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MEASUREMENT OF B(E2)↑ VALUES OF THE $5/2_2^-$ STATES OF $^{107,109}Ag$ FROM THE COULOMB EXCITATION WITH PROTONS

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From the Coulomb excitation of natural silver with protons B(E2)↑ values were measured for the $5/2_2^-$ states of $^{107,109}Ag$ using high resolution gamma-ray spectroscopy. B(E2)↑ values of all the observed states have been measured including the $5/2_2^-$ states. The observed and derived properties of the low-lying states of $^{107,109}Ag$ nuclei are tabulated.

ИЗМЕРЕНИЕ ЗНАЧЕНИЙ B(E2)↑ ДЛЯ СОСТОЯНИЙ $5/2_2^-$ ПРИ ПОМОЩИ КУЛОНОВСКОГО ВОЗБУЖДЕНИЯ $^{107,109}Ag$ ПРОТОНАМИ

В работе приведены результаты измерений вероятностей перехода B(E2)↑ для состояний $5/2_2^-$ при помощи кулоновского возбуждения природного серебра $^{107,109}Ag$ протонами с использованием γ-спектроскопии высокого разрешения. Были измерены значения B(E2)↑ для всех наблюдаемых состояний, включая состояниа $5/2_2^-$. Наблюдаемые и полученные свойства низколежащих состояний ядер $^{107,109}Ag$ приведены в таблице.

I. INTRODUCTION

The study of the Coulomb excitation is a good method for investigating the collective nature of the low-lying states of nuclei. In Coulomb excitation studies, low-energy protons have certain advantages over many other projectiles because the light projectiles do not give any significant contribution to the cross-section from the multiple Coulomb excitation. Hence, the B(E2)↑ values can be extracted from the first order perturbation theory of Alder et al. [1]. Besides, the light projectiles have a greater penetrability in the target and as a result, an appreciable yield is achieved for the low-lying states. Moreover, at bombarding energies well

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below the Coulomb barrier, there is little interference from the direct nuclear process.

In earlier Coulomb excitation studies [2—4] with low-energy protons and alpha particles only the $3/2_1^-$ and $5/2_1^-$ states were observed in ^{107,109}Ag. The high energy states were observed from the Coulomb excitation with 10 MeV alpha particles and oxygen ions [5, 6]. In the present Coulomb excitation study the $5/2_2^-$ states of ^{107,109}Ag have been observed.

II. EXPERIMENTAL PROCEDURE

A thick target (0.2 cm thick) of natural silver (99.99 %) was bombarded with protons of energies 4.0—5.0 MeV and a current of 100 nA from the Van de Graaff accelerator of the Bhabha Atomic Research Centre, Bombay. The de-excited gamma-rays were observed with a 30 cm^3 Ge(Li) detector (2.5 keV resolution at 1332 keV) at an angle of 125° with respect to the beam direction to minimize the effect of angular distribution of the gamma-rays. Gamma-gamma coincidence spectra were studied with the NaI(T1)—Ge(Li) spectrometer using a fast coincidence set up of time resolution 100 ns. The spectra were recorded in a 4096 channel ND analyser. To study the excitation function, spectra were recorded at proton energies 4.0, 4.5 and 5.0 MeV for the same amount of incident charge measured by a current integrator after suppression of secondary electrons from the target. The singles spectra were analysed using the computer code SPAN [7]. Standard sources were used for energy calibration. The absolute efficiency of the Ge(Li) detector has been measured with the standard calibrating sources of known strength under the identical geometrical condition under which the experiment was performed.

III. RESULTS

Natural silver contains two isotopes, ^{107}Ag and ^{109}Ag having abundances of 51.35 % and 49.65 %, respectively. Hence, in the bombardment of natural silver with low-energy protons, Coulomb excitation of the states of ^{107}Ag and ^{109}Ag takes place. Apart from these, the states of ^{107}Cd and ^{109}Cd were also excited from (p, n) reactions. The distinction in the nature of the excitation functions of the states excited in the above two processes has been utilized in separating the gamma-rays resulting from these two processes. The de-excited gamma-rays of energies 97.7, 324.9, 423.4 and 526.6 keV have been identified as ^{107}Ag lines (Fig. 1). The 526.6 keV gamma-ray has been observed in coincidence with the 423 keV gamma-ray and assigned as a transition from the 950 keV states of ^{107}Ag. Robinson et al. [6] have observed 625 keV and 950 keV transitions from this level. The weak 950 keV transition has not been observed in the present work. The

contribution of the 625.1 keV transition could not be estimated due to the interference of the strong 623.9 keV gamma-ray of ^{109}Cd. However, in our study the 625.1 keV gamma-ray coincides with the 325 keV gamma-ray. Hence, the excitation function of the 950 keV state has been calculated only on the basis of the 526.6 keV transition using the known branching ratio [6].

