imply that electronic excitation makes no contribution to the total specific heat.

The compensation between $C_{p,\mathrm{r}}$ and $C_{p,\mathrm{f}}$ reported for helium [11] and nitrogen is also present for oxygen, when the ground state method is compared with the Griem's method utilized in reference [4].

However, when the Griem's method is compared with that of BURHON and WIENECKE [15], which has already been mentioned in connection with Fig. 8, compensation is present only below a pressure dependent temperature, as shown in Fig. 12. The large values of ΔE_0, corresponding to the Unsold's cutoff utilized by Burhon and Wienecke, are here responsible for the lack of compensation at higher temperatures.

Level Structure of ^{143}Pr from γ Decay

E. BASHANDY *

Nuclear Physics Department, Atomic Energy Establishment, Cairo — U.A.R.

(Z. Naturforsch. **26 a**, 683—689 [1971]; received 16 November 1970)

The γ decay of ^{143}Ce has been investigated using both a Ge(Li) γ ray and a high resolution iron free double focusing β-ray spectrometer. In addition to γ rays previously reported, more γ rays could be observed. Internal conversion coefficients and multipolarities of γ transitions were determined. Ten excited nuclear energy states have been established in ^{143}Pr at 57, 351, 491, 722, 939, 1045, 1061, 1161, 1382 and 1452 keV. Possible spin values have been assigned to all these states on the basis of conversion coefficients of γ rays. The level structure of ^{143}Pr is discussed in terms of existing nuclear models.

Introduction

The decay of ^{143}Ce has been studied earlier by several groups [1–6]. Recently, we have investigated [5] the excited levels in ^{143}Pr from the decay of 33 h ^{143}Ce. Energies and relative intensities of the internal and external conversion electron lines emitted in the decay were measured [5]. Over a relatively short period of time the number of reported γ rays emitted in de-excitation of ^{143}Pr has shown a continuing increase, owing to the improving methods of detection and resolution. The latest investigation by MEGLI et al. [6] established quite a number of energy levels for ^{143}Pr, several γ rays, however, could not be placed in their proposed decay scheme.

In the present investigation, a high resolution Ge(Li) detector and an iron free double focusing β-ray spectrometer have been used. The interest has been focused on search for new γ rays and on the multipolarity assignments, with emphasis on transitions in the ^{143}Ce decay. Measurements of several internal conversion coefficients are reported from which information on excited states of ^{143}Pr could be deduced.

1. Experimental Procedure

The level structure of ^{143}Pr was investigated through the study of energies and relative intensities of γ rays produced in the decay of ^{143}Ce.

The γ ray data in this experiment were recorded using a 2.5 cm^3 Ge(Li) detector having a system resolution (FWHM) of 2.0 keV for the 661 keV γ ray of ^{137}Cs. The detector was connected through low noise electronics to a 400 channel pulse-height analyser. The experimentally deduced relative efficiency correction curve for the germanium detector is estimated to be accurate to $\pm 3-5\%$. The energy calibration was carried out before and after each irradiation by using the following standard sources of well-known energies: ^{203}Hg (72, 147 and 279.16 keV); ^{51}Cr (320.10 keV); ^{22}Na (511.006 and 1274.52 keV); ^{137}Cs (661.595 keV); ^{54}Mn (834.84 keV); ^{88}Y (898.01 and 1836.13 keV); ^{65}Zn (1115.51 keV); ^{60}Co (1173.24 and 1332.48 keV).

* Present address: Department of Physics, Faculty of Engineering, P.O. Box 1098, Tripoli, Libya.

1 G. N. RAO and H. S. HANS, Nucl. Phys. **41**, 511 [1963].
2 K. P. GOPINATHAN, M. C. JOSHI, and E. A. S. SARMA, Phys. Rev. **136**, B 1247 [1964].
3 R. V. MANCUSO, J. P. ROALSVIG, and R. G. ARNS, Phys. Rev. **140**, B 525 [1965].
4 E. A. ARUTYUNYAN, B. S. DZHELEPOV, and YU. V. KHOLNOV, Izv. Akad. Nauk SSSR (ser. fiz.) **29**, 1127 [1965]; **30**, 1253 [1966].
5 E. BASHANDY, S. G. HANNA, and A. ABD-EL-HALIEM, J. Phys. Soc. Japan **22**, 960 [1967].
6 D. G. MEGLI, V. R. POTNIS, and C. E. MANDEVILLE, Nucl. Phys. A **107**, 117 [1968].

