LOW-ENERGY EXCITED STATES OF ^{76}As FROM THE ^{76}Ge$(p,n)^{76}$As REACTION

By A. Bałanda, S. Kopta, H. I. Lizurej and W. Męczyński

Institute of Physics, Jagellonian University, Cracow*

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Spectra of gamma radiation and internal conversion electrons from several germanium targets bombarded with 2.9 MeV protons were measured. Eleven transitions between ^{76}As states excited in the ^{76}Ge(p, n) ^{76}As reaction were identified. The energies of these states were found to be 45.5, 87, 121, 166, 265, 302, 377, 515 and 550 keV. The possible values of spin of the 87 and 121 keV levels have been confined to 1^+, 2^+ and 3^+.

1. Introduction

Spectroscopic data on the odd-odd structure of the ^{76}As nucleus are very poor. To a large extent this fact follows from the lack of populated excited states of ^{76}As in radioactive decays. Therefore, investigation of these states requires use of more complex spectroscopic methods on beams.

Most of the existing data on the excited states of ^{76}As have been obtained on the basis of the spectrum of gamma radiation emitted in the reaction ^{75}As(n, γ)^{76}As [1–8]. The only data not based on the neutron capture reaction were obtained from investigations of the ^{76}Ge$(p, n)^{76}$As reaction [9].

This paper brings some more information on the low-energy excited states of ^{76}As obtained on the basis of measurements of spectra of gamma radiation and internal conversion electrons accompanying the proton bombardment of several germanium targets with various ^{76}Ge enrichment. The transitions between the ^{76}As states excited in the ^{76}Ge(p, n) ^{76}As reaction were identified on the basis of analysis of the gamma spectra. From the measured ratio of internal conversion coefficients $K/(L+M)$ the multipolarity of the transitions from the second and third level to the ground level in ^{76}As was determined, and the plausible spin values was brought down to three levels. The energy of the first, second and third excited state of ^{76}As was determined on the basis of a measurement of the relative intensities of the transitions induced in the (p, n) reaction at proton energies varied between the threshold energy of this reaction to the achievable maximum value. The remaining levels were included on the basis of energy balance and from the literature data.

* Address: Instytut Fizyki UJ, Kraków 16, Reymonta 4, Poland.

2. Experimental

A diagram of the experimental arrangement is shown in Fig. 1. Protons were accelerated to maximum energy 2.9 MeV in the C-48 cyclotron of the Institute of Nuclear Physics in Cracow. The energy spread of the proton beam was about 2 per cent. The current of the collimated beam varied between 0.5 to 3.0 μA, and the beam spot on the target plane set at an angle of 45° to the beam direction had the shape of an ellipse of the dimensions 0.4×0.3 cm. For indentifying the transitions in ^{76}As the following targets were used: natural metallic Ge, metallic Ge enriched with ^{76}Ge, and GeO_2 enriched with ^{74}Ge

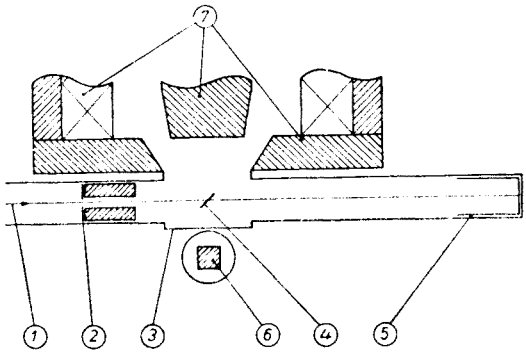

Fig. 1. Experimental arrangement. *1* — proton beam, *2* — collimator, *3* — target chamber, *4* — target, *5* — Faraday cup, *6* — Ge(Li) crystal, *7* — magnetic beta-ray spectrometer

and ^{76}Ge. The natural germanium target was made in the form of a plate about 0.3 cm thick. The GeO_2 targets, with thicknesses of the order of several mg/cm^2, were obtained by evaporating an emulsion of germanium oxides in ethyl alcohol onto thick carbon backings. Metallic germanium enriched in ^{76}Ge was deposited on thin carbon films by vacuum evaporation; the targets thus obtained were 100 and 400 μg/cm^2 thick. Targets from metallic germanium enriched with ^{76}Ge were also used in measurements of the internal conversion electron spectrum. The isotopic composition of the targets and the Q-values of the (p, n) reaction [10] are given in Table I.

