansas, and Notre Dame constructed several large solid angle NaI detectors to measure very energetic light ions with energies up to 10 times the incident MeV/u in heavy-ion reactions.[6] The detectors were calibrated with 80 MeV α particles on CH_2.

The reactions 300 MeV ^{32}S (9.38 MeV/u) + Ta and 600 MeV ^{58}Ni (10.34 MeV/u) + Ta were studied.[7] Very surprisingly, significant numbers of protons with energies up to and greater than 100 MeV and alpha particles with up to 150-200 MeV were observed. These particles are coming out with up to 10-20 times the incident MeV/u and are carrying off up to 50% and more of the total incoming energy. There is some strong collective effect which is giving rise to the concentration of such a large fraction of the total incident energy into one particle. At present there is no theory to predict such energetic particles. There is much research to be done to investigate when and where these particles are emitted during the collision and what other fragments are in coincidence with them.

Even though one does not have any theoretical understanding, these exciting results generate numbers of interesting speculations. In relation to this conference, one can speculate whether in collisions of U on U or U on Cm at energies in the range of 5-10 MeV/u such fast protons or alpha particles may be emitted at such times and locations as to cool the reaction and lead to longer sticking times for the two heavy nuclei. Also, it is known that there is enhanced alpha emission along the long axis of a prolate deformed nucleus in radioactive decay. If the most favored orientations for two heavy nuclei like U to collide and stick is end-to-end, as has been suggested,[43] there could be added enhancement to such fast alpha or fast proton emission along this axis which, in turn, could increase their sticking time. There could be other consequences as well.

SUMMARY

The thrust of this paper was to illustrate that we are continuing to find in numerous, diverse ways throughout the periodic table ($Z \lesssim 92$) new manifestations of collective nuclear behavior. These include various types of nuclear shape coexistence for low-lying levels, new "magic" numbers for deformed shapes which give stability, for examples, to very large prolate and very large oblate shapes, new collective decay modes such as heavy cluster emission, and collective concentration into a single outgoing proton or alpha particle a large fraction (up to 50% and more) of the incident energy in a heavy ion collision. The wealth and diversity of these collective phenomena strongly suggest that in the collision of two heavy nuclei, like uraniium and uranium or curium, that there should be a variety of new collective phenomena including previously inaccessible, exotic collective phenomena.

Already, Greiner[43] has suggested that if two such heavy nuclei collide and stick for even 10^{-19}s that one could see new collective excitation such as a "butterfly" type motion where the opposite ends of the two touching nuclei oscillate up and down about their touching

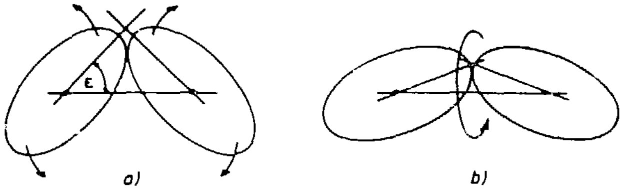

Fig. 11. Possible new collective excitations associated with two heavy ions which have stuck together as shown (from ref. 43).

point or when the angle between the two symmetry axes is not 180° when at the touching point, they can rotate about a common center of gravity (see Fig. 11). These are but two new easy to visualize collective motions and considerations of other collective behaviors should be made. Some of these phenomena may have strong bearings on the positron line production. Already, at this conference, Raefelski proposed a new way of producing e^+e^- pairs. Also at this conference, Oberacker suggested that the excitation of even one uranium nucleus into its second minima, which has a much large deformation than its ground state, would significantly change the Coulomb energy and so alter possible potential pockets which could lead to sticking. We should look at the possibility that there are new shell gaps at large deformation including very large deformations associated with second minima in the potentials for Z in the range 180-190 and N of 290-298 which could help stabilize two colliding heavy nuclei. One should explore whether the new observed emission of a very energetic proton or alpha particle could, if present in these heavy ion collisions, significantly cool the system so as to influence this sticking of the two nuclei. Finally, it is possible that there is more than one origin for the positron peaks being observed. So, in different colliding nuclear systems or even in the same system, positron lines from more than one origin may be confusing the theoretical interpretations.