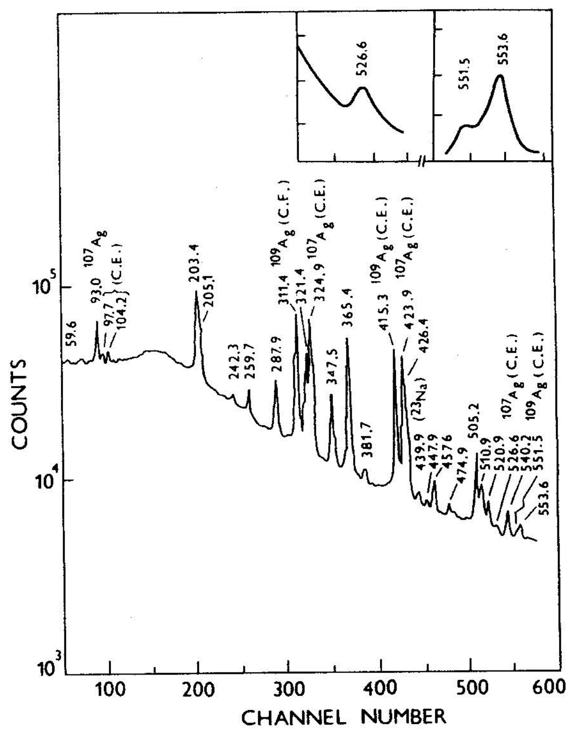

Fig. 1. A portion of the gamma-ray spectrum from the bombardment of natural silver with 5.00 MeV protons. All the Coulomb excited lines are marked with (C. E.). Other prominent peaks correspond to the ^{107,109}Cd gamma-rays.

Similarly, the 104.2, 311.4, 415.3 and 551.5 keV gamma-rays have been identified as ^{109}Ag lines. The 551.5 keV gamma-ray has been observed in coincidence with the 311 keV gamma-ray and has been assigned as a transition from the 862.9 keV state of ^{109}Ag. Robinson et al. [6] observed two more transitions from this level. The weak 862.9 keV transition has not been observed in the present work. The 447.6 keV transition from this level seems to have some contribution from an unknown gamma-ray of the energy of 447.9 keV. Hence, the excitation function of the 862.9 keV state has been calculated with the known branching ratio [6] of the 551.5 keV transition from this level.

The thick target yields for the excited states have been measured considering the internal conversion coefficients and the cascade transitions from the higher lying levels. The B(E2)↑ values of the excited states have been calculated from the first order perturbation theory of Alder et al. [1]. To calculate the thick-target integral, the stopping power of the target material has been taken from the Nuclear Data Tables [8] and the f(E2) values for the E2 excitation has been used from the work of Alder et al. [1].

The experimentally measured thick target yields for the excited states of ^{107}Ag and ^{109}Ag have been compared with the theoretically calculated values in Fig. 2 and Fig. 3, respectively. An excellent agreement has been observed between the

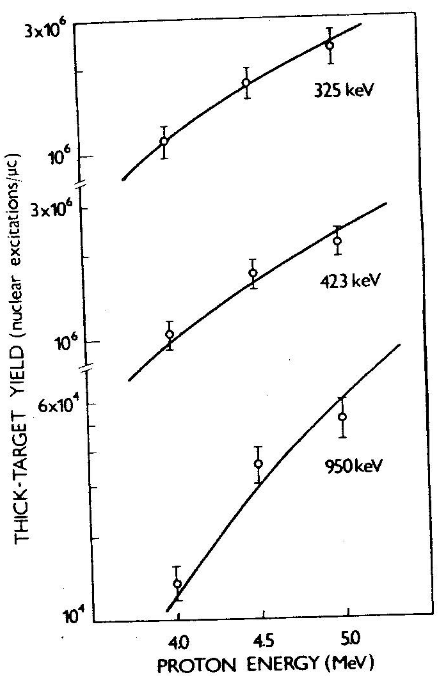

Fig. 2. Measured thick target yields of the excited states of ^{107}Ag at different proton energies. The solid line shows the theoretical yield calculated with an average B(E2)↑ value of the state.