The internal conversion electron data were recorded by means of a high resolution iron-free double focusing β-ray spectrometer [7] ($\varrho_0 = 50$ cm). With this instrument, relative momentum measurements could be made with an accuracy of a few parts in 10^5. A resolution of about 0.15% is obtained when a 0.2×2 cm^2 source and a 2 mm detector slit were used. For high energy electrons it was necessary to use a momentum resolution up to $\sim 0.5\%$ in order to detect the weak internal conversion lines. The detector employed in the present studies was a G. M. counter with a ~ 2 mg/cm^2 mica end window.

Sources of ^{143}Ce (33 h) were prepared by irradiating samples of CeO_2, enriched to 90% ^{142}Ce, at a thermal neutron flux of approximately 2×10^{12} n/cm^2 sec.

For the internal conversion studies cerium oxide was uniformally sputtered on aluminum foil of thickness 0.7 mg/cm^2. The sputtered material was distributed in a rectangular form of dimensions 0.2×2 cm^2. The thickness of the material deposited was estimated to be ~ 100 μg/cm^2.

2. Measurements and Results

The γ-ray spectrum of ^{143}Ce is shown in Figs. 1, 2 and 3. The energies and intensities of all lines observed are in good agreement with the previous values obtained by ARUTYUNYAN et al. [4] and by MEGLI et al. [6]. The curves of Figs. 1, 2, and 3 are representative for many such spectra taken at different times as the sources decayed. Thus, it was possible to plot the area under each full energy peak as a function of the time elapsed since the cessation of irradiation. The decay curve for each full energy peak was a calculated "weighed least-squares fit". Extrapolation of this curve to zero time yielded the area under the full energy peak which was used in comparing intensities. Four such curves, each plotted over a time of three half-lives, were obtained for each full energy peak. From these four curves, a weighed mean relative intensity of each γ ray was calculated. The error in each such estimated relative intensity was taken to be twice the standard deviation of this weighed mean. The relative intensities of the γ rays were ultimately corrected for the presence of preabsorbers, full energy peak-to-total ratio and efficiency of the detectors as a function of energy. These data, relative intensities and associated errors, are shown in Table 1 with similar results of Refs. [4] and [6].

In our previous work [5], we reported precise conversion electron energies especially in the low energy range. However, in the intermediate and high energy range, where the β-background is high, the

