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COULOMB EXCITATIONS OF LOW LYING LEVELS IN ^{127}I AND ^{197}Au

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The low-lying levels of ^{127}I and ^{197}Au were Coulomb excited with 3.54—4.2 MeV protons. The reduced quadrupole transition probabilities of the 203, 374.9, 418, 618.4, 628.7, 651.1 and 745.5 keV states of ^{127}I, and the 268.8, 278.9, 502, and 547.5 keV states of ^{197}Au have been measured from Coulomb excitation by observing the de-excitation gamma-rays with a high resolution Ge(Li) detector. The low-energy protons have been used for the first time to Coulomb-excite the two levels at 618.4 and 651.1 keV of ^{127}I and one level at 502 keV of ^{197}Au. The present experimental results are found in agreement with the existing experimental data except the B(E2) value of the level at 268.8 keV of ^{197}Au.

I. INTRODUCTION

The Coulomb excitation measurement have provided a considerable amount of information on energies, spins and transition moments of the low-lying excited states of nuclei. Such properties of excited states of ^{127}I and ^{197}Au have been studied through various experiments and theoretical calculations. The experimental investigations on electromagnetic properties of these nuclei have been carried out mainly by Coulomb excitation [1—18], radioactive decay [9—12] and the neutron inelastic scattering [13—18]. These experiments have fixed the spin and parities of the low-lying levels, and branching ratios for the transitions from these levels. Theoretical models [19—22] have also predicted some useful information on the low-lying levels of ^{127}I and ^{197}Au nuclei. In Coulomb excitation studies of these nuclei mostly, the heavy ions [1, 2] and alpha particles [3, 4] have been used as projectiles. It is, however, also worthwhile to re-investigate the Coulomb excitation of ^{127}I and ^{197}Au with low-energy protons by using a high energy resolution detector for detecting the de-excitation gamma-rays. The possibility of multiple Coulomb excitation with protons is negligible, hence the reduced quadrupole transition probabilities, the B(E2)↑ of the excited states, can be extracted by using the first order perturbation theory

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of Alder et al. [23]. We present the results on B(E2)↑ for seven levels in ^{127}I and four levels in ^{197}Au Coulomb excited by protons as projectiles. Our B(E2)↑ values for 618.4 and 651.1 keV levels in ^{127}I and 502 keV level in ^{197}Au are the new results, for the first time with protons, as they have not been measured in recent works [6, 27].

II. EXPERIMENT

The Coulomb excitation experiment was carried out at the Variable Energy Cyclotron, CHANDIGARH (India). Natural, thick-targets of metallic gold and Potassium iodide (99.9%) were bombarded with 3.5 and 4.2 MeV protons to produce sources of excited states of ^{127}I and ^{197}Au. The beam-current was kept in the range of 100 to 200 nA to avoid the large dead time corrections. The de-excitation gama-rays were detected by a 50 cc Ge(Li) detector having an energy resolution of 2.0 keV for the 1.332 MeV line of ^{60}Co. For the determination of reduced quadrupole transition probabilities the detector was placed at 55° to the beam direction in order to minimize the angular distribution effects.