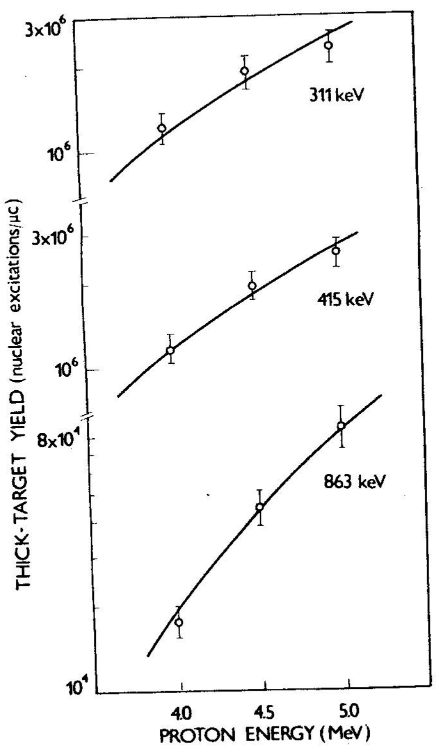

Fig. 3. Measured thick target yields of the excited states of ^{109}Ag at different proton energies. The solid line shows the theoretical yield calculated with an average B(E2)↑ value of the state.

experimental and theoretical values. This shows that the states are excited purely from the Coulomb excitation and hence there is no contribution from nuclear scattering. The absolute B(E2)↑ values measured from these states are given in Table 1.

Table 1

B(E2)↑ values of the excited states of ^{107,109}Ag

Nucleus	Level [keV]	Spin parity J^π	B(E2)↓ $e^2\ 10^{-50}\ cm^4$ Black & Gruhle [5]	Robinson et al. [6]	Present work*
^{107}Ag	324.9	$3/2^-_1$	21.9	20.2 ±1.8	21.5 ±3.0
	423.4	$5/2^-_1$	28.2	28.7 ±2.4	25.2 ±3.3
	950.0	$5/2^-_2$	2.5	2.03±0.22	2.21±0.37
^{109}Ag	311.4	$3/2^-_1$	24.9	22.2 ±1.9	22.0 ±3.2
	415.3	$5/2^-_1$	36.3	32.0 ±2.6	28.6 ±3.7
	862.9	$5/2^-_2$	2.24	1.73±0.17	2.43±0.41

* Contributions from the decay of ^{107}Cd (produced in a (p, n) reaction) to the 324.9, 423.4 and 950.0 keV levels of ^{107}Ag have been calculated and found to be negligibly small.

In the present investigation only the $3/2^-_1$, $5/2^-_1$ and $5/2^-_2$ states of ^{107}Ag and ^{109}Ag have been observed. However, the lowlying $3/2^-_2$ states in these nuclei have not been excited with protons. The B(E2)↑ values of $3/2^-_2$ states are much less compared to the B(E2)↑ values of the $5/2^-_2$ states in ^{107,109}Ag [6]. It is observed from the comparison of the B(E2)↑ values that the B(E2)↑ of the 863 keV state measured by us is higher than that measured by Robinson et al. [6]. The half-life of the 863 keV state (1.31±0.27) ps calculated from the present B(E2)↑ agrees very well with the (1.3±0.4) ps observed by Robinson et al. [6] from the Doppler shift measurement. However, it is to be pointed out that Robinson et al. have also quoted the (1.8±0.3) ps half-life for this state from the measured B(E2) value.