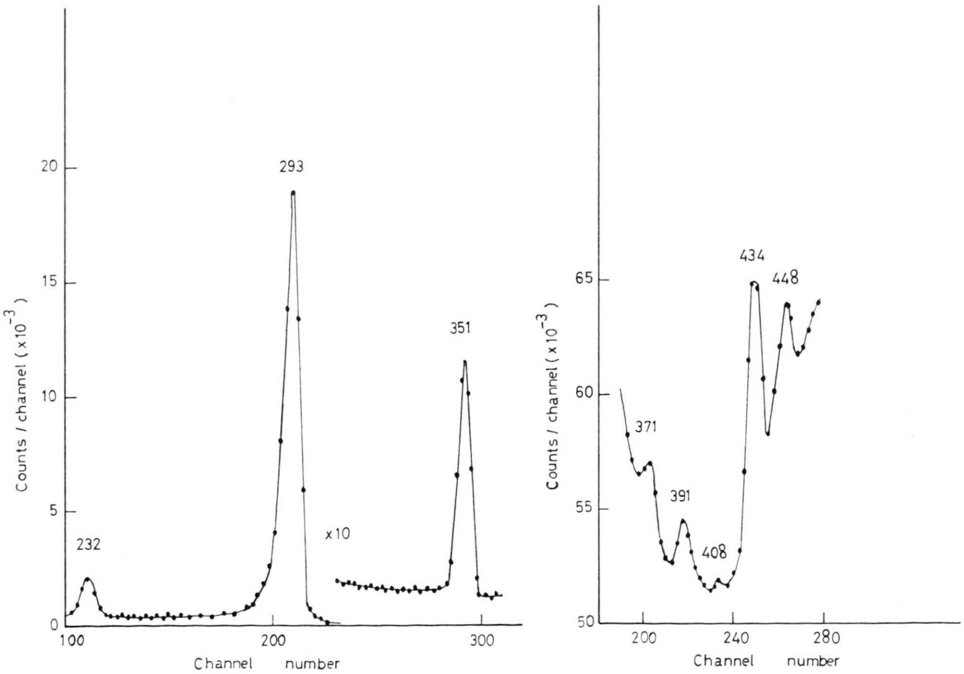

Fig. 1. γ-ray spectrum from ^{143}Ce measured with the Ge(Li) detector. The region between 232 and 450 keV.

[7] M. S. ELNESR and G. M. EL-SAYAD, Int. Rep. 2, U.A.R. A.E.E. 1965.

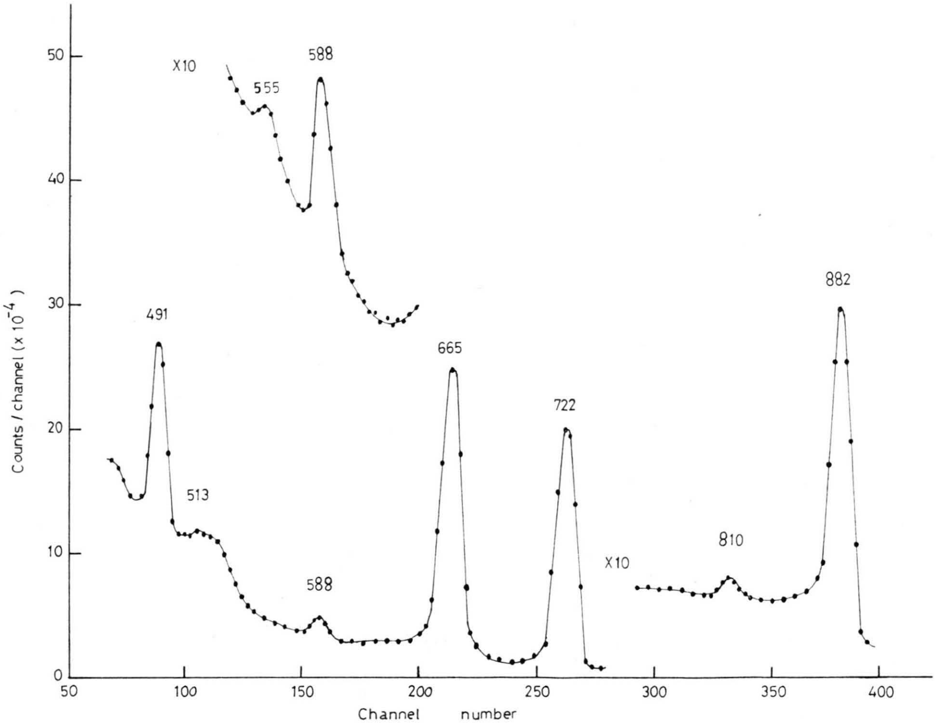

Fig. 2. γ-ray spectrum from ^{143}Ce measured with the Ge(Li) detector. The region between 490 and 882 keV.

conversion lines were very weak and it was difficult to determine them precisely. In this investigation the energy region from 200 – 1400 was searched for conversion lines. The momentum resolution of the spectrometer was varying between 0.2 and 0.5 percent depending on the accuracy required and the need to decrease the continuous β-ray spectrum as much as possible, in some energy regions, without spoiling the statistics. Possible source asymmetry was compensated for. Lines that were not fully resolved, were separated graphically making use of the known shape of a mono-energetic line. A large