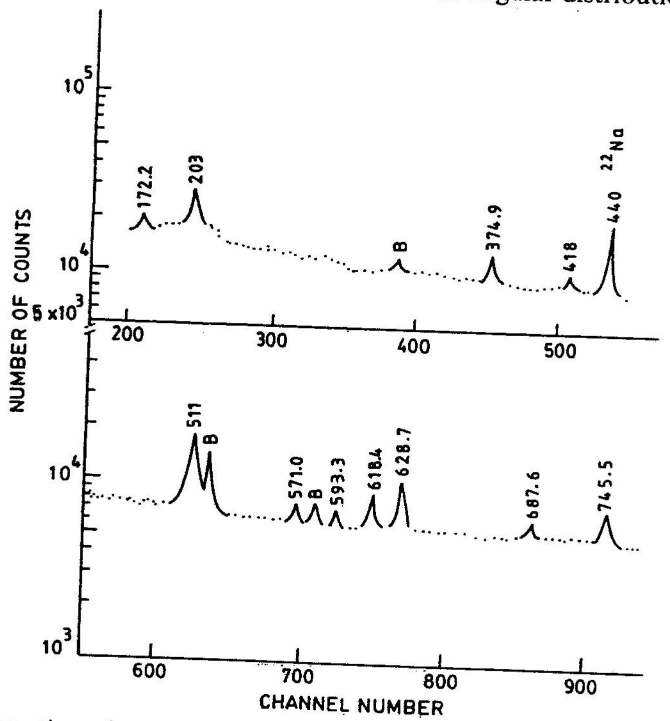

Fig. 1. Relevant portions of gamma ray spectrum observed from the bombardment of natural KI target with 3.54 MeV protons.

The thick-targets served as a Faraday cup for the charge collection. The other details of the experimental procedure are given in previously reported works [24, 25].

III. EXPERIMENTAL RESULTS

In the present experiment, the levels at 203, 374.9, 418, 618.4, 628.7, 651.1 and 745.4 keV excitation energy of ^{127}I, and the 268.8, 278.9, 502 and 547.5 keV states of ^{197}Au have been excited. The gamma-rays from the de-excitation of these levels have been identified on the basis of their values given in literature [26, 27]. The gamma-rays from background and the contaminants have also been identified and separated from those belonging to Iodine and Gold transitions. The relevant portions of the gamma-ray spectrum for ^{127}I taken at 3.54 MeV proton energy is shown in Fig. 1. The relevant portions of the spectrum of ^{197}Au with 4.2 MeV protons observed by us are given in Fig. 2. Previously reported results on ^{197}Au are given elsewhere [31]. The level diagrams for ^{127}I and ^{197}Au are shown in Figs. 3 and 4, respectively.

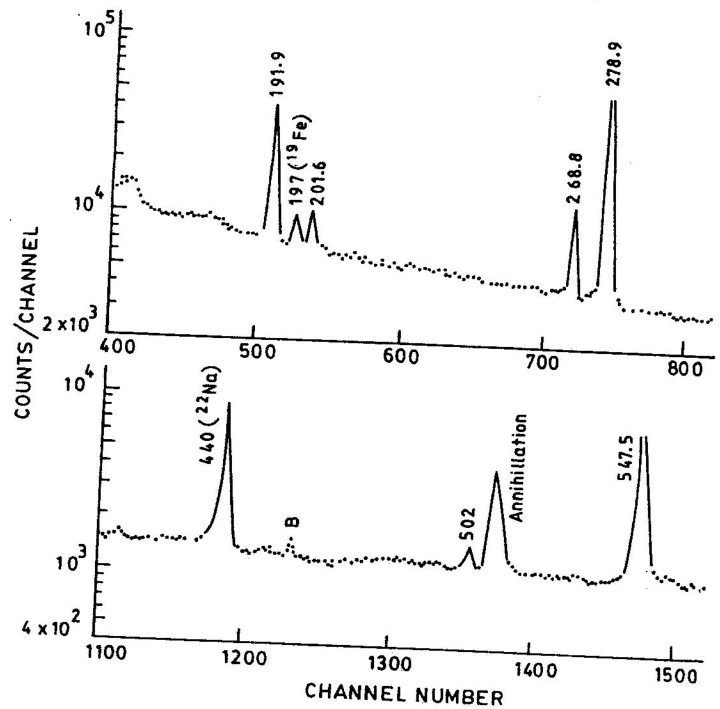

Fig. 2. Relevant portions of gamma-ray spectrum for ^{197}Au with 4.2 MeV protons.

