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NEUTRON DEFICIENT MASS SURFACE BETWEEN THE $1f_{7/2}$ and $1g_{9/2}$ SHELLS: THE MASSES OF ^{77}Kr AND ^{75}Kr*

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Abstract:

The masses of ^{77}Kr and ^{75}Kr have been measured utilizing the ^{80,78}Kr(^{3}He,^{6}He) reactions at $E3_{He}$ = 70 MeV. These new results have been integrated into the total scheme of mass measurements in the light rubidium and krypton isotopes commenced several years ago. Comparisons with several mass formulae have also been made.

Introduction:

Mass determinations of neutron deficient nuclei between the $1f_{7/2}$ and $1g_{9/2}$ shells has been hampered by low production cross sections and non-discrete decay modes. The direct mass measurements [1] of the rubidium isotopes provided a substantial base for further experiments. Unfortunately, the quoted error bars on the ground state masses for the more neutron deficient isotopes make detailed theoretical comparisons difficult. Originally, a program to precisely measure mass differences between light rubidium and krypton isotopes by utilizing beta-endpoints was commenced [2]. These measurements were fraught with typical beta-endpoint difficulties such as decay scheme uncertainty. For example, recent work [3] on ^{76}Rb decay has shown that the previously accepted decay scheme was totally wrong. These mass difference measurements heralded, however, the introduction of a simple but effective method [4,5] for precise beta-endpoint values. The mass difference for ^{76}Rb - ^{76}Kr yielded a mass for ^{76}Rb only when the ground state mass of ^{76}Kr was measured [6] via the ^{78}Kr(^{4}He,^{6}He) reaction. However, this ^{76}Rb mass value was anomalous with respect to most predictive formulae. The extra stability for

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this N = 39 case led us to this latest work, measurement of the previously unknown mass of the N = 39 nucleus, ^{75}Kr.

Experimental:

The mass of ^{75}Kr was determined by measuring the Q-value of the ^{78}Kr(^{3}He,^{6}He) reaction at $E_{^3\mathrm{He}}$ = 70 MeV. Helium-3 particles from the Texas A&M University 224-cm cyclotron were incident upon an isotopically enriched gas target statically pressurized to ~ 3 kPa. The well-collimated reaction products were detected on the focal plane of the Enge split-pole spectrograph by a single-wire proportional counter serving as the ΔE and a 1.0 cm x 5.0 cm x 600μm silicon surface barrier detector serving as the E. Particle TOF (time-of-flight) information was obtained relative to the cyclotron RF. Additional experimental details may be found elsewhere [6,7].

The 70 MeV bombarding energy and scattering angle of Θ_L = 7.25° were chosen by comparison with prior [8] (^{3}He,^{6}He) mass measurements in this mass region. Because the (^{3}He,^{6}He) cross section is only ~ 1/50 of the (^{4}He,^{6}He) cross section on any given Kr isotope, the spectrograph was calibrated by ^{6}He^{2+} particles from the ^{18}O(^{3}He,^{6}He)^{15}O reaction. The existence of two prominent ^{15}O excited states at approximately the same Q-value as predicted for the ground state of ^{75}Kr made this an ideal calibrant. After the initial calibration of the system with this reaction, successive enriched isotope samples of ^{82}Kr, ^{80}Kr and ^{78}Kr were introduced and bombarded by 21.8, 30.0 and 34.0 mC of ^{6}He^{2+} beam, respectively. A final ^{15}O spectrum was obtained for completeness.

Results:

In this mass region, one would expect the momentum mismatch to selectively populate L = 2,3 states. However, the level density is already quite high in these even-odd nuclei as demonstrated by the known beta-decay schemes for ^{77,79}Rb [9] and ^{75}Rb [10]. It is, therefore, quite fortunate that we observe primarily the negative parity, L = 2,3 states in ^{79}Kr, ^{77}Kr and ^{75}Kr, which number only a few amidst the sea of positive parity states. The spectrum arising from the ^{82}Kr(^{3}He,^{6}He)^{79}Kr reaction is shown in Fig. 1. Thus the peak labelled 1) in Fig. 1 belongs to a $3/2^-$ state [9] at 0.810 MeV and the peak labelled 2) belongs to a $3/2^-$ state at 0.183 MeV. The lower energy (higher channel numbers) shoulder on peak 2) belongs to a $5/2^-$ state at 0.149 MeV. When the Q-values for these different peaks are combined, a measured mass excess of -74.441 (31) MeV is obtained, in excellent agreement with the accepted value of -74.4389 (86) MeV [11].