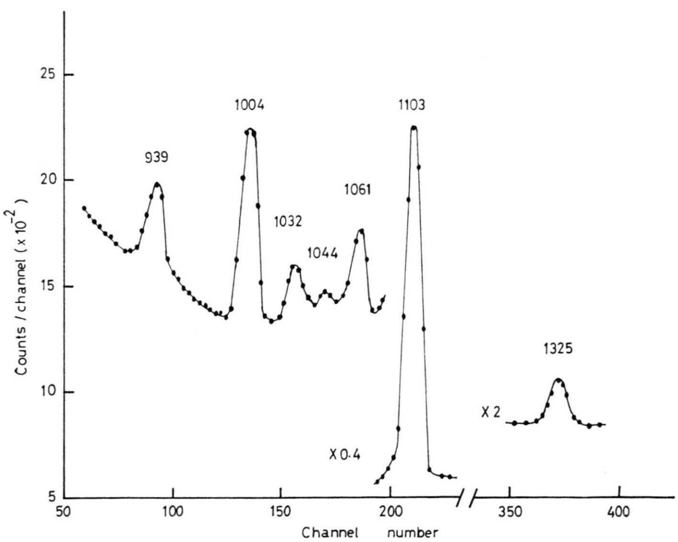

Fig. 3. Spectrum of hard γ-rays of ^{143}Ce.

Table 1. Energies and relative intensities of the gamma rays of ^{143}Ce. Energies are in keV. Relative intensities are included between parenthesis.

MEGLI et al.[6]	ARUTYUNYAN et al.[4]	Present results
57 (23.0 ± 1.00)	57 (22.0 ± 3.30)	57
		122
		141
		218 (0.15 ± 0.03)
233 (4.50 ± 0.10)	232 (5.10 ± 0.50)	232 (4.70 ± 0.20)
		291 (6.70 ± 0.70)
293 (100)	293 (100)	293 (100)
352 (7.80 ± 0.20)	351 (7.80 ± 0.80)	351 (7.70 ± 0.40)
371 (0.11 ± 0.04)	372 (0.06 ± 0.02)	371 (0.10 ± 0.05)
390 (0.11 ± 0.04)	392 (0.06 ± 0.02)	391 (0.10 ± 0.05)
		408 (0.03 ± 0.01)
435 (0.40 ± 0.10)	434 (0.40 ± 0.05)	434 (0.40 ± 0.10)
448 (0.23 ± 0.01)	448 (0.20 ± 0.03)	448 (0.20 ± 0.02)
490 (4.80 ± 0.20)	492 (5.10 ± 0.50)	491 (4.90 ± 0.40)
	500 (0.08 ± 0.02)	513 (0.09 ± 0.03)
555 (0.04 ± 0.02)	556 (0.06 ± 0.02)	555 (0.05 ± 0.02)
586 (0.68 ± 0.04)	587 (0.80 ± 0.09)	588 (0.73 ± 0.08)
665 (14.5 ± 0.40)	664 (14.9 ± 1.50)	665 (14.8 ± 0.80)
721 (13.4 ± 0.30)	721 (14.8 ± 1.50)	722 (14.0 ± 0.60)
	790 (0.04 ± p.03)	
	804 (0.09 ± 0.03)	
808 (0.08 ± 0.02)	808 (0.08 ± 0.03)	810 (0.07 ± 0.03)
880 (2.60 ± 0.40)	878 (2.80 ± 0.30)	882 (2.70 ± 0.40)
937 (0.06 ± 0.01)	936 (0.08 ± 0.01)	939 (0.07 ± 0.01)
1004 (0.16 ± 0.04)	1000 (0.20 ± 0.03)	1004 (0.18 ± 0.04)
1032 (0.05 ± 0.01)	1029 (0.07 ± 0.01)	1032 (0.06 ± 0.01)
	1044 (0.05 ± 0.01)	1044 (0.05 ± 0.01)
1061 (0.07 ± 0.02)	1058 (0.10 ± 0.02)	1061 (0.09 ± 0.02)
1102 (0.94 ± 0.04)	1102 (1.30 ± 0.20)	1103 (1.10 ± 0.06)
	1275 (0.01 ± 0.004)	
1325 (0.02 ± 0.01)	1325 (0.04 ± 0.01)	1325 (0.03 ± 0.01)