The thick-target gamma-ray yields for various transitions were measured from the area under the peak, the detector efficiency, the gamma-ray absorption in the target and target chamber, the internal conversion coefficient and the cascade transitions from higher levels feeding the level of interest, and the total charge used. The integrated charge was corrected for the dead time of the electronics set-up. The theoretical yields were obtained by integrating the theoretical excitation functions along the path of the protons in the target as described by Alder et al. [23]. The reduced quandrupole transition probabilities, the B(E2)↑ were extracted from the comparison of experimental and theoretical yields. The compound nucleus contribution to $(p, p'\gamma)$ was computed theoretically using the code CINDY [28] and it was found that in the $(p, p'\gamma)$ reaction, the Coulomb part was maximum, and the compound less than one percent at the used proton energy. In order to find the B(E2)↑ values of 268.8 and 278.9 keV levels, the contributions of 268.6 and 278.7 keV gamma rays from the transitions 547.5 → 278.9 and 547.5 → 268.8 have been substracted from the 268.8 → 0 and the 278.9 → 0 transitions using the branching ratios from literature [27].

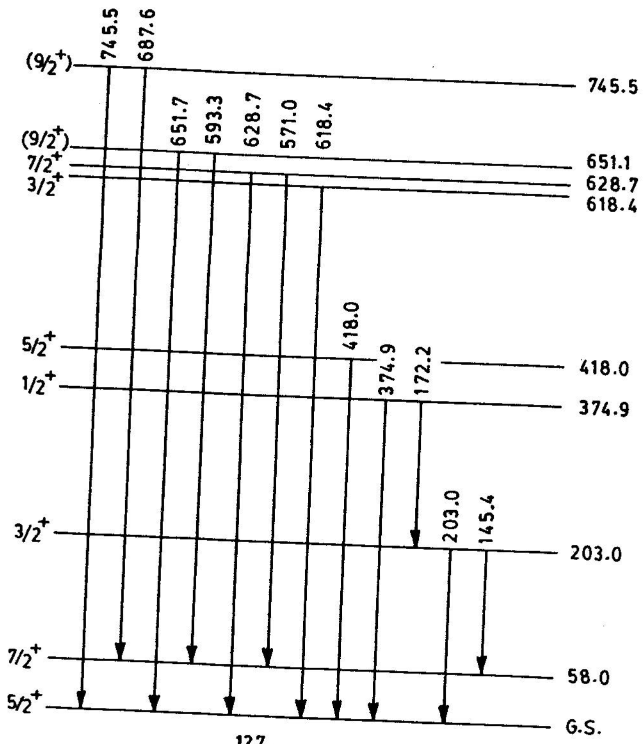

Fig. 3. Levels of ^{127}I excited in Coulomb excitation [26].

The B(E2)↑ values along with previously reported results for ^{127}I and ^{197}Au are presented in Tables I and II, respectively. The other electromagnetic properties of the excited states of these nuclei given in Tables III and IV, are determined using the multipole mixing ratios from literature [26, 27] and the present B(E2)↑ values.

The errors quoted for the (E2)↑ results arise from the uncertainty in the measurement of detector efficiency, peak area, charge collection and the stopping power of I and Au for protons.

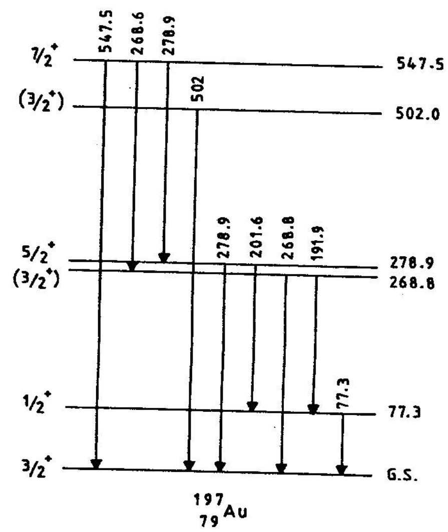

Fig. 4. Levels of ^{197}Au excited in Coulomb excitation [27].

