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Proposal to the ISOLDE Committee

Study of electric monopole transitions in ^{76,78}Kr.

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SUMMARY

We propose to measure the ratio $B(E0;0_2^+ \rightarrow 0_1^+)/B(E2;0_2^+ \rightarrow 2_1^+)$ of the $E0$ to $E2$ reduced transitions probabilities for the 0_2^+ states in ^{76}Kr and ^{78}Kr populated in the decay of ^{76}Rb and ^{78}Rb, respectively. The case of ^{78}Kr appears to be the easier one and would be investigated first. We ask for a total of nine shifts to be divided in three runs of equal duration.

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1. Introduction

The problem of the nature of low-lying 0^+ excited states in even-even nuclei of the A=70-80 region is still a matter of some debate (see, e.g., ref. [1]). The theoretical investigation of the properties of the low-lying levels of this mass region has mainly been carried out in the framework of the IBA-2 model. In particular, for even krypton isotopes, a systematic investigation has been performed by Kaup and Gelberg [2]. They have satisfactorily reproduced the excitation pattern of the low-lying levels with the exception of the 0_2^+ states which then were interpreted as "intruder" states lying outside the model space used. Subsequently, several authors [3 –6] have made use of the same hamiltonian parameters determined by Kaup and Gelberg and extended their calculations to include $E2$ transition rates obtaining a reasonable agreement with the experiment.

As a consequence of our recent experimental work on ^{80}Kr [7] we were led to reconsider the problem of a satisfactory description, in terms of the IBA-2 model, of the 0^+ states in the isotopes ^{78,80,82}Kr. By using a different set for the hamiltonian parameters we could reasonably reproduce the excitation energy of the low-lying states including the 0_2^+ states. Due to the flexibility of the IBA-2 model, the simple comparison of the excitation patterns does not allow us to draw any definite conclusion about the goodness of the description. A more stringent test is provided by the comparison of theoretical and experimental values of $E2$ transition rates. This is shown in Table I where the theoretical values obtained by other authors [4,5] are also reported. It is seen that the general agreement with the available experimental data is of the same quality for both sets of calculated data. In particular, we remark that for our calculation the agreement is reasonable also for the $0_2^+ \rightarrow 2_1^+$ transitions in ^{80}Kr and ^{82}Kr.

Additional information on the structure of the 0^+ states can be obtained by the study

Table I Experimental and theoretical values for $B(E2)$ transition strengths (given in e^2b^2) in ^{78,80,82}Kr. The values $e_\pi = 0.087\,\mathrm{eb}$, $e_\nu = 0.075\,\mathrm{eb}$ for boson effective charges have been used. The values obtained by other authors in the framework of the IBA-2 model are reported for comparison.

	^{78}Kr			^{80}Kr		^{82}Kr		
$B(E2)$	exp.$^{a)}$	Ref. [7]	Ref. [4]	exp.$^{b)}$	Ref. [7]	exp.$^{c)}$	Ref. [7]	Ref. [5]
$2_1^+ \rightarrow 0_1^+$	0.120(8)	0.094	0.131	0.076(6)	0.070	0.0436(18)	0.054	0.045
$0_2^+ \rightarrow 2_1^+$				0.07(3)$^{d)}$	0.058	0.030(10)	0.050	
$2_2^+ \rightarrow 0_1^+$	0.0030(4)	0.0007	0.004	0.0006(1)	0	0.0002(1)	0.0003	0.0020
$2_2^+ \rightarrow 2_1^+$	0.012(4)	0.110	0.118	0.05(1)	0.10	0.016(8)	0.079	0.056
$2_3^+ \rightarrow 0_1^+$						0.0006(4)	0.0002	0.0008
$2_3^+ \rightarrow 2_1^+$						0.014(8)	0.010	0.017
$3_1^+ \rightarrow 2_1^+$				0.0012(2)	0.0003			
$3_1^+ \rightarrow 2_2^+$				0.072(10)	0.071			
$4_1^+ \rightarrow 2_1^+$	0.174(14)	0.142	0.191	0.064(6)	0.107	0.065(24)	0.083	0.068
$4_2^+ \rightarrow 2_1^+$				0.0007(4)	0.00002	0.024(6)	0.0002	0.0002
$4_2^+ \rightarrow 2_2^+$	0.115(16)	0.080	0.097	0.10(5)	0.06	0.018(5)	0.048	0.036
$4_2^+ \rightarrow 4_1^+$	0.048(12)	0.060	0.063	0.07(4)	0.05	0.082(20)	0.040	
$6_1^+ \rightarrow 4_1^+$	0.20(3)	0.16	0.21	0.13(3)	0.14			

