LEVEL STUDIES OF ^{73}As VIA ^{73}Ge(p n)^{73}As REACTION AND DENSITY OF DISCRETE LEVELS IN ^{73}As

by

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Received on November 17, 2008; accepted on June 7, 2009

The excited states of ^{73}As have been investigated via the ^{73}Ge(p, nγ)^{73}As reaction with the proton beam energies from 2.5-4.3 MeV. The parameters of the nuclear level density formula have been determined from the extensive and complete level scheme for ^{73}As. The Bethe formula for the back-shifted Fermi gas model and the constant temperature model are compared with the experimental level densities.

Key words: level schemes of ^{73}As, ^{73}Ge(p, nγ)^{73}As reaction, angular distribution, Fermi gas model

INTRODUCTION

The structure of ^{73}As nucleus has been investigated via single proton transfer reactions [1-3] and the (p, t) reaction [4]. However, these studies are somewhat inconsistent with each other. On the other hand, in all statistical theories the nuclear level density is the most characteristic quantity and plays an essential role in the study of the nuclear structure.

In this work we have investigated the excited states of ^{73}As and then determined nuclear level density parameters of the Bethe formula and constant temperature model for the ^{73}As nucleus.

EXPERIMENTAL PROCEDURE

A thick self-supporting pellet of spectroscopically pure natural Ge was used as a target. The proton beam of 2.5 MeV to 4.3 MeV energies was used for bombardment to excite the levels of ^{73}As through the ^{73}Ge (p, nγ)^{73}As reaction (Q value = –1.12 MeV). The target was placed at an angle of 45 degrees with respect to the beam direction and was thick enough to stop incident protons. The angular distributions were measured at 0°, 30°, 45°, 55°, 75°, and 90°. The γ-rays were detected with a 70 cm^3 coaxial HPGe detector with a resolution of 1.9 keV for the 1332 keV line of ^{60}Co. The excitation functions of various γ-rays have been measured at 55° in the range of 2.5 MeV to 4.3 MeV beam energies to ascertain that the channel of the compound decay is dominant as compared to the Coulomb excitation at the incident proton energy of 4.3 MeV. The other details of the experimental procedure are given in our previous publications [5, 6].

DATA ANALYSIS

The gamma-ray spectra were analyzed using the computer code PEAKFIT [7]. A typical γ-ray spectrum at 90 degrees for an incident proton energy of 4.3 MeV is given in our previous publication [8]. The excitation functions of all the observed γ-rays were analyzed carefully as a function of energy and those from (p, nγ) reaction were easily identified with a characteristic rise above their threshold energy. The relative branching ratios used for further analysis are the weighted average of the respective values at 4.0 MeV and 4.3 MeV bombarding energies.

The extraction of multipole mixing ratios of the observed transitions and the assignment of spin values to the excited levels were made from the χ^2-fitting of

Nuclear Technology & Radiation Protection
Scientific paper
UDC: 539.125.4/.5:539.1.074
DOI: 10.2298/NTRP0902082B

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angular distribution data at 4.3 MeV proton beam energy. The optical model parameter sets given by C. M. Perey and F. G. Perey [9], which are based on the results of F. G. Perey [10] for protons and Wilmore and Hodgson [11] for neutrons, were used to calculate the transmission coefficients. Beside the observed neutron channel, all known (p, p'γ) channels and (p, nγ) channels were included as competing channels. The Moldauer was also taken into account width the fluctuation correction [3]. The typical experimental angular distributions of some of the observed transitions together with theoretical curves for different possible spins of the levels and the respective χ^2-fitting are given in our previous publication [8]. The 0.1% confidence limit was used to exclude unacceptable spins and δ values. The coefficients A_2 and A_4 from the polynomial fits to the experimental distribution along with the multipole mixing ratios (δ) are given in tab. 1.

STATISTICAL FORMULA

The nuclear temperature T can be defined by the nuclear level density $\rho(E)$ [12]

$$\frac{1}{T} = \frac{\mathrm{d}}{\mathrm{d}E} Ln\rho(E) \tag{1}$$

The integration yields the constant temperature Fermi gas formula [13]

$$\rho(E) = \frac{1}{T}\exp\frac{E - E_0}{T} \tag{2}$$

The nuclear temperature T and the ground state back shift E_0 can be determined using the experimental data on the level density. The Bethe formula of the level density [14] for the back-shifted Fermi gas model [15, 16] can be written

$$\rho(E) = \frac{\exp(2\sqrt{E - E_1})}{12\sqrt{2}\sigma\, a^{1/4}(E - E_1)^{5/4}} \tag{3}$$

