Two Neutron Decay in ^{42,44}Mg

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Ground state 2n-decay, a novel decay mode, has been reported for ^{16}Be [1], ^{24}O [2] and ^{26}O [3]. So far this decay mode has been confined to light mass region since the heavy nuclei are difficult to access and therefore other regions remain unexplored. Theoretical computations indicate that the neutron rich ^{42,44}Mg are 2n-unbound due to S_{2n}<0 and S_{1n}>0 and predicted [4] to have deformed 2n-halo which points to the role of dineutron correlations of the valence neutrons in 2n-radioactivity. On the other hand, ^{40}Mg being relatively weakly bound with positive separation energy, does not indicate 2n-radioactivity. Moreover, the occupancy in $2p_{3/2}$ neutron orbital and the fact of the neighbouring odd-A ^{39}Mg being unbound, indicate importance of pairing correlations near to the most exotic and neutron rich heaviest isotopes ^{40}Mg.[5].

To probe 2n-radioactivity, which is essentially the energetically allowed simultaneous emission of two-neutrons, we first estimate neutron separation energies S_n and S_{2n} for ^{40,42,44}Mg shown in Table I. Here, it is interesting to note that in case of ^{42,44}Mg, $S_{2n} < 0$ and $S_n > 0$, which means that the emission of two valence neutrons or dineutron is allowed but the sequential emission of one neutron is energetically forbidden indicating 2n-radioactivity that points towards the dineutron correlations as well. To further investigate 2n-decay in ^{40,42,44}Mg, we perform the shell-model calculations using NuShellX [6] by employing SDPF-U interaction [7] in $sd - pf$ model space for ^{40,42,44}Mg. The possible configurations consistent with the experimental and theoretical treatments considered for ^{40,42,44}Mg are ^{40}Mg with $\nu(1f^2_{7/2},2p^4_{3/2},2p^2_{1/2},1f^0_{5/2})$, ^{42}Mg with $\nu(1f^4_{7/2},2p^4_{3/2},2p^0_{1/2},1f^2_{5/2})$, and ^{44}Mg with $\nu(1f^5_{7/2},2p^4_{3/2},2p^1_{1/2},1f^2_{5/2})$. The S_n and S_{2n} obtained from these calculations are given in Table I. Gratifyingly, the shell-model configurations also demonstrate the weakening of N=28 magicity in ^{40}Mg owing to the occupancy in p-states. Fig. 1 shows the level schemes of ^{40,42,44}Mg which demonstrate the

TABLE I: Neutron separation energies S_n and S_{2n} calculated using shell-model [6] and NSM [8], experimental data [9] and other theory FRDM [10] for comparison.

	^{40}Mg		^{42}Mg		^{44}Mg	
	S_n	S_{2n}	S_n	S_{2n}	S_n	S_{2n}
Expt.	2.00	1.90	-	-	-	-
NSM	2.31	0.10	1.22	-1.66	0.13	-3.73
Shell-Model	1.38	2.01	0.90	-0.85	0.91	-0.42
FRDM	2.87	2.83	0.92	-2.23	0.01	-2.72

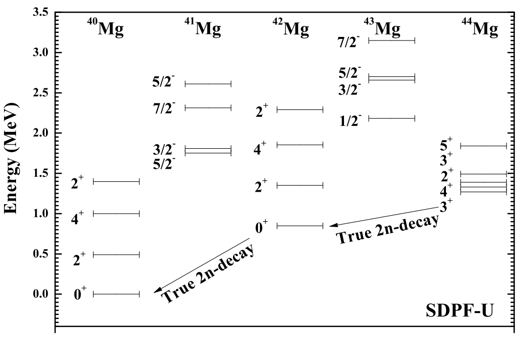

FIG. 1: Level schemes of $^{40-44}$Mg by shell-model using NuShellX [6] and SDPF-U interaction [7].

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probability of $0^+ \rightarrow 0^+$ transition from ^{42}Mg to ^{40}Mg via 2n-emission as a favoured transition. To estimate half-lives of 2n-emission,

TABLE II: Half-lives of few true 2p/2n-decay candidates using new Geiger-Nuttall law by Liu *et al.* [11], formula from Sreeja *et al.* [12], NRDX [13], and UNIV [14] formulas. Experimental data are taken from Refs. [15].