$^{a)}$ Ref. Nucl. Data Sheets **63**, 1 (1987).
$^{b)}$ Ref. Nucl. data Sheets **36**, 127 (1982).
$^{c)}$ Ref. Nucl. Data Sheets **50**, 1 (1987).
$^{d)}$ Ref. [7].

of their decay via electric monopole transitions.

2. Electric monopole transitions

In a single particle model the electric monopole operator $\hat{T}(E0)$ is given by:

$$\hat{T}(E0) = e\sum_{i=1}^{N_p} r_i^2$$

where N_p is the proton number. The reduced transition probability $B(E0)$ and transition strength $\rho^2(E0)$ between 0_i^+ and 0_j^+ states are expressed in terms of the nuclear radius R and the atomic number Z as follows:

$$B(E0) = Z^2 \left|\left\langle 0_j^+ | \hat{T}(E0) | 0_i^+ \right\rangle\right|^2$$

$$\rho^2(E0) = \frac{B(E0)}{e^2 R^4}$$

Essentially then, by measuring $B(E0)$, one determines the square of an off diagonal matrix element of the same operator whose diagonal matrix element gives the mean square charge radius which, for the ground state, has been extensively investigated at ISOLDE [8].

In the standard IBA-2 model the electric monopole operator is given (to the first order) by the relation:

$$\hat{T}(E0) = \beta_{0\pi}\hat{n}_{d\pi} + \beta_{0\nu}\hat{n}_{d\nu} + \gamma_{0\nu}\hat{N}_\nu + \gamma_{0\pi}\hat{N}_\pi .$$

where $\hat{N}_\nu$ and $\hat{N}_\pi$ are the total number of neutron and proton bosons, $\hat{n}_{d\nu}$ and $\hat{n}_{d\pi}$ are the number of neutron and proton d–bosons, respectively, and $\gamma_{0\nu}$, $\gamma_{0\pi}$, $\beta_{0\nu}$ and $\beta_{0\pi}$ are parameters of the model.

Only the last two terms in this expression contribute to the transition rates as N_π and N_ν are good quantum numbers. The so called "effective monopole charge" $\beta_{0\pi}$ and $\beta_{0\nu}$

have to be determined by a comparison of experimental and theoretical values of $B(E0)$. However, the experimental data on $E0$ transitions are so limited that information on $\beta_{0\pi}$ and $\beta_{0\nu}$ has only been extracted for a restricted number of nuclei. In a detailed study of ^{110,112,114}Cd [9 ,10] we recently determined the value of $\beta_{0\pi}$ and $\beta_{0\nu}$ by exploiting the data on $E0$ transitions between $0_2^+ \rightarrow 0_1^+$ and $2_i^+ \rightarrow 2_j^+$ states. At present such an analysis is not feasible for even krypton isotopes, since the monopole strength $\rho^2(E0)$ has only been determined for the $0_2^+ \rightarrow 0_1^+$, $0_3^+ \rightarrow 0_1^+$ transitions in ^{82}Kr [5 ,11] and for the $0_2^+ \rightarrow 0_1^+$ transition in ^{80}Kr [7].

Table II The experimental values of $\rho^2(E0)$ in ^{80,82}Kr compared to the theoretical ones evaluated using for the $E0$ operator the parameters values $\beta_{0\nu} = 0.25\,\mathrm{e\,fm}^2$, $\beta_{0\pi} = 0.1\,\mathrm{e\,fm}^2$.

