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High-spin states following multi-nucleon transfer

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Abstract. High-spin states in neutron-rich nuclei, populated following deep-inelastic multi-nucleon transfer, have been studied using the GAMMASPHERE array at the LBNL, USA. A ^{64}Ni beam at an energy $\sim 15\%$ above the Coulomb barrier was incident upon a thick ^{208}Pb target, leading to the population of more than 130 different nuclei. The strongest channels correspond to nuclei close to the projectile and target, although transfer of up to 50 nucleons has been observed. New high-spin states in neutron-rich ^{60,62}Fe and ^{68,70,72}Zn nuclei have been observed. Some limitations of this method of high-spin spectroscopy are discussed, including the apparent difficulty of populating odd-odd and odd-even isotopes via this type of reaction. The data have been searched for superdeformed (SD) states in the $A = 190$–200 region, but no evidence for their presence has been found.

PACS. 21.10.Re Collective levels – 23.20.Lv Gamma transitions and level energies – 25.70.Gh Compound nucleus – 27.90.+b $220 \leq A$

1 Introduction

Recently, it has been shown that deep-inelastic multi-nucleon transfer reactions (DIS) populate high-spin states in nuclei which cannot be reached by conventional heavy-ion fusion-evaporation reactions [1–4]. DIS reactions populate relatively high-angular-momentum states in nuclei along the valley of stability and even towards the neutron-rich side. States up to spin $I \approx 30\hbar$ have been observed in heavy outgoing fragments [3].

Deep inelastic transfer reactions thus allow experimental access to high-spin structures in new, previously inaccessible regions of the Segré chart.

In such reactions, where the projectile nucleus is incident upon the target at an energy above the Coulomb barrier but where the formation of a compound nucleus is inhibited, the interacting nuclei come together long enough to exchange some number of nucleons before flying apart. The two outgoing fragments share the angular momentum and excitation energy brought about by the reaction. The angular momentum is divided into three components — that of the target-like fragment, that of the projectile-like fragment and the relative motion between the two. This last component depends on the degree of contact between the beam and target nuclei; previous studies have shown that, in multi-nucleon transfer reactions, it accounts on average for something close to 5/7 of the total angular momentum available in the reaction, the amount one would expect using a simple classical model of the motion of colliding spheres. Either fragment (or both) may emit one or more neutrons (and perhaps protons) if their excitation energy is high enough, and then decay via γ-ray emission.

DIS reactions result in the population of a large range of product nuclei, with most of the intensity concentrated close to the target or projectile system. The N/Z ratio of the product nuclei tends toward that of the compound system [1,2]. Thus, by judicious choice of projectile and target nuclei, it is possible to produce a fairly specific range of nuclei with significant intensity.

The γ decay of neutron-rich Ni isotopes including ^{67}Ni has been successfully studied by Pawlat *et al.* using multi-nucleon transfer techniques [5]. A thick ^{208}Pb target was bombarded with a 350 MeV beam of ^{64}N, allowing the population via quasi-elastic scattering of states up to spins of approximately $8\hbar$ in $^{64\text{-}67}$Ni. Significant yields were also noted for the neighbouring neutron-rich isotopes. This experiment was carried out using the OSIRIS γ-ray spectrometer at HMI, Berlin, which consisted of 11 Compton suppressed Ge detectors. In a subsequent experiment

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a ^{64}Ni beam was used with a ^{130}Te target (backed with ^{208}Pb) while γ-rays were detected with the GASP array at INFN, Legnaro. Using this more sensitive array three γ-ray transitions were placed in the $N = 40$ closed shell nucleus ^{68}Ni [6].

In the present experiment, the ^{64}Ni + ^{208}Pb reaction was studied using the GAMMASPHERE γ-ray detector array. The increased resolving power and efficiency of this array allowed the extension of the analysis from γ-γ to γ-γ-γ coincidences, as well as providing great improvements in the efficiency and sensitivity of detection. Thus it has been possible to investigate relatively high-spin structures populated via proton transfer channels to and from the projectile nucleus. We present here the expanded level schemes deduced for ^{60,62}Fe and ^{68,70,72}Zn, which are populated following the transfer of 2 protons from and to the projectile, respectively. The study of these nuclei is important in allowing us to understand the role of the $g_{9/2}$ neutron intruder orbital in determining the structure of nuclei close to the $Z = 28$ shell gap. In addition, these nuclei with two proton holes or particles outside the $Z = 28$ closed shell span the $N = 40$ sub-shell closure: ^{60,62}Fe have 34 and 36 neutrons respectively, whilst the Zn isotopes presented here have 38, 40 and 42 neutrons.