The gamma radiation spectra were measured by means of a Ge(Li) detector of active volume 0.7 cm^3. The energy resolving power of the detector for the 401 keV transition in

TABLE I

Isotopic composition of targets and Q-values of (p, n) reactions

Isotope	Q (MeV) of (p, n) reaction [10]	Isotopic composition (%) of target		
		$Ge_{natural}$	$^{74}GeO_2$	^{76}Ge, $^{76}GeO_2$
^{70}Ge	−7.32	20.52	1.5	1.7
^{72}Ge	−5.14	27.43	2.4	2.7
^{73}Ge	−1.15	7.76	1.8	1.4
^{74}Ge	−3.38	36.54	92.7	4.2
^{76}Ge	−1.87	7.75	1.6	90.0

was 7 keV. The gamma spectra were registered on a NTA 512-channel analyser. For energy calibration the ^{54}Mn, ^{60}Co, ^{75}Se and ^{137}Cs sources and the ^{65}Cu(p, n)^{65}Zn reaction were used. The spectrum of internal conversion electrons was measured with a beta spectrometer with a thick magnetic lens, adapted for work on beam [11]. The resolving power of the spectrometer for a source of 0.5 cm diameter was two per cent, whereas transmission was one per cent. The target was set on the magnetic axis of the spectrometer, 2.6 cm away from the normal source position.

3. Measurements and results

a) Identification of transitions in ^{76}As

The spectra of gamma radiation emitted from the germanium targets bombarded with 2.9 MeV protons are presented in Figs 2 to 5. The measuring time of each spectrum was several hours. The energies and relative intensities of the transitions are arranged in Table II. Transition intensities were determined with an accuracy of 20 per cent.

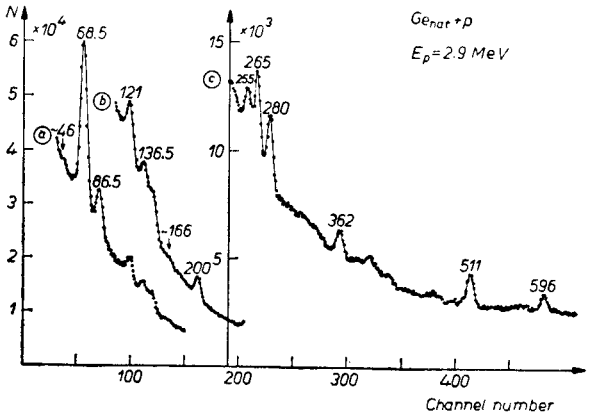

Fig. 2. Spectrum of gamma radiation emitted from $Ge_{natural}$ target bombarded with 2.9 MeV protons

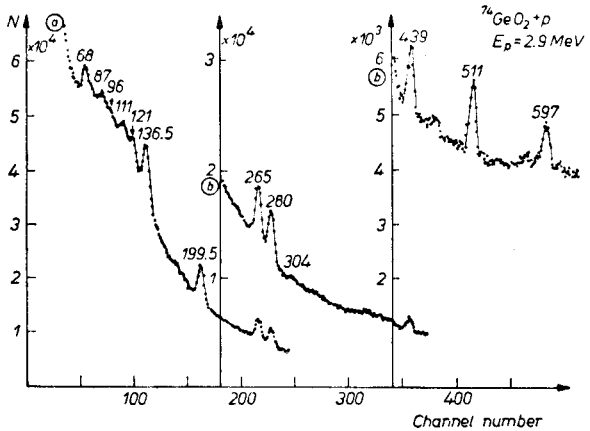

Fig. 3. Spectrum of gamma radiation emitted from $^{74}GeO_2$ target bombarded with 2.9 MeV protons

