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New results on proton emission from odd-odd nuclei

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Abstract. ^{78}Kr beams were used to bombard ^{58}Ni, ^{92}Mo and ^{96}Ru, producing three new, odd-odd, proton-emitting isotopes, ^{130}Eu, ^{164m}Ir and ^{170}Au. Preliminary experimental and theoretical results will be presented in this paper.

PACS. 21.10.Tg Lifetimes – 23.50.+z Decay by proton emission – 27.60.+j $90 \leq A \leq 149$ – 27.70.+q $150 \leq A \leq 189$

1 Introduction

Proton radioactivity has provided a unique opportunity to obtain spectroscopic information on nuclei beyond the proton drip line [1]. The experimentally measured proton separation energies provide a rigorous test of mass model predictions far from stability [2]. Proton decay rates from spherical nuclei have been used to determine the orbital angular momentum of the emitted proton, and thereby used to infer the proton orbital in the parent nucleus. Detailed studies of decay rates of spherical nuclei have shown a sensitivity of the proton decay spectroscopic factor to the shell occupancy consistent with a low-seniority shell model calculation [2]. There is also great interest in studying the effects of large nuclear deformations on proton decay rates [3–5], spurred on by the discovery of the highly deformed proton emitters ^{131}Eu, ^{141}Ho [6]. The subsequent observation of fine structure in ^{131}Eu demonstrated that the branching ratio between decay to the ground and 2^+ states in the daughter nucleus was very sensitive to the different angular-momentum components in the parent nuclear wave function [7]. Furthermore, the low 2^+ excitation energy confirmed the large deformations involved.

The present paper describes the latest results on odd-odd proton emitters in spherical and highly deformed nuclei. In general, odd-odd nuclei have very similar proton separation energies to the odd-even neighbour lying closer to stability. These nuclei provide an opportunity to explore the effect of coupling between the odd proton and odd neutron on the proton decay probability.

2 Experimental method

The search for new odd-odd proton emitters was undertaken at ANL using the ATLAS accelerator complex to provide a ^{78}Kr beam. The beam bombards a target placed upstream of the Fragment Mass Analyzer (FMA) [8] and produces nuclei via fusion evaporation which recoil out of the target and enter the FMA. The recoils of interest are dispersed horizontally at the focal plane according to their A/Q where they pass through a gas-filled position sensitive Parallel Grid Counter (PGAC). The position signal from the PGAC provides time-of-flight and A/Q information on the recoils which are implanted into a 48×48 Double-Sided Silicon Strip Detector (DSSD) [9]. The 48 orthogonal strips form 2304 pixels within which implanted nuclei and their subsequent decays can be correlated.

The new results described below were all calibrated using the known ground- and isomeric-state proton decays of ^{167}Ir [2] produced by bombarding a ^{92}Mo target with a 437 MeV beam of ^{78}Kr.

3 Results and discussion

3.1 Proton decay of ^{130}Eu

^{130}Eu was produced by bombarding a 425 μg/cm^2 target of ^{58}Ni with a 432 MeV ^{78}Kr beam, the resulting decay spectrum is shown in fig. 1(a). The main competition to proton decay is β-decay, but, as can be seen in fig. 1(b), simple implant-decay time gates cleaned up the spectrum

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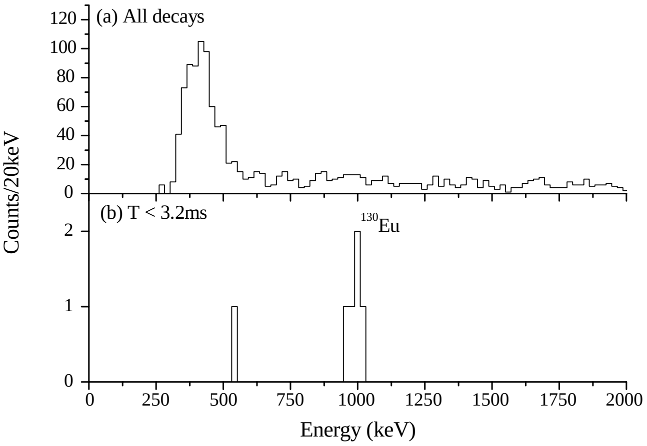