This reaction also populates, with a significant intensity, a number of $A \sim 200$ Po, Bi, Pb, Tl and Hg nuclei [2] close to the target (^{208}Pb). Superdeformation around $A = 190$ has been extremely well studied since the first observation of a superdeformed (SD) band in this mass region by Moore *et al.* [7], with SD states observed in neutron-deficient Au, Hg, Tl, Pb, Bi and Po isotopes. However, this island of superdeformation is predicted to extend towards stable and even neutron-rich isotopes [8]. It is very difficult to populate such nuclei at high spins using conventional heavy ion fusion evaporation reactions due to a lack of suitable stable beam/target combinations. The use of the GAMMASPHERE array, with its excellent sensitivity and selectivity, offered a unique opportunity to investigate the possibility of populating SD states in relatively neutron-rich Po, Pb, Hg nuclei and the possibility of confirming the theoretical predictions for the existence of a deep SD minimum in this region.

2 Experimental details

The experiment was carried out at the Lawrence Berkeley National Laboratory, Berkeley, California using the multi-detector GAMMASPHERE array. A thick (40 mg cm^{-2}) ^{208}Pb target was placed at the focal point of the GAMMASPHERE multi-detector array, which at the time consisted of 83 Compton suppressed Ge detectors. The beam of ^{64}Ni was provided by the 88$''$ Cyclotron at an energy of 360 MeV (15% above the Coulomb barrier at the front of the target). The aims of the experiment were twofold: i) to study high-spin states in neutron-rich nuclei close to both beam and target and ii) to investigate the possibility of populating SD states in stable/neutron-rich nuclei around $A = 200$. At this beam energy, it was expected that the most intensely populated projectile-like fragments would reach spins of approximately $12\hbar$. The target-like fragments were expected to be populated at higher spins, between about 23 $\hbar$ and the limit allowed by the fission barrier.

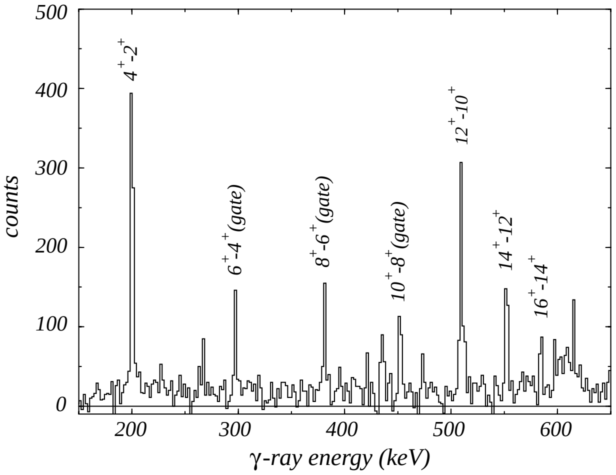

Fig. 1. Double-gated spectrum showing the yrast sequence of ^{156}Gd observed in the data. The presence of this sequence to spin $I = 16\hbar$ indicates that the transfer over 50 nucleons has taken place from the target to the projectile. The spectrum was created by summing double gates on the $6^+ \to 4^+$, $8^+ \to 6^+$ and $10^+ \to 8^+$ transitions.

During 48 hours of beam-time, a total of 7×10^8 events (triple- and higher-fold coincidences) were collected. Approximately 45% of these were triple-coincidence events. Use of a thick target insured that all γ-rays were emitted by nuclei which were stopped (or stopping) in the target material. Gamma-rays were assigned to nuclei based on high-fold (triple) γ-ray coincidences. The data were sorted into a 3-dimensional histogram (a cube) with non-linear compression to allow the study of γ-ray coincidences across a large energy range. This cube was analysed using the RADWARE package [9]. A second cube, with a linear energy dispersion, was also sorted. This cube, which spanned a much smaller energy range, was used to search for evidence of SD structures associated with $A \sim 200$ nuclei.