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REFERENCES

1. J. H. Hamilton, P. G. Hansen, and E. F. Zganjar, in: Reports on Progress in Physics 48: 631 (1985).
2. J. H. Hamilton, in: Nucleus-Nucleus Collisions from the Coulomb Barrier Up to the Quark-Gluon Plasma, (Proc. Int. School of Nuclear Physics), in "Progress in Particle and Nuclear Physics," Vol. 15, A. Faessler, ed., Pergamon Press, NY (1985), p. 107.
3. J. H. Hamilton and J. Maruhn, Scientific American (July, 1986), p. 80.
4. A. Sandulescu, D. N. Poenaru, and W. Greiner, Sov. J. Part. Nucl. 11:528 (1980).
5. D. N. Poenaru, M. Ivascu, A. Sandulescu, and W. Greiner, Phys. Rev. C 32: 572 (1985).
6. C. F. Maguire, D. G. Kovar, C. Beck, C. N. Davids, D. Henderson, M. F. Vineyard, F. W. Prosser, S. V. Reinart, J. J. Kolata, Bull. Am. Phys. Soc. 30:1769 (1985).
7. P. Shulman, F. Becchetti, J. Janecke, R. Stern, D. Kovar, C. Davids, M. Vineyard, C. Beck, and C. F. Maguire, Bull. Am. Phys. Soc. 31:840 (1986).

8. M. Baranger and R. A. Sorenson, *Scientific American* (1969), p. 58.
9. J. H. Hamilton, R. B. Piercey, R. Soundranayagam, A. V. Ramayya, C. F. Maguire, X.-J. Sun, Z. Z. Zhao, J. Roth, L. Cleemann, J. Eberth, T. Heck, W. Neumann, M. Nolte, R. L. Robinson, H. J. Kim, S. Frauendorf, J. Döring, L. Funke, G. Winter, J. C. Wells, J. Lin, A. C. Rester, and H. K. Carter, in *Proc. IV Int. Conf. On Nuclei Far From Stability*, CERN81-09 (1981), p. 391; R. F. Piercey, J.H. Hamilton, R. Soundranayagam, A. V. Ramayya, C. F. Maguire, X.-J. Sun, Z. Z. Zhao, R. L. Robinson, H. J. Kim, S. Frauendorf, J. Döring, L. Funke, G. Winter, J. Roth, L. Cleemann, J. Eberth, W. Neuman, J. C. Wells, J. Lin, A. C. Rester, and H. K. Carter, *Phys. Rev. Lett.* 47: 1514 (1981).
10. P. Möller and R. A. Nix, *At. and Nucl. Data Tables* 26: 165 (1981).
11. R. Bengtsson, P. Möller, R. A. Nix, and J.-Y. Zhang, *Physica Scripta* 29:402 (1984).
12. M. Brack, J. Damgaard, A. S. Jensen, H. C. Pauli, V. M. Strutinsky, and C. Y. Wong, *Rev. of Mod. Phys.* 44:320 (1972).
13. R. B. Piercey, F. E. Dunnam, M. L. Muga, A. C. Rester, A. V. Ramayya, J. H. Hamilton, J. Eberth, and E. F. Zganjar, *Int. Conf. on Instrumentation for Heavy-Ion Nuclear Research*, Oak Ridge, Oak Ridge National Laboratory, CONF-841005, (1984), p. 27.
14. S. Wen, A. V. Ramayya, S. J. Robinson, C. F. Maguire, W. C. Ma, X. Zhao, T. M. Cormier, P. M. Stwertka, J. D. Cole, E. F. Zganjar, R. B. Piercey, M. A. Herath-Banda, J. Eberth, and M. Wiosna, *J. Phys. G Lett.* 11:L173 (1985).
15. B. Wörmann, J. Heese, K. P. Lieb, L. Lühmann, F. Raether, D. Alber, H. Grawe, and B. Spellmeyer, *Z. Phys.* A322:171 (1985).
16. X. Zhao, A. V. Ramayya, C. F. Maguire, J. Kormicki, W. C. Ma, S. Wen, J. H. Hamilton, Z-M. Chen, L. Chaturvedi, T. C. Cormier, M. Statteson, E. F. Zganjar, M. Kortelhathi, J. D. Cole, J. Eberth, N. Schmal, R. B. Piercey, and M. A. Herath-Banda, *Bull. Am. Phys. Soc.* 31:772 (1986).
17. G. D. Dracoulis, A. E. Stuchbery, A. P. Byrne, A. R. Poletti, S. J. Poletti, J. Gerl, and R. A. Bark, *J. Phys. G:Nucl. Phys.* 12:L97 (1986).
18. R. Bengtsson, J.-y. Zhang, J. H. Hamilton, and Leon K. Peker, *J. Phys. G Letts.* (1986), in press.
19. G. D. Dracoulis, P. M. Walker, and A. Johnson, *J. Phys. G* 4:714 (1978).
20. J. L. Durell, G. D. Dracoulis, C. Fahlander, and A. P. Byrne, *Phys. Lett.* 115B:367 (1982).
21. H. J. Rose and G. A. Jones, *Nature* 307:245 (1984).
22. A. Sandulescu, D. N. Poenaru, W. Greiner, and J. H. Hamilton, *Phys. Rev. Lett.* 54:490 (1985).
23. J. H. Hamilton, *Proc. Fifth Adriatic Int. Conf. On Nuclear Physics*, in: "Fundamental Problems in Heavy Ion Collisions," N. Cindro and W. Greiner, eds., Singapore, World Scientific, (1984), p. 111.
24. D. V. Alexandrov, A. F. Beliatsky, Yu. A. Gluhov, E. Yu. Nikolsky, B. G. Novatsky, A. A. Ogloblin, and D. N. Stepanov, *Pis'ma Zh. Eksp. Teor. Fiz.* 40:152 (1984).
25. S. Gales, E. Hourani, M. Hussonnois, J. P. Shapira, L. Stab, and M. Vergner, *Phys. Rev. Lett.* 53:759 (1984).
26. P. B. Price, J. D. Stevenson, and S. W. Barwick, *Phys. Rev. Lett.* 54:297 (1985).
27. W. Kutschera, J. Ahmad, S. G. Armato, III, A. M. Friedman, J. E. Gindler, W. Henning, T. Ishii, M. Paul, and K. E. Rehm, *Phys. Rev. C* 32:2036 (1985).
28. E. Hourani, M. Houssonnois, L. Stab, L. Brillard, S. Gales, and J. P. Shapira, *Phys. Lett.* 160B:375 (1985).