Figures 2A and 2B show the results from the ^{80}Kr(^{3}He,^{6}He)^{77}Kr and ^{78}Kr (^{3}He,^{6}He)^{75}Kr reactions, respectively. Again, detailed spectroscopic information has been utilized in identifying the observed peaks. Peaks 3) and 1) in the ^{77}Kr spectrum can be attributed to the first ($J^{\pi} = 3/2^-$) and the second ($J^{\pi} = 5/2^-$) excited states at 0.066 and 0.245 MeV. The weighted average of the Q-values after

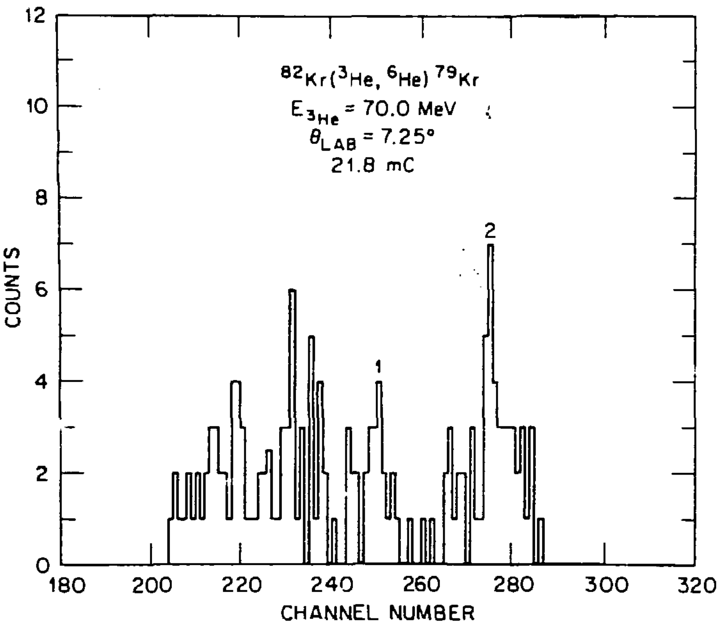

Figure 1. Gated ^{6}He position spectrum at $E_{^3He}$ = 70 MeV for the ^{82}Kr(^{3}He,^{6}He)^{79}Kr reaction. Peak labels are discussed in text.

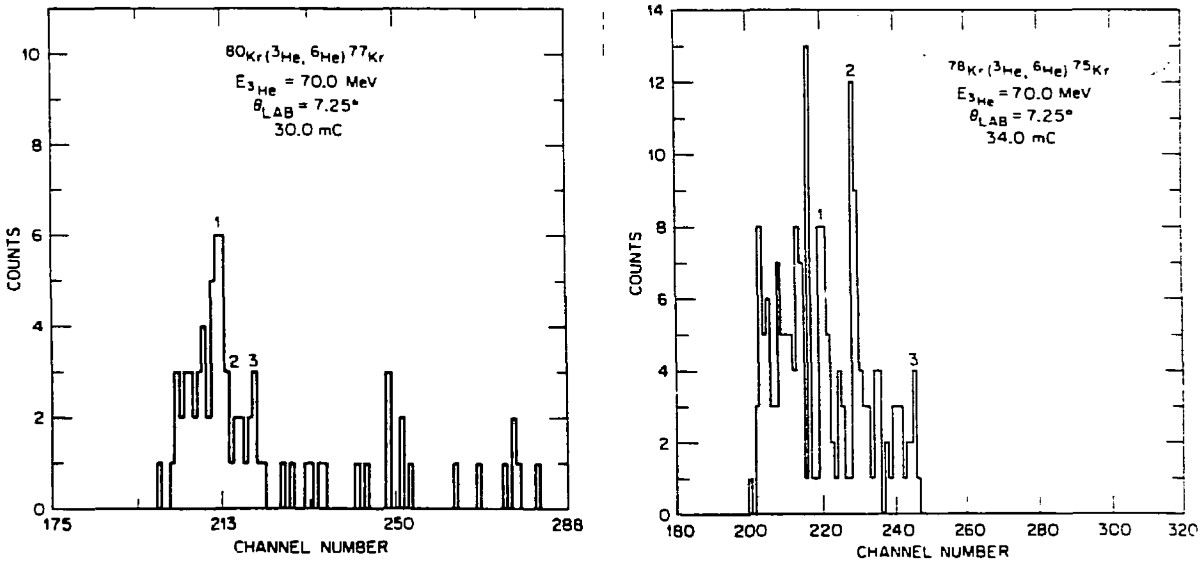

Figure 2. Gated ^{6}He position spectra at $E_{^3He}$ = 70 MeV for the reactions: (a) ^{80}Kr(^{3}He,^{6}He)^{77}Kr and (b) ^{78}Kr(^{3}He,^{6}He)^{75}Kr. Peak labels are discussed in text.