3 Results and discussion

3.1 General remarks

Deep inelastic transfer reactions populate a broad range of nuclei, with most of the intensity concentrated in the regions of the nuclear chart close to the target and projectile nuclei, but also extending towards the area between the two. For the ^{64}Ni + ^{208}Pb reaction the product yields have been well studied by Krolas *et al.* [2]. With the selectivity of the GAMMASPHERE array, it has been possible to observe γ-rays associated with nuclei populated by transfer of a very large number of nucleons. For example, γ-rays de-exciting levels up to spin $I = 16\hbar$ in the yrast sequence

Table 1. Some of the more strongly populated target-like nuclei observed in prompt triple-coincidence data obtained with the reaction ^{64}Ni on ^{208}Pb. The intensity has been normalized to 1000 units for ^{206}Pb. See text for more details.

Nucleus	Intensity in γ^3 (arb. units)	Nucleus	Intensity in γ^3 (arb. units)
^{212}Po	39 ± 5	^{201}Pb	82 ± 5
^{211}Po	—	^{200}Pb	151 ± 7
^{210}Po	88 ± 7	^{199}Pb	35 ± 4
^{209}Po	142 ± 14	^{198}Pb	28 ± 4
^{208}Po	462 ± 17	^{206}Tl	49 ± 6
^{207}Po	72 ± 7	^{205}Tl	163 ± 10
^{206}Po	148 ± 10	^{204}Tl	—
^{205}Po	61 ± 6	^{203}Tl	134 ± 9
^{204}Po	45 ± 5	^{202}Tl	41 ± 5
^{209}Bi	88 ± 8	^{201}Tl	39 ± 5
^{208}Bi	171 ± 11	^{204}Hg	10 ± 2
^{207}Bi	67 ± 7	^{203}Hg	—
^{206}Bi	80 ± 7	^{202}Hg	8 ± 2
^{205}Bi	97 ± 8	^{201}Hg	—
^{204}Bi	—	^{200}Hg	53 ± 6
^{203}Bi	24 ± 4	^{199}Hg	50 ± 6
^{208}Pb	184 ± 11	^{198}Hg	263 ± 13
^{207}Pb	33 ± 5	^{197}Hg	118 ± 8
^{206}Pb	1000 ± 24	^{196}Hg	165 ± 11
^{205}Pb	310 ± 14	^{195}Hg	65 ± 6
^{204}Pb	420 ± 18	^{194}Hg	37 ± 5
^{203}Pb	118 ± 9	^{193}Hg	8 ± 2
^{202}Pb	445 ± 20	^{192}Hg	6 ± 2

of ^{156}Gd (18 protons and 34 neutrons removed from the target) have been observed, see fig. 1.

Although it is possible that this residue is a result of fission of the ^{64}Ni + ^{208}Pb compound system, it is at the tail end of an unbroken distribution in target-like fragments. While the intensity of the lower transitions in this cascade may be augmented by contributions from β-decay the observation of states up to spin 16 indicates that spectroscopy of nuclei following the transfer of more than 50 nucleons is possible. However, such exotic channels take only a tiny fraction of the total reaction cross-section. The majority of the intensity is concentrated on nuclei only a few mass units from the initial projectile and target species. Table 1 lists some of the target-like nuclei for which it has been possible to measure the relative intensity of the ground-state transitions in triple-γ coincidences. The intensities have been measured by double-gating above the transition of interest and correcting for detector efficiency. The intensity listed in table 1 is simply the peak volume (normalized to 1000 units for ^{206}Pb) in the triples data. For nuclei where the decay path branches below the 6^+ (or equivalent) level, combinations of such double-gated spectra have been used and the total intensity summed. While these intensities are not measures of the yields of the nuclei, they do provide a good indication of the usefulness of the reaction in achieving the spectroscopy of a nucleus. The nuclei in table 1 represent the more strongly-populated target-like fragments, *i.e.* those for which the spectroscopy of relatively high-spin states is statistically feasible.

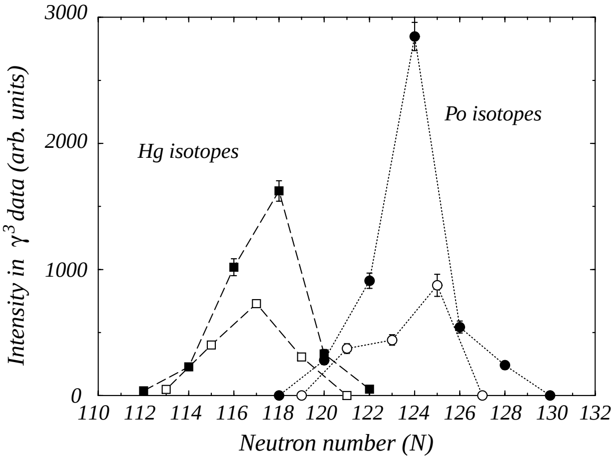

Fig. 2. Figure showing the (approximate) relative intensities of different isotopes of Po (circles) and Hg (squares) as a function of neutron number. The filled and open symbols represent even-even and even-odd isotopes, respectively. These measurements are not intended to represent the yields of the nuclei produced, but to highlight the extent to which yrast population (and therefore the population of high-angular-momentum states) is favored in the even-even nuclei.