In this case, the level density parameter a and the ground state back shift E_1 are obtained by a fit to the experimental results. The distribution of spins J is determined [13, 14] by the spin cut-off parameter σ^2

$$f(J) = \exp\frac{J^2}{2\sigma^2} - \exp\frac{(J + 1)^2}{2\sigma^2} = \frac{2J + 1}{2\sigma^2}\exp\frac{(J + 1/2)^2}{2\sigma^2} \tag{4}$$

With this spin distribution, the spin-dependent level density is

$$\rho(E, J) = \rho(E) f(J) \tag{5}$$

where σ^2 is related to an effective moment of inertia I_{eff} and to the nuclear temperature T [12, 15]

$$\sigma^2 = \frac{I_{\mathrm{eff}} T}{\hbar^2} \tag{6}$$

The nuclear moment of inertia for a rigid body is $I_{\mathrm{rigid}} = (2/5)MR^2$ (where $M = A$, the amu nuclear mass; $R = 1.25A^{1/3}$, the nuclear radius) resulting in [15]

$$\sigma^2 = 0.0150A^{5/3}T \tag{7}$$

Gilbert and Cameron [13] calculated the spin cut-off parameter for the Bethe formula with the reduced moment of inertia

$$\sigma^2 = 0.0888A^{2/3}\sqrt{a(E - E_1)} \tag{8}$$

FIT OF THE LEVEL DENSITY FORMULA

Each of the two level density formula has two free parameters. It may be obtained by fitting the measured level schemes experimentally. We have applied these formulas to the measured level scheme for ^{73}As reported in tab. 1. Our best fit values obtained using the Bethe formula are the level density parameter a = = 5.26 MeV^{-1} and the back shift E_1 = –2.839 MeV. The results obtained using the constant temperature formula are T = 1.617 MeV and the back shift E_0 = = –4.791 MeV.

The accumulated levels $N(E)$ as a function of energy are plotted in figs. 1 and 2. The examination of these figures shows that the agreement between the theory and experiment is very good and both formulas fit the measured level scheme equally well.

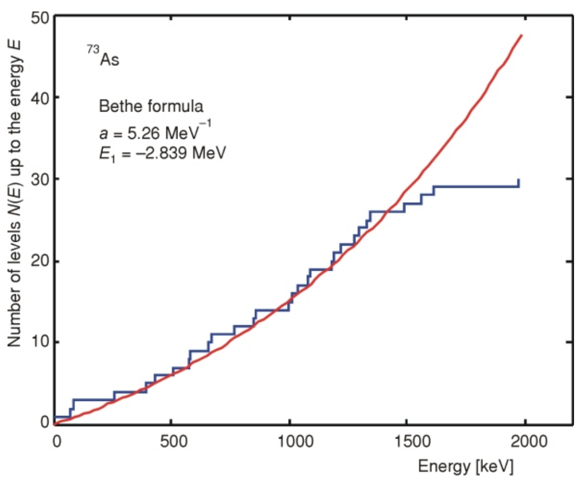

Figure 1. Plot of the number of levels $N(E)$ up to the energy E for ^{73}As together with the fitted curve calculated by the Bethe formula

Table 1. The results of the angular distribution measurements in ^{73}As

Transitions	Gamma rays [keV]	J_i^π J_f^π	Multipole mixing ratios, σ	A_2	A_4
674.0 509.8	164.2	$\frac{5}{2}$ $\frac{5}{2}$	$1.39^{0.8}_{0.6}$	–0.34(5)*	–0.001 (5)
769.6	769.6	$\frac{5}{2}$ $\frac{3}{2}$	0.74 1.6	0.065(23)	0.009(24)
850.4 0	850.4	$\frac{5}{2}$ $\frac{3}{2}$	$0.2^{0.1}_{0.2}$	–0.003(16)	–0.000(16)
860.5 0	860.5	$\frac{7}{2}$ $\frac{3}{2}$	–1 0.3	0.004(37)	0.004(42)
993.7 0	993.7	$\frac{7}{2}$ $\frac{3}{2}$	0.5 0.1 or $0.3^{0.6}_{0.7}$	–0.033(35)	0.003(36)
1037.0 427.8	609.1	$\frac{13}{2}$ $\frac{9}{2}$	$10.6^{0.02}_{0.03}$	0.096(6)	0.001(6)
1086.7 84.2	1002.4	$\frac{5}{2}$ $\frac{1}{2}$	1.5 0.01	–0.035(58)	–0.007(58)
1177.8 67.0	1110.9	$\frac{7}{2}$ $\frac{5}{2}$	$0.5^{0.2}_{0.1}$	0.002(16)	–0.003(16)
1221.3 67.0	1154.1	$\frac{7}{2}$ $\frac{5}{2}$	–0.3 0.1	0.027(30)	0.006(30)
1274.9 509.8	765.1	$\frac{7}{2}$ $\frac{5}{2}$	$1.8^{0.12}_{0.06}$	–0.013(53)	–0.008(54)
1344.1 67.0	1277.2	$\frac{7}{2}$ $\frac{5}{2}$	$1.3^{0.5}_{0.4}$	–0.032(50)	0.001(51)
1489.3 509.8	979.3	$\frac{5}{2}$ $\frac{5}{2}$	–1.8 0.1 or –0.2 0.1	0.018(72)	0.011(73)
1557.1 860.5	696.5	$\frac{7}{2}$ $\frac{7}{2}$	0.5 0.1	–0.023(50)	0.003(50)
1612.2 67.0	1545.3	$\frac{7}{2}$ $\frac{5}{2}$	$1.3^{1.0}_{0.6}$	–0.045(60)	0.001(60)
1975.2 1274.9	700.5	$\frac{5}{2}$ $\frac{7}{2}$ $\frac{7}{2}$ $\frac{7}{2}$	$0.05^{0.02}_{0.08}$ 0.97 0.05	0.014(75)	0.000(77)