True 2p-decay candidates						
Nucleus	Expt.	$Log_{10}T(1/2)$				
	Q	Expt.	Liu	Sreeja	NRDX	UNIV
^{19}Mg	0.75	-11.40	-12.03	-10.66	-12.50	-14.06
^{45}Fe	1.10	-2.40	-2.21	-1.25	-4.27	-4.71
^{48}Ni	1.29	-2.52	-2.59	-1.61	-4.76	-5.17
^{54}Zn	1.48	-2.43	-2.81	-1.83	-5.08	-5.55
^{67}Kr	1.69	-1.70	-0.58	0.31	-2.94	-3.27
True 2n-decay candidate						
^{26}O	1.59	-11.35	-12.02	-10.65	-13.28	-14.37

TABLE III: Half-lives for true 2n-decay candidates.

Nucleus	Theories		$Log_{10}T(1/2)$			
	Theories	Q	Liu	Sreeja	NRDX	UNIV
^{42}Mg	NSM	3.22	-10.55	-9.24	-13.33	-13.87
	Shell-Model	2.42	-8.05	-6.85	-10.68	-11.13
	FRDM	3.80	-11.84	-10.48	-14.70	-15.26
^{44}Mg	NSM	5.19	-12.02	-15.17	-16.49	-16.95
	Shell-Model	2.00	-2.97	-4.66	-7.58	-7.79
	FRDM	4.29	-10.54	-13.45	-15.04	-15.52

we use a method analogous to that used for 2p-emission using the (i) new Geiger-Nuttall law by Liu *et al.* [11], and (ii) empirical formula proposed by Sreeja *et al.* [12]. Also, in a novel attempt, we consider 2n-decay as one of the cluster decay due to simultaneous 2n-emission, approximating no interaction between the two independent neutrons. This allows us to estimate half-life of 2n-decay in ^{42,44}Mg using few widely known empirical/semi-empirical formulae of cluster decay viz. using NRDX [13] and UNIV [14]. The Q-values for 2n-decay are calculated analogously as for 2p-decay using the formula [16]. Before estimating 2n-decay halflife, we tried these formulae to compute half-life of 2p-decay for experimentally known 2p-emitters (^{19}Mg , ^{45}Fe, ^{48}Ni, ^{54}Zn, ^{67}Kr) and 2n-emitter (^{26}O [3]) (see Table II). The agreement between the experimental half-lives and all the formulae justifies their application to 2n-decay. Table III shows 2n-decay half-lives using various formulae which show good agreement and endorses the use of approximation of 2n-decay with cluster decay and other formulae. Our predicted half-lives show ^{42,44}Mg to be true 2n-decay nuclei. Though the half-lives estimated by used formulas are slightly off but most importantly, are within the experimental reach. A further study in this direction is needed.

GS and MA thank SERB (DST),Govt. of India under SIR/2022/000566 and WOS-A.

References

[1] A. Spyrou *et al.*, Phys. Rev. Lett. **108**, 102501 (2012).

[2] M. D. Jones *et al.*, Phys. Rev. C **92** 051306(R) (2015).

[3] Z. Kohley *et al.* Phys. Rev. Lett. **110** 152501 (2013).

[4] G. Saxena *et al.*, J. Phys. G: Nucl. Part. Phys. **48** 125102 (2021).

[5] H. L. Crawford *et al.*, Phys. Rev. Lett. **122** 052501 (2019).

[6] B. A. Brown *et al.*, Nuclear Data Sheets **120** 115 (2014).

[7] F. Nowacki *et al.*, Phys. Rev. C **79** 014310 (2009).

[8] M. Aggarwal, Phys. Lett. B **693** 489 (2010).

[9] http://www.nndc.bnl.gov/

[10] P. Moller *et al.*, Atomic Data and Nuclear Data Tables **109–110** 1 (2016).

[11] Hong-Ming Liu *et al.*, Chinese Physics C 45 024108 (2021).

[12] I. Sreeja *et al.* Eur. Phys. J. A **55** 33 (2019).

[13] D. Ni *et al.*, Phys. Rev. C **78** 044310 (2008).

[14] D. N. Poenaru *et al.*, Phys. Rev. C **83** 014601 (2011).

[15] M. Gonalves *et al.*, Phys. Lett. B **774** 14 (2017).

[16] O. A. P. Tavares *et al.*, Eur. Phys. J. A **54** 65 (2018).