On inspection of table 1 it becomes apparent that there is some staggering in the intensity with which even- and odd-A isotopes are observed in the data. To some extent, this may be explained by reference to the more complex decay paths of odd and doubly odd nuclei. However, the effect appears to be systematic and is clearly visible in both target- and projectile-like fragments. Projectile-like fragments are not included in table 1 because, in general, their high-spin level schemes are less well known and, therefore, measurements of this nature are extremely unreliable. However, it should be noted that it has not been possible to identify *any* transitions associated with odd or doubly odd projectile-like nuclei in the data, even via the technique of gating on the target-like partner fragments. Thus we have been unable to study the high-spin decays of, for example, Co/Cu isotopes, which are produced via single proton transfer from/to the projectile nuclei and which one might expect to be populated with a similar cross-section and angular momentum to the observed Fe/Zn nuclei.

The relative intensities of the ground-state transitions of the various Po and Hg isotopes produced in this experiment are plotted in fig. 2. These nuclei have been chosen to illustrate the odd-even population effect as their decay schemes are very well known and they are populated with significant intensities to reasonably high spins in our data set. The intensities of even-even isotopes of each species are indicated by filled symbols, while the odd-even isotopes are shown with open symbols. For both Po and Hg nuclei there is a marked reduction in the intensity of the odd-A nuclei compared to the neighbouring even-A isotopes. This pattern of a generally lower strength is clearest in the Hg isotopes. Such behaviour may be caused by the tendency of the odd-A nuclei to evaporate the more weakly bound, last nucleon. Those nuclei which are populated with relatively high spins and excitation energies (*i.e.* those for which the spectroscopy of high-spin states may be possible) are more likely to be formed above the particle emission threshold, and thus the technique employed here for extracting a measure of the high-spin intensity rather than the yield highlights this effect. It is also possible (although less likely) that pairing may be a factor in the transfer of nucleons between target and projectile nuclei. Certainly, whatever the mechanism behind the reduction in the intensity of the odd-A and odd-odd nuclei, the systematic difference between the population of odd-odd, odd-even and even-even nuclei indicates that reactions of this type may be best suited to the study of even-A isotopes. Further investigation into this question is required, however, as it may be that the effect is enhanced by the use of the doubly magic ^{208}Pb target and semi-magic ^{64}Ni beam. The use of a mid-shell nucleus as projectile or target may indeed affect the ease with which nucleons (paired or unpaired) are exchanged during the reaction. It would also be interesting to see whether an odd-A beam (or target) resulted in greater population of odd-A target-like (or beam-like) fragments, or whether the odd particle might not be emitted during the compound nucleus phase of the reaction process. Heavy-ion induced fission studies have indicated [10] that where the compound nucleus has an odd value of Z, the odd proton appears to be emitted *prior* to the fission process, and not by one of the outgoing fission fragments. Thus it may be that the use of an odd-A target has little effect on the population of odd-A nuclei in DIS reactions. More experimental work is necessary to elucidate this point.