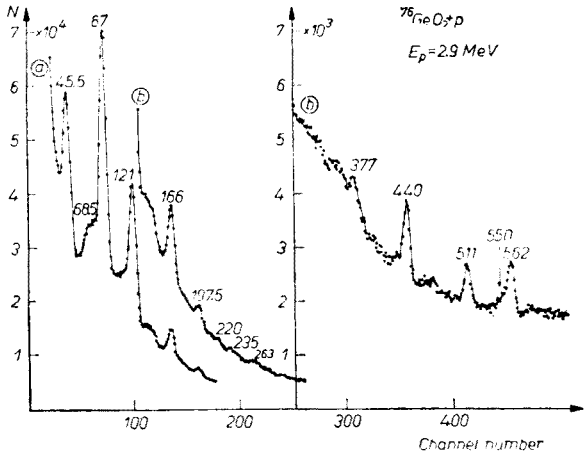

Fig. 4. Spectrum of gamma radiation emitted from $^{76}GeO_2$ target bombarded with 2.9 MeV protons

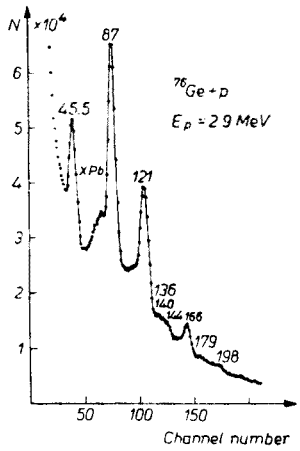

Fig. 5. Spectrum of gamma radiation emitted from ^{76}Ge target bombarded with 2.9 MeV protons

The presence of the isotopes ^{18}O, ^{23}Na and ^{12}C in the targets or backings gave rise to the lines of 111 and 198 keV, 440 keV and 511 keV in the spectra. These lines correspond to the transitions excited in the reactions: $^{18}O(p, \gamma)^{19}F$, $^{23}Na(p, p')^{23}Na^*$ and $^{12}C(p,\gamma)^{13}N$ respectively. The 255 and 362 keV transitions became existent in the $^{73}Ge(p,n)^{73}As$ reaction, and they appear only in the spectrum emitted by the $Ge_{natural}$ target, containing the highest percentage of ^{73}Ge. The 68.5 keV line corresponds to a transition in ^{73}Ge. The spectrum emitted from the $^{74}GeO_2$ target exhibits the lines: 96, 121, 136.5, 265, 280 and 304 keV; they correspond to transitions induced in the $^{74}Ge(p, \gamma)^{75}As$ reaction. This spectrum also has a 587 keV line associated with the $^{74}Ge(p,p')^{74}Ge^*$ reaction. The 45.5, 87, 121, 136, 140, 166, 220, 235, 377 and 550 keV lines seen in the spectrum emitted from the ^{76}Ge and $^{76}GeO_2$ targets were assigned to transitions between states of ^{76}As. The 121 and 136 keV lines in the list above do not correspond despite conformity regarding energy, to transitions in

TABLE II

Gamma lines emitted from germanium targets bombarded with 2.9 MeV protons

$Ge_{natural}$		$^{74}GeO_2$		^{76}Ge, $^{76}GeO_2$*	
E_γ (keV)	I_γ	E_γ (keV)	I_γ	E_γ (keV)	I_γ
46	?			45.5	123
68.5	410	68	310	68.5	?
86.5	100	87	100	87	100
		96	?		
		111	155		
121	84	121	200	121	86
136.5	29	136.5	1550	136	
				140	40
				144	
166	25			166	50
				179	?
200	115	199.5	3250	198	12
				220	3
				235	5.5
255	26				
265	54	265	1950	263	8
280	46	280	1950		
		304	170		
362	36				
				377	17
		439	1500	440	70
511	110	511	1750	511	48
				550	16
				562	80
596		597	2900		

* Data up to 200 keV refer to ^{76}Ge, over 200 keV to $^{76}GeO_2$.

^{75}As. For in such case the 136 keV line should be much more intense, and in the discussed spectrum teh lines at 265 and 280 keV should also appear. The 562 keV line is associated with the $^{76}Ge(p,p')^{76}Ge$ reaction. The origin of the weak 179 keV transition was not established.