29. W. Greiner, private communication (1985).
30. A. Sandulescu, Yu. S. Zamyatnin, J. A. Lebedev, B. F. Myasoedov, S. P. Tretyakova, and D. Hasegan, JINR Rapid Communications 5:5 (1984).
31. S. W. Barwick, P. B. Price, and J. D. Stevenson, Phys. Rev. C 31:1984 (1985).
32. S. P. Tretyakova, A. Sandulescu, Yu. S. Zamyatnin, Yu. S. Korotkin, and V. L. Micheev, JINR Rapid Communications 7:23 (1985).
33. S. P. Tretyakova, A. Sandulescu, V. L. Micheev, D. Hasegan, J. A. Lebedev, Yu. S. Zamyatnin, Yu. S. Korotkin, and B. F. Myasoedov, JINR Rapid Communications 13:34 (1985).
34. A. H. Jaffey and A. Hirsch, in Nuclear Fission, by R. Vandenbosch and J. R. Huizenga, Academic Press, NY (1973).
35. G. N. Flerov et al., Dokl. Akad. Nauk SSSR 3:69 (1958) [Sov. Phys. Dokl. 3:79 (1958)].
36. E. Segre, Phys. Rev. 86:21 (1951).
37. B. M. Alexandrov, L. S. Krivokhatski, L. Z. Malkin, and K. A. Petrzhak, Sov. J. At. Energy 20:352 (1966).
38. A. Ghiorso, G. H. Higgins, A. E. Larsh, G. T. Seaborg, and S. G Thompson, Phys. Rev. 87:163 (1952).
39. V. A. Druin, V. P. Perelygin, and G. I. Khlebnikov, Zh. Eksp. Teor. Fiz. 40:1296 (1961) [Sov. Phys. JETP 13·913 (1961)].
40. V. A. Druin, V. L. Mikheev, and N. K. Skobelev, Zh. Eksp. Teor. Fiz. 40:1261 (1961)[Sov. Phys. JETP 13:889 (1961)].
41. M. Greiner and W. Scheid, J. Phys. G Lett. (in press).
42. D. N. Poenaru, W. Greiner, M. Ivascu, and A. Sandulescu, Phys. Rev. C 32:2198 (1986).
43. W. Greiner, Nucl. Phys. A447:271c (1985).