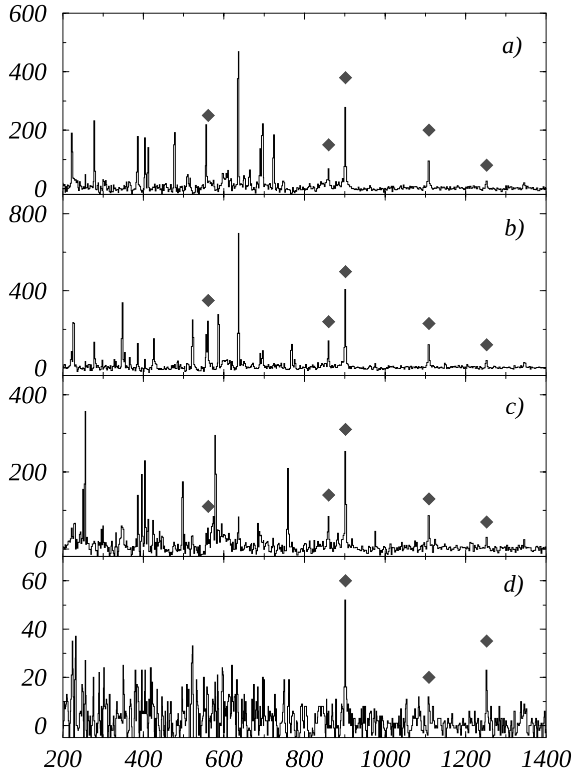

Fig. 3. Spectra obtained by setting a single pair of gates on the $2^+ \rightarrow 0^+$ transition in ^{70}Zn and the $2^+ \rightarrow 0^+$ transition in (a) ^{196}Hg, (b) ^{198}Hg, (c) ^{200}Hg and (d) the heaviest possible complementary fragment, ^{202}Hg. The peaks marked with diamonds correspond to other transitions identified as occurring during the high-spin decay of ^{70}Zn.

3.2 Spectroscopy of ^{60,62}Fe and ^{68,70,72}Zn

Much new information has been obtained concerning excited states in neutron-rich nuclei close to the projectile nucleus, ^{64}Ni. One of the advantages of using DIS reactions to study nuclei in which very little is known about the energies of the yrast states is that one can make use of the correlation between projectile-like and complementary target-like fragments. Thus one can assign (or confirm the assignment of) a γ-ray to a particular nucleus by gating on γ-rays in the complementary fragment. For example, γ-rays in each of the heavier Zn isotopes (two protons more than the Ni beam) are observed in coincidence with γ-rays from one of a range of Hg isotopes (two protons less than the Pb target). In fact, one sees a specific distribution of Hg isotopes in coincidence with a gate on a Zn γ-ray which is characteristic of that particular isotope. Thus ^{70}Zn is observed in coincidence with Hg isotopes up to and including ^{202}Hg (the complementary partner when no neutrons are evaporated by either of the product nuclei), whilst ^{72}Zn is observed in coincidence with Hg isotopes up to ^{200}Hg. As an enormous number of nuclei are populated in the reaction, this cross coincidence technique proves to be an invaluable means of making isotopic assignments. This idea is illustrated in fig. 3(a)-(d). Figure 3(a) shows the spectrum obtained by setting a single pair of gates on the ground-state transition in ^{70}Zn and the ground-state transition in ^{196}Hg; fig. 3(b) shows a similar spectrum with the second gate set on the ground-state transition in ^{198}Hg; fig. 3(c) shows the spectrum with the second gate on the ground-state transition in ^{200}Hg and fig. 3(d) with the second gate on the ground-state transition in ^{202}Hg. The peaks marked with filled diamonds are associated with the decay of ^{70}Zn. One can immediately see the selectivity of such a procedure. Once a few transitions have been established in a nucleus, coincidences between them can be checked and used to build the level scheme to higher spin. Using such techniques, states up to spins of approximately $8\hbar$ have been observed for the first time in ^{60,62}Fe (the heaviest stable isotope is ^{58}Fe), and states up to spins of 10-12$\hbar$ have been identified in $^{68\text{-}72}$Zn (the heaviest stable isotope is ^{70}Zn).

Partial level schemes for ^{60,62}Fe and ^{68,70,72}Zn from the current work are shown in figs. 4 and 5, respectively. Previous work [11,12] had established levels up to spin $I = 6\hbar$ and excitation energy 4.359 MeV in ^{60}Fe (studied via HIFE using ^{15}N and ^{18}O beams on a ^{48}Ca target) and spin $I = 4\hbar$ and excitation energy 3.634 MeV in ^{62}Fe (levels established from the β-decay of ^{62}Mn). It is