	^{80}Kr		^{82}Kr	
$\rho^2(J_i^+ \rightarrow J_f^+)$	Ref.[7]	theor.	Ref.[5,11]	theor.
$0_2^+ \rightarrow 0_1^+$	0.021(9)	0.028	0.008(3)	0.011
$2_2^+ \rightarrow 2_1^+$	≤ 0.05	0.0009		
$0_3^+ \rightarrow 0_1^+$			0.007(6)	0.002

On the other hand, by adopting for $\beta_{0\pi}$ and $\beta_{0\nu}$ the same values determined for the cadmium isotopes, we found a reasonable agreement between experimental and calculated values of the monopole strength $\rho^2(E0)$ (see Table II). This gives some support to the thesis that the 0_2^+ state lies indeed within the IBA-2 model space. It appears however that a real improvement in our understanding of the 0_2^+ states in krypton isotopes could be provided by the measurement of as many monopole transition strength as possible so as to put to a stringent test the different theoretical interpretations. The subject of the present proposal is the study of the $0_2^+ \rightarrow 0_1^+$transition in ^{76,78}Kr.

3. The determination of the monopole strength ρ^2 in ^{76,78}Kr

The systematics of experimental low-lying positive parity states in even krypton nuclei is schematically reported in Fig. 1. We propose to investigate the $0_2^+ \rightarrow 0_1^+$ transitions in ^{78}Kr and ^{76}Kr populated in the decay of ^{78}Rb and ^{76}Rb, which can be easily produced at ISOLDE.

The determination of the monopole transition strength $\rho^2(E0)$ requires, as a first step, the measurement of the branching ratio:

$$q^2 = \frac{I_K(0_2^+ \rightarrow 0_1^+)}{I_K(0_2^+ \rightarrow 2_1^+)}$$

where I_K is the intensity of the K-internal conversion line for the indicated transition. From the experimental value of q^2 it is possible to deduce the ratio $B(E0)/B(E2)$:

$$X = \frac{B(E0; 0_2^+ \rightarrow 0_1^+)}{B(E2; 0_2^+ \rightarrow 2_1^+)} = 2.56 \cdot 10^9 A^{\frac{4}{3}} E_\gamma^5[\mathrm{MeV}] \frac{\alpha_K(E2)}{\Omega_K[\mathrm{s}^{-1}]} q^2$$

where Ω_K is the so called "electronic" factor for the K-conversion of the E0 transition, α_K the K-conversion coefficient for the relevant $E2$ transition and E_γ is the energy of the gamma deexciting the 0_2^+ level. The quantities Ω_K and α_K can be calculated to a high precision [12 ,13] so that, if the $B(E2; 0_2^+ \rightarrow 2_1^+)$ value is known, one can deduce the transition strength via the equation:

$$\rho^2(E0) = \frac{X \cdot B(E2)}{e^2 R^4}$$

The $B(E2)$ value can be evaluated from the value of the lifetime τ of the 0_2^+ level according to the expression:

$$B(E2)(\mathrm{e}^2\mathrm{fm}^4) = \frac{8.16 \cdot 10^{-10}}{\tau(\mathrm{s}) E_\gamma^5(\mathrm{MeV})}$$

For ^{80}Kr we determined the lifetime of the 0_2^+ level, populated through inelastic proton scattering at 6.5 MeV, via the Doppler shift attenuation method in gas at the Laboratori Nazionali di Legnaro (Padua – Italy) [7], and we plan to do the same for ^{78}Kr (an enriched sample of this gas has been bought). For ^{76}Kr one could possibly use the same method populating the 0_2^+ level via the (p,t) reaction on ^{78}Kr [14].

4. Experimental set–up

Our experimental set-up to measure the ratio q^2 is based on an electron transport system shown schematically in Fig. 2.

The electrons are deflected by a magnetic field onto a $5\,\mathrm{cm}^2 \times 6\,\mathrm{mm}$ silicon detector cooled down to liquid nitrogen temperature. The momentum acceptance is $\Delta p/p$=0.18 and the maximum transmitted energy about 3 MeV. The overall full peak efficiency is about 1% in the 150-1500 keV energy range. Typical energy resolution of the silicon detector is 2.6 keV for 1 MeV electrons.

Since the intensities of the K-conversion electron lines corresponding to $0_2^+ \rightarrow 0_1^+$ and $0_2^+ \rightarrow 2_1^+$ transitions are necessarily measured at different times (for different magnetic field settings) it is necessary to normalize the corresponding energy spectra. This is most conveniently done by simultaneously recording e.g. the $0_2^+ \rightarrow 2_1^+$ gamma-ray, using a standard germanium detector.