* The numbers in the brackets in the last two columns indicate the uncertainties in the deduced values of the coefficients.

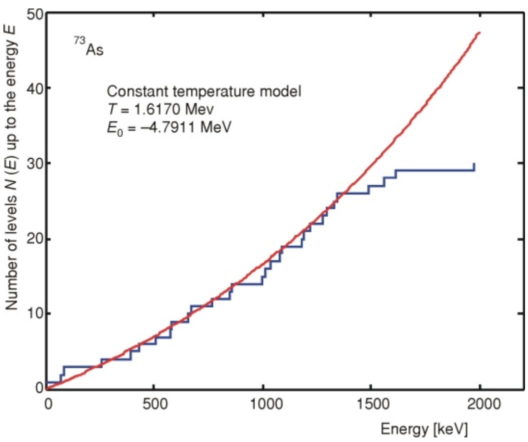

Figure 2. Plot of the number of levels $N(E)$ up to the energy E for ^{73}As, together with the fitted curve calculated by the constant temperature model

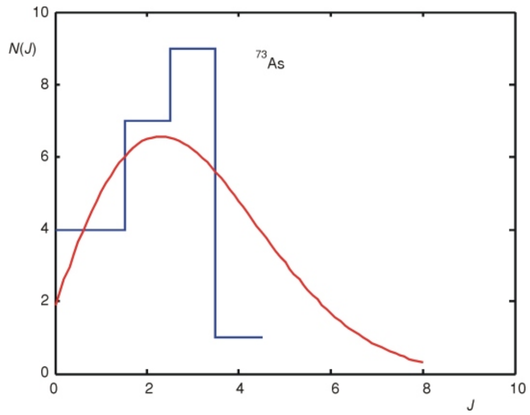

Figure 3. The spin distribution of low-lying states. The histogram is the experimental data (data from tab. 1). The curve is the description by the statistical distribution with $\sigma^2 = 7.820$

Furthermore, the spin cut-off parameter σ^2 has been obtained by fitting the known spin distribution, N(J) of tab. 1 with the theoretical expression (4) shown in fig. 3. Our best fit value of this parameter is σ . This deduced value is very different from its corresponding rigid body value of σ^2 = 14.67. This finding is opposite to the claim made by some authors that the spin cut-off parameter reduces to its rigid body value at lower energies.

CONCLUSION

The purpose of the present study was to provide additional experimental information on the existing level structure of ^{73}As through (p, nγ) reaction.We have measured the γ-ray energies, branching ratios and multipole mixing ratios of various transitions in ^{73}As.

The complete and extensive nuclear level scheme of ^{73}As provides a sufficient basis for statistical interpretations of low energy nuclear level schemes using various tests of statistical theories. The level density near the ground state is well reproduced by the Bethe formula as well as by the constant temperature formula if two parameters are fitted.

Then, the spin cut-off parameter of ^{73}As has been determined from the analysis of the experimental data on spins of low-lying states given in tab. 1. It is not confirmed with its corresponding rigid body value.

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ПРОУЧАВАЊЕ ПОБУЂЕНИХ СТАЊА И ГУСТИНЕ ДИСКРЕТНИХ НИВОА АРСЕНА ПОСРЕДСТВОМ РЕАКЦИЈЕ ^{73}Ge (p, *n*γ) ^{73}As

Сноповима протона енергије од 2.5 MeV до 4.3 MeV испитивана су побуђена стања ^{73}As посредством реакције ^{73}Ge (p, nγ) ^{73}As. На основу свеобухватне шеме нивоа 73Ac, одређени су параметри формуле за густину нуклеарних нивоа. Бетеова формула за густине нивоа по Фермијевом шифтованом гасном моделу и формула по моделу константне температуре, упоређени су са експериментално добијеним густинама нивоа.

Кључне речи: шеме нивоа ^{73}As, реакција ^{73}Ge (p, nγ) ^{73}As, угаона расподела, Фермијев гасни модел