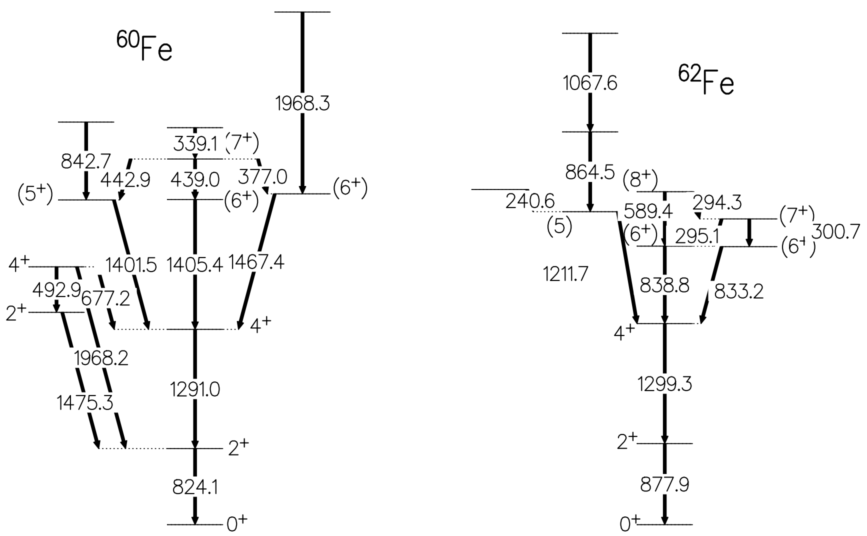

Fig. 4. High-spin level schemes for ^{60,62}Fe deduced from the DIS experiment.

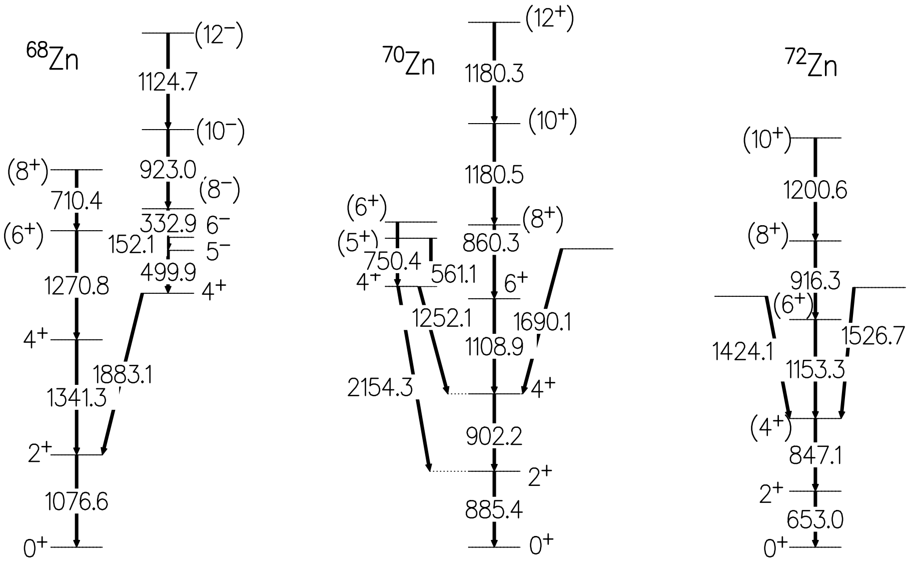

Fig. 5. High-spin level schemes for ^{68,70,72}Zn deduced from the DIS experiment.

immediately obvious what an impressive probe of high-spin states in neutron-rich nuclei DIS reactions provide. The decay of ^{60}Fe had previously been studied using HIFE reactions [11]. The excellent energy resolution of the GAMMASPHERE array has allowed the clarification of the previously published level scheme as well as its expansion. The previously observed 1402 keV transition feeding the $I^{\pi} = 4^{+}$ state has been shown to consist of two γ-rays, one of energy 1401.5 keV and another, of similar intensity, of energy 1405.4 keV. In addition, the levels which these γ-rays de-excite are both fed by transitions of very similar energies, 442.9 and 439.0 keV, originating from a level at excitation energy $E_x = 3.960$ MeV. In addition to these transitions, a 377.0 keV γ-ray also depopulates the 3.960 MeV level state, feeding a new level at 3.583 MeV which then de-excites via a 1467.4 keV γ-ray feeding the 4^{+} level. Thus three gamma-rays are observed to populate the 4^{+} level.

In the case of ^{62}Fe, which has a neutron-to-proton ratio of 1.38, it has been possible to extend the yrast level-scheme by 8 new levels, up to a maximum excitation energy of 5.321 MeV and a maximum spin of approximately $9\hbar$. The spins and parities of the new levels are uncertain, as insufficient statistic preclude a full analysis of the angular distributions and correlations. Thus spins and parities are assigned only on the basis of comparison with the structure of neighbouring nuclei. Assuming that DIS reactions populate mainly yrast and near yrast states, the majority of the transitions will be stretched quadrupole or dipole in nature. (Parallel work concerning the Fe isotopes has been carried out by Pawlat *et al.* [13] using data obtained in a ^{130}Te+^{64}Ni reaction.)