being corrected for this γ-ray energy yield a mass excess for ^{77}Kr of -70.155 (25). Events in channel numbers higher than peak 3) arise from imperfect collimation of reaction products from the HAVAR entrance windows. A spectrum collected for 10.0 mC on an evacuated gas cell proved this source. Fortunately no interferences were observed. The ^{75}Kr spectrum has had this background removed. The peaks labelled 1), 2) and 3) in the ^{75}Kr spectrum represent scattering to the $7/2^-$ state at 0.611 MeV, the $5/2^-$ state at 0.358 MeV and the $5/2^+$ state at 0.00 MeV (ground state) (levels taken from Ref.[10]). The weighted and corrected average of those Q-values yield a mass excess for ^{75}Kr of -64.231 [16] MeV. The mass of ^{75}Kr was previously unknown whereas this new value for ^{77}Kr more precisely defines the mass of ^{77}Rb as well as ^{77}Kr.

Discussions and Conclusions:

Table 1 contains a summary of our results from these Kr (^{3}He,^{6}He) reactions.

Table 1. Summary of Kr Mass Measurements (All values in MeV unless noted)

	^{79}Kr	^{77}Kr	^{75}Kr
Q-value	-8.977	-10.646	-12.970
γ-energy	0.165	0.245	0.358
Range Correction	0.025	0.001	0.018
Average Mass Excess	-74.441	-70.155	-64.231
Uncertainty (keV)	31	25	16
Literature	-74.4389	-70.231	-64.162
Uncertainty (keV)	8.6	30	5

The mass excess for ^{79}Kr demonstrates that our analysis and data reproduce the accepted value. The new ^{75}Kr value is within 20 keV of Wapstra's [11] systematic prediction. This new ^{77}Kr measurement, however, mandates a β-decay energy of 3086 keV compared with our measured [2] value of 2760 keV. This 2760 keV endpoint could not possibly increase to 3086 keV, thus suggesting that the total spectroscopy of the decay sequence ^{77}Rb→^{77}Kr→^{77}Br is not understood as well as previously thought. We do assert, however, that the peak assignments in Fig. 2 are correct. We observe the $J^\pi = 5/2^+$ ground state of ^{75}Kr and with proper statistics would similarly observe the ground state of ^{77}Kr as a shoulder on peak 3 (in the ^{77}Kr spectrum) since it is only 66 keV removed and the measured resolution is only ~50 keV. This new ^{77}Kr mass also permits a recalculation of the ^{77}Rb mass (-64.883 (29)keV) based upon the beta-endpoint value previously obtained [2]; this value is ~215 keV larger than the direct mass measurement [1] number (-65.100 (105) keV). A summary of all the beta-decay energy values in this region is depicted in Fig. 3.

If one compares all of these masses with the theoretical predictions [12, 13, 14] illustrated in Fig. 4, we observe that the recursive mass formulae (numbers 5, 6 and 7 in Fig. 4) consistently are closer to the measured value if the ^{76}Rb mass is discounted. Most mass formulae predict the Kr masses rather well, but tend to miss the Rb masses, especially ^{76}Rb. Since the $^{75}_{36}$Kr$_{39}$ value is consistent with other Kr isotopes, the previously alluded to N = 39 extra stability present in $^{76}_{37}$Rb$_{39}$ is totally absent.

One must thus assume that ^{76}Rb is a unique case. It is now understood that

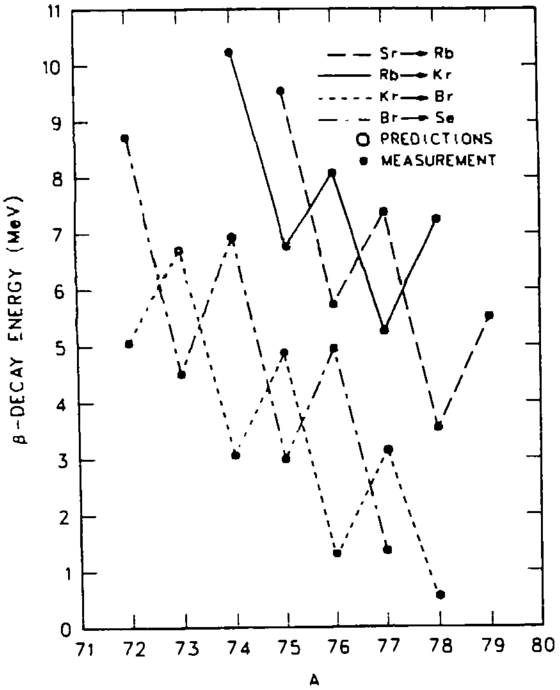

Figure 3. Beta-decay energy systematics for light strontium, rubidium, krypton and bromine isotopes. Predictions are taken from ref. [11].