IV. DISCUSSION

The proximity of the energies the $3/2^-_1$, $5/2^-_1$, $3/2^-_2$ and $5/2^-_2$ states in ^{107}Ag and ^{109}Ag and the $1/2^-$ gound states show a similarity of these two nuclei. The observed properties such as B(E2) and B(M1) of the transitions from these states (Table 2) show further the possibility of describing these two nuclei together. According to the shell model, the ground state and the $3/2^-_1$ and $5/2^-_1$ states may be described as $2p_{1/2}$, $2p_{3/2}$ and $1f_{5/2}$ single particle states. This interpretation will lead to a "normal" M1 transition between the $p_{3/2}\rightarrow p_{1/2}$ orbitals, whereas the $f_{5/2}\rightarrow p_{3/2}$

Table 2

Properties of the excited states of $^{107,109}Ag$

Nucleus	Level [keV]	J^π	E_γ [keV]	Gamma-ray branching ratio [%]	$B(E2)_d$ [$e^2 \cdot cm^4 \times 10^{-50}$]	$B(E2)_d$ B[E2]$_{s.p.}$	Mixing ratio* δ	$B(M1) \times 10^2$ [eħ/2MC]^2	$T_{1/2}$ [ps]
^{107}Ag	324.9	$3/2^-$	324.9		10.8 ±1.5	36	−0.189±0.014	23	4.9 ±0.8
	423.4	$5/2^-$	423.4	94.3	8.4 ±1.1	28			45.6 ±6.0
			97.7	5.7	2.7	8.6	−0.059±0.018	5.2	
	950.0	$5/2^-$	950.0	12±1*	0.74±0.12	2.5			1.20±0.22
^{109}Ag	311.4	$3/2^-$	311.4		11.0 ±1.6	36	−0.196±0.027	20	6.4 ±1.6
	415.3	$5/2^-$	415.3	95.2	9.5 ±1.2	31			44.5 ±5.6
			104.2	4.8	0.73	2.2	−0.039±0.017	3.6	
	862.9	$5/2^-$	862.9	9.0±1.0*	0.81±0.14	2.6			1.31±0.27

* Values are taken from ref. [6].

transition should be l-forbidden as $\Delta l = 2$. If these states are described as single particle states, obviously one should not expect large B(E2)↓ values over the single particle estimates for the transitions from them. The properties of these states given in Table 2 show a different situation. The B(E2)↓ values are considerably enhanced. The B(M1) values of the $3/2_1^- \to 1/2^-$ transitions are hindered and there exist M1 components in the $5/2_1^- \to 3/2_1^-$ transitions. The observed properties do not agree with the shell model predictions.

According to the core excitation model by de-Shalit [9] the $3/2_1^-$ and $5/2_1^-$ states might result from the coupling of the proton (or hole) in the $p_{1/2}$ orbital to the 2_1^+ states of the neighbouring even, vibrational core nuclei. If this be the situation, the $3/2_1^-$ and $5/2_1^-$ doublets in $^{107}_{47}Ag$, and $^{109}_{47}Ag$ can be compared with the 2_1^+ states of the neighbouring even even core nuclei such as $^{106}_{46}Pd$ and $^{108}_{48}Cd$, and $^{108}_{46}Pd$ and $^{110}_{48}Cd$. The doublet centre of mass is at 384 keV in ^{107}Ag and 375 keV in ^{109}Ag. These are to be compared with the 2_1^+ excitation of 511 keV in ^{106}Pd, 633 keV in ^{108}Cd, 435 keV in ^{108}Pd and 658 keV in ^{110}Cd. The doublet centre of mass is about 67 % of the average value of the 2_1^+ excitations of the neighbouring core nuclei. The B(E2)↓ of the transitions from these doublets are close to the B(E2)↓ values of the transitions from the 2_1^+ states of the neighbouring nuclei [10, 11]. The $3/2_1^-$ and $5/2_1^-$ states show a similar E2 enhancement as the 2_1^+ core states. According to the core excitation model the B(M1) transition from the $3/2_1^- \to 1/2^-$ state is "core forbidden". The B(M1) transitions about 0.2 nm from the $3/2_1^-$ states may arise from the admixture of $|0\, p_{3/2} 3/2\rangle$ in $|2\, p_{1/2} 3/2\rangle$. Hence, we observe that the core excitation model explains the properties of the $3/2_1^-$ and $5/2_1^-$ states reasonably well. From a similar argument of the core excitation model the higher excited states may also be considered as arising from the coupling of the $p_{1/2}$ proton (or hole) coupled to the two-quadrupole phonon states of the neighbouring even even nuclei. A search for such states was made earlier [12, 13] from (p,p')inelastic scattering experiments. The second $3/2^-$ and $5/2^-$ states were identified as the core coupled states. However, the B(E2)↓ of the transitions $0.0014 e^2b^2$ from the 787 keV state in ^{107}Ag and $0.00043\, e^2b^2$ from the 702 keV state in ^{109}Ag [6] cannot be explained easily from the core excitation model. This may be due to the large admixture from the single particle states. The $(^3He, d)$ reaction study by Kuhfeld and Hintz [14] shows that the first and second $3/2^-$ states of ^{107}Ag contain an appreciable admixture of the $2p_{3/2}$ proton hole component. This may be one of the reason of the small B(E2)↓ of the transitions from the $3/2_2^-$ states. The B(E2)↓ of the transitions from the $3/2_2^-$ states. The B(E2)↓ values of the transitions from the $5/2_2^-$ states appear to be close to the B(E2)↓ of the transitions from the 2_2^+ states of the neighbouring even even nuclei [10, 11].