Table I

B(E2) values for the levels in ^{127}I

Level (keV)	Measured B(E2)↑ $e^2 cm^4 \times 10^{-50}$				calculated B(E2)↑ $e^2 cm^4 \times 10^{-50}$	
	Present	Ref. [2]	Ref. [3]	Ref. [4]	Ref. [20]	Ref. [29]
203.0	4.41 ± 0.6	3.3 ± 0.5	4.3 ± 0.5	3.5 ± 0.5	0.87	2.87
374.9	3.0 ± 0.4	2.9 ± 0.4	2.7 ± 0.3	1.5 ± 0.2	1.71	11.4
418.0	0.54 ± 0.08	0.72 ± 0.11		6.1 ± 1.2	0.84	
618.4	0.23 ± 0.03		0.18 ± 0.04		0.89	
628.7	8.5 ± 1.2	8.7 ± 1.3	8.3 ± 1.2		7.63	
651.1	1.8 ± 0.3	2.35 ± 0.35	2.3 ± 0.3		0.02	
745.5	11.5 ± 1.5	13.50 ± 2.02	12.4 ± 1.3		7.75	

Table II

B(E2) values for the levels in ^{197}Au

Level Energy (keV)	Measured B(E2)↑ $e^2 cm^4 \times 10^{-50}$			
	Present	Ref. [8]	Ref. [11]	Ref. [5]
268.8	5.73 ± 0.41	8.29 ± 1.2	10.5	
278.9	21.8 ± 2.0	31.4 ± 1.8	36	22.5 ± 2.7
502.6	0.21 ± 0.05			
547.5	44.8 ± 2.2	44.7 ± 2.2	50.6	

Table III

Properties of the excited states of ^{127}I

Level Energy (keV)	J^π	B(E2)↑ $e^2 cm^4 \times 10^{-50}$	$\frac{B(E2)\uparrow}{B(E2)_{SP}}$	$\tau(E2)$
2030	$3/2^+$	6.61 ± 0.84	17.4 ± 2.5	3.4 ± 0.4 ns
374.9	$1/2^+$	9.0 ± 1.2	23.7 ± 3.2	47.6 ± 6.3 ps
418.0	$5/2^+$	0.54 ± 0.08	1.4 ± 0.2	1.2 ± 0.2 ns
618.4	$3/2^+$	0.35 ± 0.05	0.91 ± 0.13	257 ± 37 ps
628.7	$7/2^+$	6.38 ± 0.90	16.8 ± 2.4	12.2 ± 1.7 ps
651.1	$(9/2^+)$	1.08 ± 0.18	2.8 ± 0.5	2.3 ± 0.4 ps
745.5	$(9/2^+)$	6.9 ± 0.9	18.2 ± 2.4	4.0 ± 0.5 ps

Table IV

Properties of the excited states of ^{197}Au

Level Energy (keV)	J^π	B(E2)↓ $e^2 cm^4 \times 10^{-50}$	$\frac{B(E2)\downarrow}{B(E2)_{SP}}$	$\tau(E2)$
268.8	$3/2^+$	5.73 ± 0.41	8.4 ± 0.6	0.35 ± 0.04 ps
278.9	$5/2^+$	21.2 ± 1.3	31.1 ± 1.9	224 ± 21 ps
502.6	$(3/2^+)$*	0.21 ± 0.05	0.35 ± 0.08	1.2 ± 0.3 ns
547.5	$7/2^+$	22.35 ± 1.47	32.8 ± 2.2	6.8 ± 0.5 ps

* Ref. [18]

IV. DISCUSSION

The Coulomb excitation of ^{127}I and ^{197}Au nuclei is via the E2 mode, with the ground state J^π for these nuclei being $5/2^+$ and $3/2^+$, respectively. Hence the J^π for these nuclei being $5/2^+$ and $3/2^+$, respectively. Hence the J^π for all the excited states of ^{127}I are restricted to $1, 2^+, 3/2^+, 5/2^+, 7/2^+$ or $9/2^+$; while in the case of

Au^{197}, the levels should have the J^π as $1/2^+$, $3/2^+$, $5/2^+$ or $7/2^+$. The spins and parities shown in the second column of Tables III and IV are taken from literature [26, 27].

The reduced quadrupole transition probabilities for the excited states of both nuclei are in general agreement with the previously reported values [2—5, 8, 11]. However, the B(E2)↑ values for the 618.4 and 651.1 keV levels in ^{127}I slightly differ (within experimental errors) from those determined by Renwick et al. [3] and Ward et al. [2]. The comparison of the B(E2)↑ with single particle estimates shows that the levels at 203, 374.9, 628.7 and 745.5 keV are in nature more collective while the states at 418.0, 618.4 and 651.1 keV have a higher single particle contribution.