The data acquisition is performed by means of a multi-channel analyzer operating in multiplexed mode, remote-controlled by a Macintosh II computer, on which a first on-line analysis is performed.

5. Conclusions and beam request

Compared to the case of ^{80}Kr we have for the ^{76,78}Kr the advantage of a stronger population of the 0_2^+ state but also the disadvantage of a far more complicated decay scheme (see in Fig. 3 the comparison between ^{80}Kr e ^{78}Kr) which could cause some difficulties due to gamma induced background on the silicon detector. We are at the moment modifying the experimental set-up to provide a more effective shielding of the detector.

Basing on our experience on ^{80}Kr, we estimate that a total of 9 shifts (divided in 3 runs, each of 3 shifts) will be sufficient to perform the measurements. The compactness of the apparatus makes it simple in use and easily transportable, so that we could be ready to measure at short notice.

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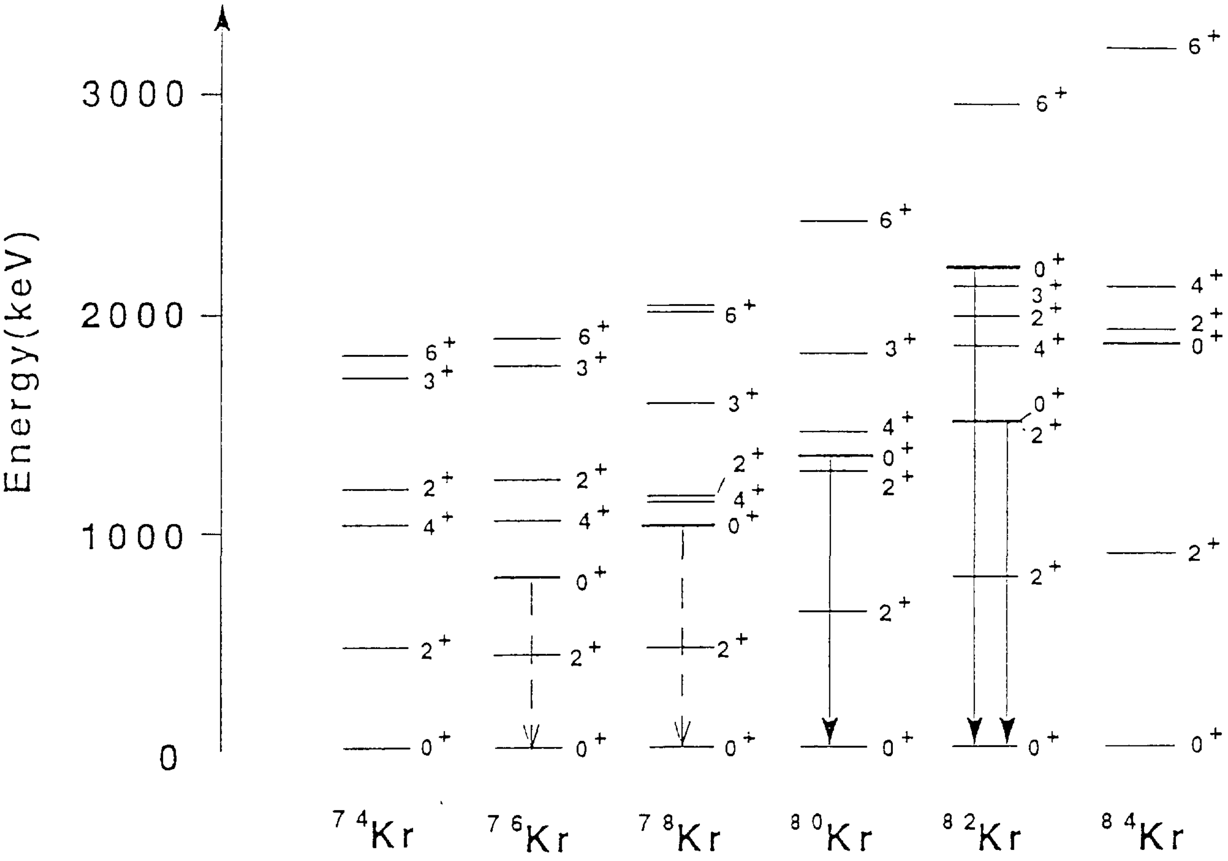

Fig.1 – Schematic excitation pattern of low energy states in even krypton isotopes. Continuous arrows mark the $E0$ transitions already studied. Dashed arrows mark the $E0$ transitions we propose to investigate.