The limitation of the weak coupling model in these nuclei prompted various workers [15, 16] to carry out theoretical calculations using the intermediate-coupling model (ICM). These calculations could not reproduce the B(E2)↓ of the transitions from the $3/2_2^-$ states in ^{107,109}Ag nuclei. The theoretical calculation has also been carried out in the frame work of the Alaga model by Paar [17]. In this calculation a three-proton hole cluster moving in the $g_{9/2}$, $p_{1/2}$ and $p_{3/2}$ shell model states is coupled to the quadrupole vibrational field with vibrator states up to three phonons. This description of Ag nuclei from the even-even Sn core reproduced the positions of the states as well as the B(E2) and B(M1) of the transitions from the excited states quite satisfactorily. Hence it is concluded that the simple picture of one proton (or hole) in a $p_{1/2}$ orbital coupled to the neighbouring even even core is not adequate for the higher excited states of Ag nuclei. The proton holes in other orbitals play a significant role at a higher excitation energy.

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REFERENCES

[1] Alder, K., Bohr, A., Huss, T., Mottelson, B., Winther, A.: Rev. Mod. Phys. *28* (1956), 432.
[2] McGowan, F. K., Stelson, P. H.: Phys. Rev. *99* (1955), 127.
[3] McGowan, F. K., Stelson, P. H.: Phys. Rev. *109* (1958), 901.
[4] Cottrel, C. W.: Nucl. Phys. A *204* (1973), 161.
[5] Black, J. L., Gruhle, W.: Nucl. Phys. A *93* (1967), 1.
[6] Robinson, R. L., McGowan, F. K., Stelson, P. H., Milner, W. T.: Nucl. Phys. A *150* (1970), 225.
[7] Basu, S. K., Patro, A. P.: Nucl. Ins. Meth. *126* (1975), 115
[8] Northcliffe, N. C., Schilling, R. F.: Nucl. Data Tables A *7* (1970), 233.
[9] de-Shalit, A.: Phys. Rev. *122* (1961), 1530.
[10] Robinson, R. L., McGowan, F. K., Stelson, P. H., Milner, W. T., Sayer, R. O.: Nucl. Phys. A *124* (1969), 553.
[11] Milner, W. T., McGowan, F. K., Stelson, P. H., Robinson, R. L., Sayer, R. O.: Nucl. Phys. A *129* (1969), 687.
[12] Ford, J. L. C. Jr., Wong, C., Tamura, T., Robinson, R. L., Stelson, P. H.: Phys. Rev. *158* (1967), 1194.
[13] Ford, J. L. C. Jr., Robinson, R. L., Stelson, P. H., Tamura, T., Wong, C.: Nucl. Phys. A *142* (1970), 525.
[14] Kuhfeld, A. W., Hintz, N. M.: Nucl. Phys. A *247* (1975), 152.
[15] Gujrathi, S. C., Pathak, B. P.: Lett. Nuovo Cim. *1* (1971), 887.
[16] Naqib, I. M., Thomas, D. J., Wakefield, B.: J. Phys. A *6* (1973), 1580.
[17] Paar, V.: Nucl. Phys. A *211* (1973), 29.

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