PIONIC 2p LEVEL WIDTHS IN LIGHT NUCLEI

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ABSTRACT

The yields of muonic and pionic 2p-1s X-ray transitions are given for Be, ^{10}B , $^{\text{nat}}\text{B}$ and C. Pionic 2p populations are calculated, and the natural widths of the pionic 2p levels from Be to Na are deduced by comparison with X-ray transition rates calculated with realistic pion wave functions.

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This paper provides an extension of previous work¹⁾ on the pionic 2p-1s yields for nuclei from N to Na in two directions. We report here on measurements of the 2p-1s yields for the lighter nuclei Be, ^{10}B , $^{\text{nat}}\text{B}$ and C, and from these data we deduce the natural 2p level widths $\Gamma(2p)$ due to pion absorption by comparison with the 2p-1s X-ray transition rate W_X . In Ref. 1, W_X was calculated on a purely electromagnetic basis. Now we take into account the effect of the strong π -nucleus interaction on W_X . We give here also the correspondingly modified values for the nuclei dealt with in Ref. 1. The measurements were performed at the CERN 600 MeV Synchro-cyclotron using a scintillation counter telescope with coincidence counters 1, 2, 3 in front of the target and a veto counter $\bar{4}$ behind the target²⁾. The majority of the spectra were measured with a windowless Ge detector of volume $0.8 \text{ cm}^2 \times 1.0 \text{ cm}$. Its energy resolution was 0.8 keV at 70 keV. The Be and $^{\text{nat}}\text{B}$ targets were of cylindrical shape with a diameter of 9 cm and a thickness of 2 g/cm². The ^{10}B powder was contained in a rectangular box ($8 \times 6 \text{ cm}^2$) with a thickness of 0.6 g/cm². The C target was a graphite sheet of 5.4 g/cm².

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The 2p-1s X-ray yields Y_{π} were determined by two methods. The first method is based on a detailed comparison between muonic and pionic lines measured simultaneously, and is explained in Ref. 1. The yields of the muonic reference lines are given in Table 1, columns 1 and 2.

In the second method, Y_{π} is also determined by comparison with the muonic 2p-1s or 3p-1s line, but the intensity of this reference line is taken from a separately measured muonic spectrum. The pionic and muonic spectra were normalized via the stop rates corrected for scattered particles (particles which pass counter 3 but miss counter 4) by subtracting the (1234) rate counted without target. Furthermore, the pion stop rates were corrected for the muon contamination of the beam. This second method was, however, not applicable for ^{10}B and C. The ^{10}B target was so thin that the correction due to the scattering of particles behind counter 3 was large, and hence the resulting stop rate uncertain. In the C case, the effective target size was not well defined because all the surrounding counters contained carbon.

The Y_{π} values obtained from the two methods are given in Table 2, columns 1 and 2. In column 3, the mean of columns 1 and 2 is listed, and this is used for further calculations.

$\Gamma(2p)$, the partial width of the pionic 2p level due to nuclear absorption, and Y_{π} are related by

$$\Gamma(2p) = \hbar \{ W_X [P(2p)/Y_{\pi} - 1] - W_A \}, \quad (1)$$

where W_X is the pionic 2p-1s X-ray rate, W_A the corresponding Auger rate, and $P(2p)$ the population of the pionic 2p level. W_A was calculated with a program written by J. Hüfner³⁾. $P(2p)$ was determined in the same way as described in Ref. 1. The parameters used and results for $P(2p)$ are given in Table 1, columns 3 and 4, and Table 2, columns 6-8, respectively.

In Ref. 1, W_X was calculated in the usual way, taking energies and wave functions of the pionic levels as determined by purely electromagnetic interaction. Recently, a quantitative theoretical analysis⁴⁾ of pionic atoms has shown a large effect of the strong interaction on the pionic wave functions. Due to the repulsive local potential, the 1s pionic wave function, for example, is shifted outwards and overlaps more with the 2p wave function. In this way the square of the transition matrix element is increased by 11 to 43 per cent for Be to Na, respectively. However,

this is mostly compensated by the decrease in the transition energy. Table 3 summarizes the X-ray rates both for electromagnetic interaction with a point nucleus (W_X^{el}), and for electromagnetic plus strong interaction with an extended nucleus (W_X).

The measured intensities were corrected for relative detection efficiency of the X-ray detector and absorption in the target. The relative efficiency of the Ge detector in the energy region from 20 keV to 150 keV was determined by using absolutely calibrated sources of ^{57}Co , ^{137}Cs , ^{241}Am , and a source of ^{182}Ta .

The widths $\Gamma(2p)$ calculated from Eq. (1) with the new W_X are listed in Table 3. The errors include an estimated relative error of 10 per cent for the calculated $P(2p)$ values. We also included in Table 3 the slightly modified values for the elements from N to Na which result from the experimental data of Ref. 1. Earlier results^{5,6)}, treated as described in Ref. 1, are given in columns 4 and 5 of Table 2.

A detailed comparison of the final results of this paper (the widths $\Gamma(2p)$ of Table 3) with the values from an optical potential calculation will be given in a forthcoming paper.

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Table 1

Muonic yields Y_μ (per cent) and parameters of the "initial distribution"

	$Y_\mu(2p-1s)$	$Y_\mu(3p-1s)$	Parameters	
			a_{n-1}^*	f^*
	1	2	3	4
Be	69 ± 2	19 ± 1	0.40	0.91
^{10}B	63 ± 2	21 ± 1	0.30	0.85
natB	65 ± 2	19 ± 1	0.30	0.87
C	64 ± 2	20 ± 1	0.30	0.87

*) for the meaning of the symbols, see Ref. 1.

Table 2

Pionic 2p-1s yields Y_π and populations of the pionic 2p levels $P(2p)$ (per cent)

Y _π				P(2p)				
This work				Ref. 5	Ref. 6	With a _{n-1} of Table 1, col. 3	With f of Table 1, col. 4	Mean Value
1	2	3	4	5	6	7	8	
Be	10.8 ± 1.5	10.0 ± 2.4	10.5 ± 1.4	15.0 ± 1.6	15.5	66	67	67
¹⁰ B	11.0 ± 1.6		11.0 ± 1.6			61	61	61
natB	12.3 ± 1.1	14.0 ± 3.1	12.5 ± 1.0	10.9 ± 1.4	13.9	61	63	62
C	7.5 ± 2.0		7.5 ± 2.0	7.6 ± 0.9	11.7	61	63	62

Table 3

2p-1s X-ray transition rates and 2p level widths

	$w_X^{el} [10^{14} \text{ sec}^{-1}]$	$w_X [10^{14} \text{ sec}^{-1}]$	$\Gamma(2p) \text{ (eV)}$
	1	2	3
Be	0.44	0.44	0.16 ± 0.03
^{10}B	1.07	1.06	0.32 ± 0.06
^{nat}B	1.07	1.04	0.27 ± 0.04
C	2.22	2.14	1.02 ± 0.29
N	4.12	3.95	2.1 ± 0.3
^{16}O	7.02	6.70	4.7 ± 0.8
^{18}O	7.02	6.48	3.8 ± 0.7
F	11.2	10.6	11.2 ± 1.9 *)
Na	25.1	22.0	34.6 ± 7.6

*) This width is obtained with $Y_{\pi} = 4.1 \pm 0.7$ per cent, which replaces the value of Ref. 1.

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