The nucleus ^{68}Zn has been previously studied via the reaction ^{65}Cu(α,pγ) [14] and levels up to a tentative spin of $8\hbar$ established in the ground-state band. This earlier work has been confirmed and the level scheme extended to excitation energy $E_x = 5.992$ MeV and a maximum spin of approximately $12\hbar$. In the case of ^{70}Zn, previous studies using the decay of ^{70}Cu [15] had established a number of transitions up to spin of $4\hbar$. Further work using ^{70}Zn(n,n′) and ^{70}Zn(p,p′) reactions [16,17] identified a number of levels with spins up to $5\hbar$. The results of the present work differ slightly from the earlier publications; it has been possible to expand the high-spin level scheme by 7 new transitions, to $E_x = 6.118$ MeV and maximum spin $I \approx 12\hbar$.

Finally, it has been possible to perform high-spin spectroscopy for ^{72}Zn, which has a neutron-to-proton ratio of 1.4 and is one of the most neutron-rich nuclei populated in the reaction. Here, previous work [15,18] had established several low-spin levels including the 2^+ and an excited 0^+ state at 1499.1 keV. The current work confirms the 2_1^+ state at 653.0 keV excitation energy. A 847.1 keV gamma-ray feeds this 2^+ state. Since our reaction is likely to populate mainly yrast excited states, this probably originates from a 4^+ excited state. Under this assumption, we find excited 0^+ and 4^+ states lying within 1 keV of each other, forming, presumably, two members of a nearly degenerate two-phonon multiplet. It would be of interest to search for the transition depopulating the third member of this multiplet. In addition, it has been possible to identify three new transitions feeding the state at 1500 keV and to extend the ground-state sequence to a total of five transitions, a maximum excitation energy of 4.770 MeV and approximate spin of $10\hbar$. (Again, parallel work has been performed on the neutron-rich Zn isotopes by Pawlat *et al.* [19].)

3.3 Search for evidence of superdeformed structures

The products of the reaction which lie in the neutron-rich $A \approx 190$–200 region are shown in fig. 6, the size of the black triangles giving an idea of the relative population intensity. Also shown on the figure are nuclei in which superdeformed bands have been observed (marked with grey triangles in the bottom left-hand corner). The contour lines show the calculated 2.0 MeV and 3.5 MeV well depth of the superdeformed minimum and provide an indication of the extent of the superdeformed island [8] (dotted and dashed lines).

As can be seen, the reaction populates exactly those nuclei in which it was hoped superdeformation might be studied. For example, the nuclei $^{200\text{-}208}$Pb are strongly populated; also, the strongest Hg isotopes observed in the data are $^{196\text{-}198}$Hg. All these nuclei are predicted to be excellent candidates for superdeformation. However, no firm evidence for the presence of superdeformation has been found in the data. Discounting the possibility that there is no stable superdeformed minimum in these nuclei, there are several factors which could preclude the observation of discrete SD bands in this data. Firstly, the statistics are relatively poor even in the strongest channels. While the Pb and Hg isotopes of interest are populated with enough intensity to allow spectroscopy up to fairly high spins, the actual cross-section compared to the population of lighter isotopes of the same species via HIFE reactions is smaller by an order of magnitude or more. Secondly, normal deformed states in these nuclei have been observed up to a maximum spin of $\sim 25\hbar$ in this reaction. This upper limit may be due either to lifetime effects (Doppler broadening due to incomplete stopping of the recoils in the target for short lifetimes) or to the limited maximum angular momentum brought in by the reaction. It may be that the maximum spins populated in the present work are just below the critical angular momentum (in this mass region, $I \approx 40\hbar$), where SD population will take place. Even if suitable spins are reached, the fraction of each channel which results in such states being populated is extremely small. Both of these points combine to make it very difficult to observe SD states in this type of reaction.