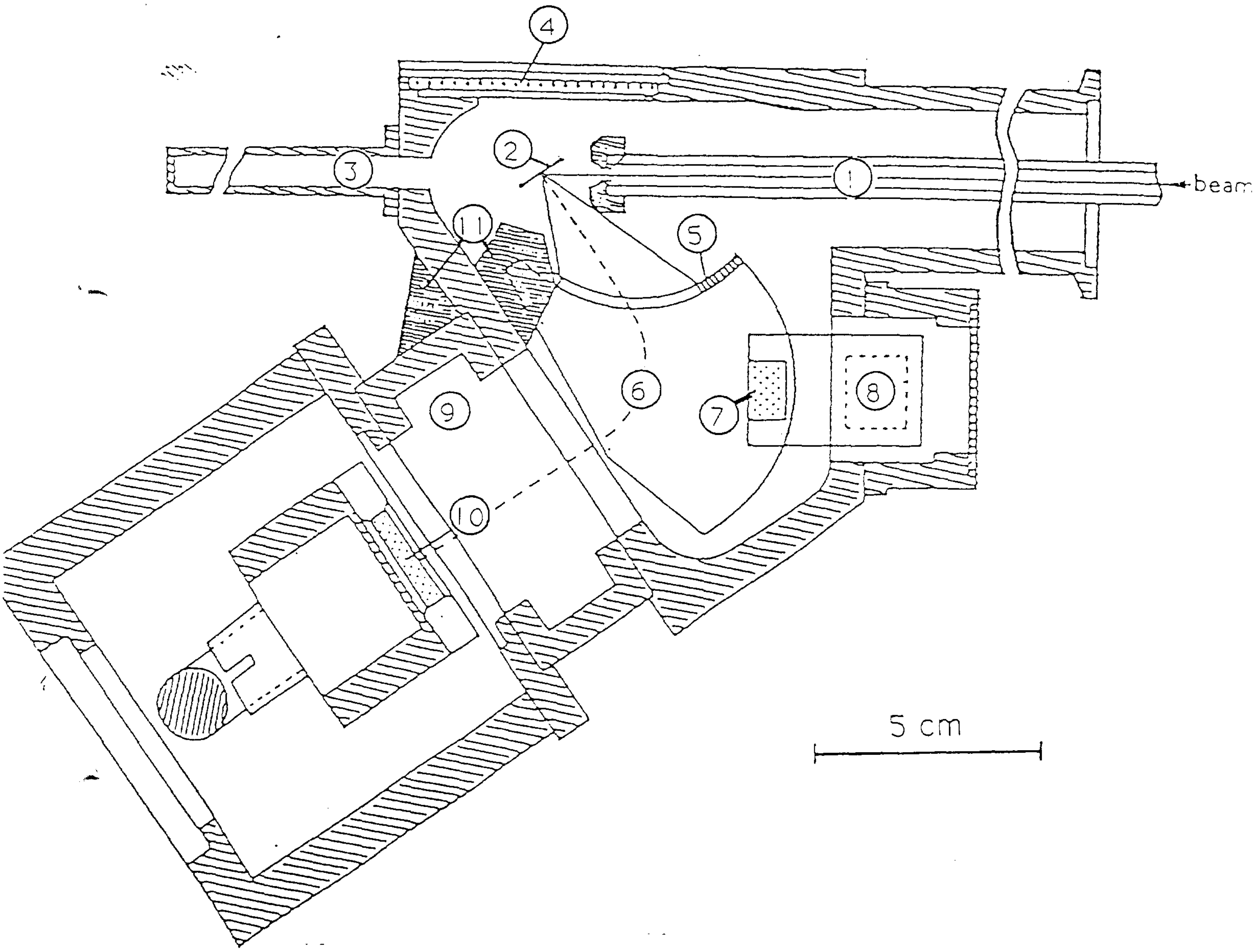

Fig.2 – Schematic view of the electron transport system for the measurement of internal conversion electrons: (1) iron channel, (2) target, (3) beam catcher, (4) plexiglass window, (5) entrance baffle, (6) pole pieces, (7) Hall probe, (8) thermostat, (9) vacuum valve, (10) Si(Li) detector, (11) lead screen.