Fig. 1. Spectra showing (a) all the decay products from the reaction $^{78}\mathrm{Kr} + {}^{58}\mathrm{Ni}$ with slits in place to only transmit $A = 130$ recoils and (b) the decay products which are present after a 3.2 ms time gate has been placed between an implanting recoil and a decay occurring within the same pixel of the DSSD.

enough for the ^{130}Eu proton peak to be seen. This is because $E_{\mathrm{p}} = 1020(15)$ keV is high enough in energy that the ^{130}Eu ($t_{1/2} = 900^{+610}_{-260}$ μs) decays via proton emission faster than β-decay can occur.

Spherical WKB [1] calculations do not agree at all with the experimental results. Therefore, detailed calculations on this nucleus, taking into account the angular momentum of the odd neutron, as well as the deformation of the potential barrier are currently being undertaken using the formalism of Ferreira and Maglione [10]. Preliminary results indicate that ^{130}Eu is indeed highly deformed, with a deformation of ~ 0.3, consistent with that of its odd-even neighbour ^{131}Eu [6]. Using this deformation and assuming $K_{\mathrm{p}} = 3/2^+$ for the proton, as in ^{131}Eu, initial calculations indicate a ground-state spin of 2^+ for ^{130}Eu, with the unpaired spectator neutron having $K_{\mathrm{n}} = 1/2^+$. This yields a spectroscopic factor of ~ 0.6 which is reasonably close to the 0.5 expected from theory.

3.2 Proton decay of $^{164\mathrm{m}}$Ir

Proton emission has already been observed for three Ir isotopes, ^{165,166,167}Ir [2]. These results are consistent with proton decay from a spherical nucleus. Isomeric proton decays were assigned to $h_{11/2}$ proton emission in ^{166,167}Ir in addition to ground-state proton decays from lower-spin states. In the case of ^{165}Ir only $h_{11/2}$ proton emission was observed indicating the low-spin ground-state proton decay was too short for observation [2]. In the present experiment, proton emission from ^{164}Ir was searched for by bombarding a 773 μg/cm^2 thick target of ^{92}Mo with a 437 MeV ^{78}Kr beam. The known proton decay $^{165\mathrm{m}}$Ir can clearly be seen in fig. 2(b), and when a further condition requiring the daughter ^{163}Os α-decay is set, we see a peak at 1807(14) keV which we assigned to $^{164\mathrm{m}}$Ir, see fig. 2(c). The half-life of this peak is $t_{1/2} = 58^{+46}_{-18}$ μs. This is in good agreement with results reported from an independent experiment at Jyväskylä [11].

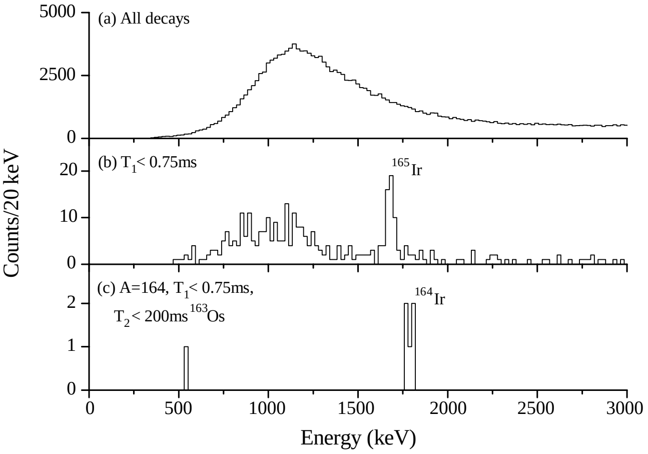

Fig. 2. Spectra showing the decay products from the reaction $^{78}\mathrm{Kr} + {}^{92}\mathrm{Mo}$ with (a) no conditions and (b) the condition that the decay occurs within 0.75 ms after a recoil has been implanted within the same pixel of the DSSD. The conditions are tightened in (c) to further require the daughter α-decay of ^{163}Os within 200 ms of the initial decay within the same pixel, and only decays associated with $A = 164$ recoils are shown.