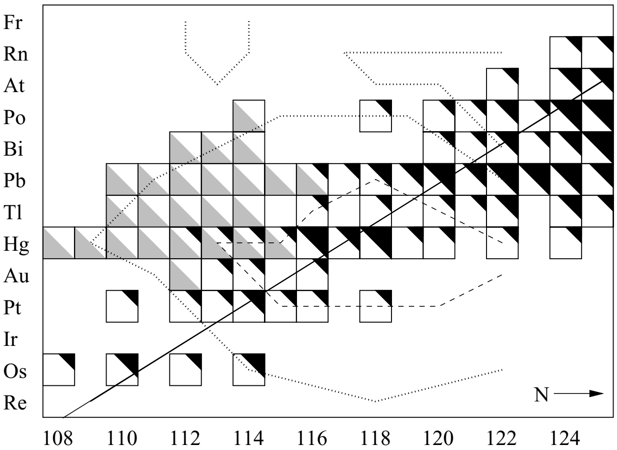

Fig. 6. Nuclei produced in the ^{64}Ni + ^{208}Pb reaction in the region around $A \approx 190$–200 where superdeformation is predicted [8]. A black triangle in the upper right-hand corner indicates that an isotope has been identified in the γ^3 data obtained in the reaction: the size of the triangle corresponds to the intensity with which the isotope is populated. Isotopes in which superdeformed bands have been observed previously are marked with grey triangles in the lower left-hand corner. The dotted and dashed lines show the predicted contour lines for SD well depths of 2.0 and 3.5 MeV, respectively. The solid line shows the N/Z ratio of the compound ^{64}Ni + ^{208}Pb system.

Finally, again due to Doppler effects, the use of a thick target limits the sensitivity of SD searches to the lowest five or so transitions in an SD cascade. The complexity of the DIS spectrum adds to the difficulty of identifying such a short, weakly populated cascade of transitions.

All of these factors conspire against the observation of SD states in this data. However, one should not preclude the possibility of using DIS reactions to populate SD bands in this region. Higher spins could be reached with a greater intensity if a heavier beam were used; a different choice of reaction might enhance the production of deformed nuclei; and perhaps a smaller fragmentation of the reaction cross-section can be achieved with different beam/target combinations. For example, a ^{174}Yb beam incident on a ^{208}Pb target at 15% above the Coulomb barrier would result in both projectile- and target-like fragments in the mass region of interest, with estimated maximum spins in the region of $40\hbar$. The overlap in the population distribution of "light" and "heavy" fragments would augment the intensity of the reaction channels of interest and the higher spins reached might therefore allow the observation of SD states. However, in such a situation the fraction of the reaction going to fission would also be greatly enhanced and it is not clear how much would be gained.

4 Conclusions

High-spin states up to $\sim 25\hbar$ have been populated in neutron-rich nuclei in the superdeformed mass 190–200 region following a deep-inelastic multi-nucleon transfer reaction with a ^{64}Ni beam incident on a ^{208}Pb target. To date, no superdeformed states have been observed. The authors hope that further study into the feasibility of using DIS reactions to populate these states will be carried out.

In the neutron-rich, projectile-like fragments ^{60,62}Fe and ^{68,70,72}Zn, the data have revealed new high-spin states up to $\sim 12\hbar$. In the past, such stable and neutron-rich nuclei have generally been studied using pick-up or stripping reactions or via β-decay studies. The data obtained in the current experiment (and other similar experiments) shows that DIS reactions provide an effective means of accessing yrast and near-yrast high-spin states in these nuclei. However, it must be stressed that there are several difficulties associated with this technique. One of the most significant disadvantages is the inability to perform DCO analyses of the data, which hinders the assignment of spin and parity to newly observed levels. Another problem is the fragmentation of the reaction cross-section. As the total intensity is divided among many (in this case, over 130) channels, the time scale for an experiment to provide large statistics for a single channel is much greater than that required for conventional reactions. Thirdly, the angular momentum available to the final fragments is considerably lower than the total angular momentum brought into the reaction. In addition, it appears that these reactions are not well suited to the study of odd-odd and odd-even nuclei, especially in lighter mass regions, although further experimental work is required to investigate this question fully. However, the DIS mechanism does favour the study of light, neutron-rich nuclei where neutron transfer raises the N/Z ratio towards that of the compound system [20]. Finally, the best results are obtained for those nuclei in which at least one or two γ-rays are already known and which therefore can be easily identified in the data. The use of a thick target precludes fragment identification via mass/charge separation and it is only with the strongest channels that one can actually identify new isotopes using the complementary fragment technique. This means that studies of this type do not provide an equivalent to high-spin studies using HIFE reactions. However, despite the limitations described above, it is possible to obtain a great deal of new information concerning stable and neutron-rich nuclei by employing DIS reactions. Until high-intensity neutron-rich radioactive beams become available, multi-nucleon transfer represents the best means of populating high-spin states in nuclei along the valley of stability.

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