An additional corroboration of the identification of transitions in ^{76}As made here was achieved on the basis of a measurement of the gamma spectrum emitted from the irradiated $^{76}GeO_2$ target after the beam was switched off. The spectrum was found to include a 560 keV line (which corresponds to a transition in ^{76}Se) with half-life $T_{1/2} = 26.21 \pm 0.2$ h, what is in accord with the literature data on the disintegrations of the ground state of ^{76}As [12].

b) Internal conversion electron spectrum

A part of the spectrum of internal conversion electrons emitted from the ^{76}Ge target bombarded with 2.9 MeV protons is presented in Fig. 6. The beam was monitored by means of a Ge(Li) detector which registered the 87 keV transition in ^{76}As. The spread of the

experimental points is due primarily to beam instability. The spectrum exhibits the K and L lines of the 87 keV transition and the K line of the 121 keV transition in ^{76}As. The K line of the 45.5 keV transition in ^{76}As was masked by the high δ-electron background. The ener-

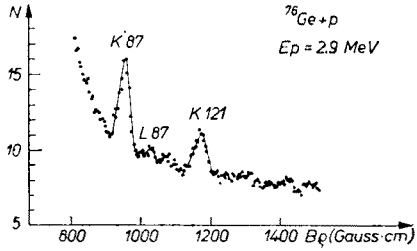

Fig. 6. Spectrum of internal conversion electrons emitted from ^{76}Ge target bombarded with 2.9 MeV protons

gies and intensities of the observed conversion electron lines are arranged in Table III. A comparison of the values of the internal conversion coefficient ratio $K/L+M)$ for the 87 and 121 keV transitions with their theoretical values [13] showed that these are

TABLE III

Lines of internal conversion electron emitted from ^{76}Ge target bombarded with 2.9 MeV protons

E_γ (keV)	line	E_e (keV)	I_e	K/(L+M)	multipolarity
87.0±0.3	K	75.1	100	9.5±2	dipole
	L+M	85.5	10.5		
121.0±0.5	K	109.1	43	9±2*	dipole

* The quoted value is an estimate of the lower extreme of $K/(L+M)$ value.

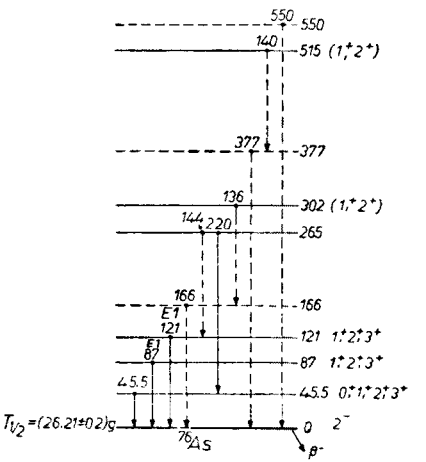

Fig. 7. Proposed energy level scheme of ^{76}As. The 302 keV (1+, 2+) and 515 keV (1+, 2+) levels are introduced in accord with Ref. [5], and the possible spin values of the 46 keV level with Refs [7, 8]

dipole transitions. On the basis of the values of the intensities of the gamma and conversion electron lines corresponding to the 87 and 121 keV transitions (Tables II and III), the ratio of conversion coefficients for these transitions was calculated. It is $\alpha_{K121}/\alpha_{K87} = 0.5 \pm 0.15$.

c) Level scheme for ^{76}As

The proposed energy-level diagram for ^{76}As is presented in Fig. 7. Basing on measurements of the relative intensities of the 45.5, 87 and 121 keV transitions in ^{76}As, induced in the (p, n) reaction for proton energies of 2.00, 2.27, 2.41, 2.63 and 2.90 MeV, it was found that they are transitions from the first, second and third excited level, respectively, to the ground level of the examined nucleus. The other transitions, except for the 235 keV one, are included in the scheme, with the assumption that the 302 and 515 keV levels exist [5]. If we accept that the transition from the neutron capture state in ^{76}As, having spin 1^- or 2^-, to the 87 and 121 keV states are of the E1 type [6, 8], the possible values of spin for these states are 0^+, 1^+, 2^+ and 3^+. Since the transitions from the 87 and 121 keV states to the ground state of ^{76}As, with spin 2^- [12], are dipole ones (Table III), the possible values of spin for these states must be limited to 1^+, 2^+ and 3^+.

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