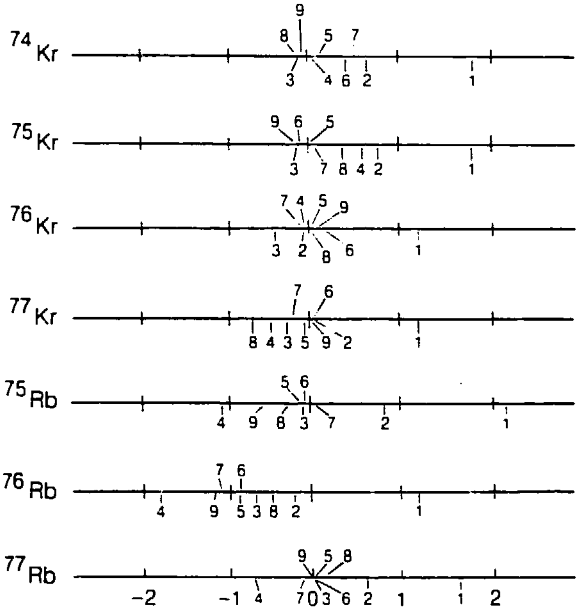

Figure 4. Mass formulae comparisons for several rubidium and krypton isotopes. All predictions are taken from ref. [12] (unless noted) and correspond to 1) Myers, 2) Groote et al., 3) Seeger and Howard, 4) Liran and Zeldes, 5) Janecke, Garvey-Kelson, 6) Comay and Kelson, 7) Janecke and Eynon, 8) Moller and Nix [13] and 9) Monohan and Serduke [14].

^{76}Rb is one of the most deformed nuclei known [3,15]. If one considers the mass predictions depicted in Fig. 4 in a sequential ^{78}Rb → ^{75}Rb manner, the formula which comes closest to the correct answer is Moller-Nix [16]. We attribute this fact to their prolate shape deformation inclusion. There may exist, however, other effects in ^{76}Rb which serve to make it even more unique and thus warranting additional study. Although our understanding of the rudimentary nuclear physics has been furthered by all of these mass determinations, probably more questions have arisen than have been answered. We hope to answer some of these questions in the near future.

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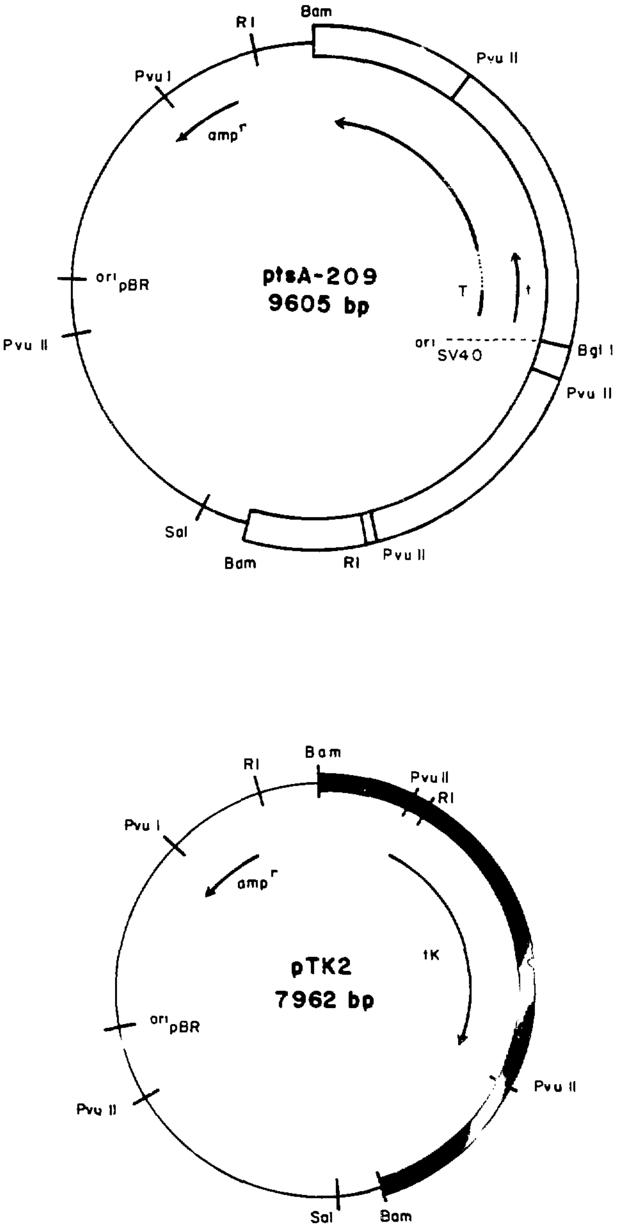

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Figure A.3. Physical Maps of Plasmids ptsA-209 and pTK2.