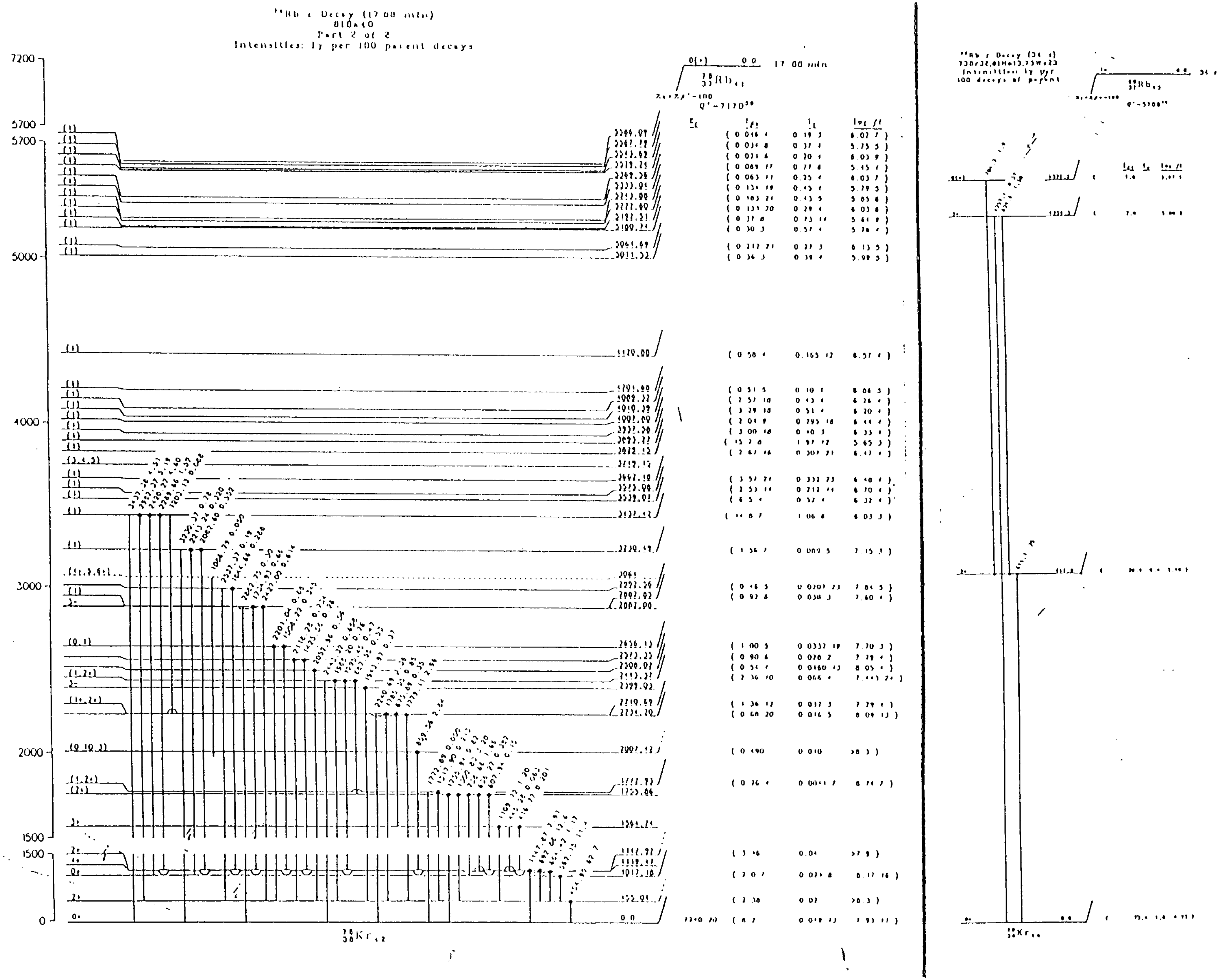

Fig.3 – A comparison of the decay schemes of ^{80}Rb and ^{78}Rb to ^{80}Kr and ^{78}Kr.