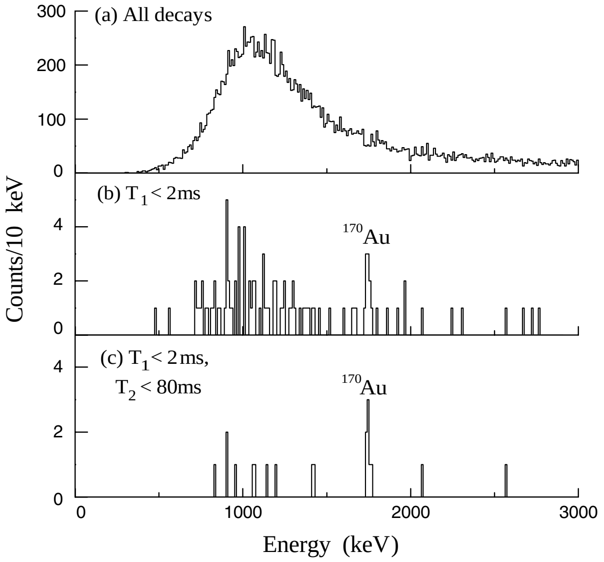

Fig. 3. Spectra showing the decay products from the reaction $^{78}\mathrm{Kr} + {}^{96}\mathrm{Ru}$ with (a) no conditions and (b) the condition that the decay occurs within 2 ms after a recoil has been implanted within the same pixel of the DSSD. A further condition that a second decay occurs within 80 ms of the first is added in (c).

Preliminary WKB calculations indicate that the proton-emitting orbital is probably $\pi h_{11/2}$, similar to the odd-even neighbour ^{165}Ir [2]. This assignment would yield a $S_{\mathrm{exp}} \sim 0.35$, in good agreement with a low-seniority shell model prediction of 0.33 [2] and is therefore consistent with ^{164}Ir being a near-spherical nucleus. As with ^{165}Ir, it is most likely that the proton decay is from an isomeric state with the low-spin ground-state decay being too short-lived for observation. This would be consistent with the level ordering found for proton-emitting states in the odd-odd neighbour ^{166}Ir. The element Ir is presently unique in exhibiting proton decay from four different isotopes.

3.3 Proton decay of ^{170}Au

^{171}Au is currently the only known proton-emitting Au isotope [2,12]. Proton emission has been observed from the short-lived $s_{1/2}$ ground state [12] and a longer-lived $h_{11/2}$ isomeric state at an excitation energy at 250 keV [2]. The proton decay spectroscopic factor agrees well with a low-seniority shell model calculation which, when coupled with the transition rates agreeing with WKB calculations, indicates that ^{171}Au has a near-spherical shape.

In the present experiment, the proton decay of ^{170}Au was searched for by bombarding a 513 μg/cm^2 thick target of ^{96}Ru with a 400 MeV ^{78}Kr beam. The proton decay of ^{170}Au is clearly present at an energy $E_{\mathrm{p}} = 1735(9)$ keV in fig. 3(b) (and more clearly in fig. 3(c)) with a half-life $t_{1/2} = 570^{+310}_{-150}$ μs. An alpha branch was also identified from ^{170}Au ($E_\alpha = 7056(15)$ keV) implying a proton decay branch $B_{\mathrm{p}} = 0.75(15)\%$. WKB calculations also indicate that the proton was emitted from a $\pi h_{11/2}$ orbital, with a $S_{\mathrm{exp}} \sim 0.21$ This spectroscopic factor is in good agreement with a low-seniority shell model prediction of 0.22, indicating that ^{170}Au is spherical.

4 Conclusion

Proton decays from three odd-odd proton-emitting nuclei ^{130}Eu, ^{164}Ir and ^{170}Au are reported. For $^{164\mathrm{m}}$Ir and ^{170}Au the proton decay rates are well reproduced assuming spherical shapes using a low-seniority shell model calculation assuming spectator neutrons. The proton decay of ^{130}Eu indicates it is highly deformed. In this case explicit account needs to be taken of the coupling of the odd neutron and odd proton to form a proton-emitting state with a specific K quantum number.

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