The experimental data of ^{127}I can be compared with the unified calculations of Rustgi et al. [20], since the other calculations are less comprehensive, either failing to take into account the mixing between single particle states or including only one single particle level. Rustgi et al. [20] have considered the odd proton to occupy the $2d_{5/2}$, $1g_{7/2}$ and $2d_{3/2}$ single particle levels and also considered up to three quadrupole phonons of vibration of the core. Kisslinger and Sorensen [29] have derived a completely different structure for the ^{127}I low lying levels. In their model, the enhanced E2 transition rates could result from a constructive interference between single particle states while the collective one is caused by the transitions with a change in the phonon number. In this region of non-deformed nuclei, the weak coupling model is more applicable. The results of Auble et al. [30] from a (3He, d) reaction indicate that the lowest two single particle states of ^{127}I, i.e. the $2d_{3/2}$ and $3s_{1/2}$, are centred in the vicinity of 1.2 to 2.5 MeV in excitation, that is, at about double the quadrupole phonon energy of the double even core. Hence the remaining positive parity states below one MeV should have a configuration of a phonon of quadrupole-vibration coupled to a proton in the $d_{5/2}$ or $g_{7/2}$ single particle levels. This is consistent with the fact that there states are weakly excited in the (3He, d) reaction [30]. By comparing the B(E2) of the transition $1/2^+ \to 5/2^+$ ($9.1 \pm 1.2 e^2 cm^4 \times 10^{-50}$) in ^{127}I, with the B(E2, $2_1^+ \to 0_1^+$) of the core (^{126}Te) ($= 10.6 \pm 0.7 e^2 cm^4 \times 10^{-50}$) shows that the lowest $1/2^+$ state possesses a particularly simple structure consisting predominantly of a phonon coupled to a $d_{5/2}$ proton. For the ^{127}I nucleus, the agreement with our B(E2) results (Table III) is within the experimental errors. This shows that the odd proton is relatively weakly coupled to the core.

The excited states of ^{197}Au are found to have comparable B(E2)↑ values with the previous results [5, 8, 11] except the level at 268.8 keV. R. P. Sharma et al. [11] have found the B(E2) for this level through internal conversion measurements using a poor detection system. This indirect measurement of B(E2) involves large uncertainties. The still higher value of B(E2) for the 268.8 keV level by McGowan et al. [8] is perhaps due to the use of the small Ge(Li) detector, which might have resulted in poor detection. In our case we have used a much bigger detector from which we excepted more reliable results. The level at 502 keV was obtained in the neutron inelastic scattering [15, 16] but we have extracted for the first time the B(E2)↑ values with a high contribution of single particle excitation. The other levels are highly collective in excitation.

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КУЛОНОВСКОЕ ВОЗБУЖДЕНИЕ НИЗКОЛЕЖАЩИХ УРОВНЕЙ В ЯДРАХ ^{127}I И ^{197}Au

В работе приведены результаты исследований кулоновского возбуждения низколежащих уровней ядер ^{127}I и ^{197}Au при помощи протонов с энергией 3,54—4,2 МэВ. На основе кулоновского возбуждения ядер и наблюдения соответствующих гамма-лучей при помощи германиевого (литиевого) детектора высокого разрешения измерены приведенные вероятности квадрупольных переходов состояний с энергиями 203; 374,9; 418; 618,4; 628,7; 651.1 и 745,5 кэВ в ядре ^{127}I и состояний с энергиями 268,8; 278,9; 502 и 547,5 кэВ в ядре ^{197}Au. Впервые использовались низкоэнергетические протоны для кулоновского возбуждения двух уровней с энергией 618,4 и 651,1 кэВ в ядре ^{127}I и одного уровня с энергией 502 кэВ в ядре ^{197}Au. Выявлено хорошее согласие полученных экспериментальных данных с существующими данными, за исключением значения B (E2) для уровня с энергией 268,8 кэВ в ядре ^{197}Au.