number of sufficiently isolated lines in the electron spectrum itself yielded the necessary information about the line shapes in the various energy regions. A typical example of the data taken during this investigation is displayed in Figs. 4 and 5. The observed conversion electron spectrum was carefully analysed, and several γ transitions are ascribed to the decay of ^{143}Ce. The low energy γ rays (57 keV, 122 keV, 141 keV, 218 keV, 291 keV, and 408 keV) were carefully confirmed, see Fig. 5, since they are difficult to observe in γ spectrum.

The intensities of the internal conversion lines were determined from the measured areas under the peaks, taken into consideration the corrections for the absorption in the mica counter end window as well as the corrections for the decay. In deducing the areas of partially resolved lines, it was found convenient to subtract the background and β continuum rates. The electron line intensities were determined from measurements relative to the K-conversion line of the 293 keV transition.

3. Internal Conversion Coefficients and Multipole Assignments

The multipolarities of low energy transitions were determined by comparing the measured K/L ratios

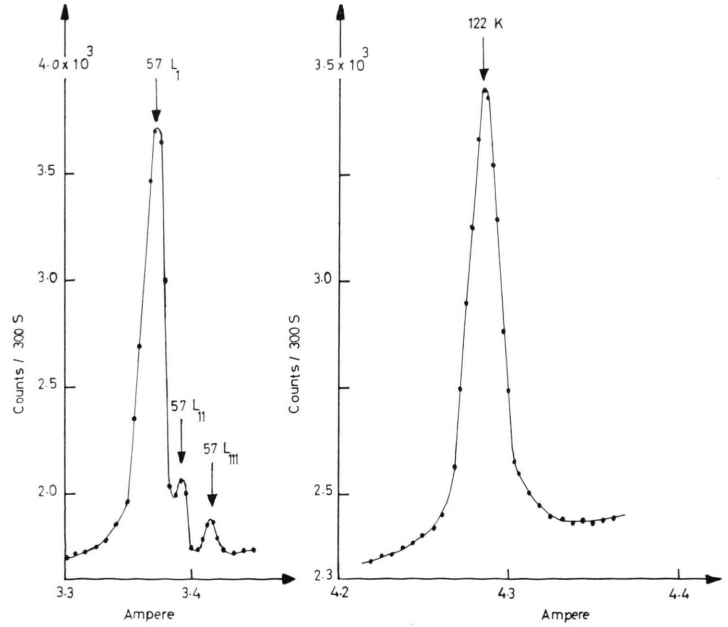

Fig. 4. The internal conversion lines of the 57 and 122 keV transitions in ^{143}Pr.

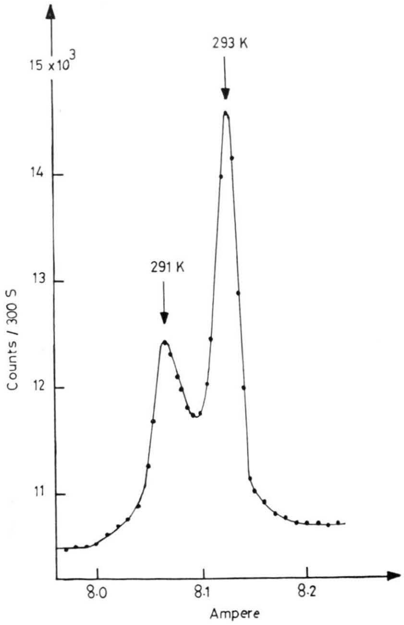

Fig. 5. The internal K-conversion lines of the 291 and 293 keV transitions in ^{143}Pr.

with the corresponding theoretical ratios derived by interpolation from the K and L shell conversion coefficients calculated by SLIV and BAND [8]. Therefore, the K/L ratio of the 57 keV γ ray proved [5] that the transition has a magnetic dipole character with a minor E2 admixture. While the K/L ratios of the 122 keV and the 141 keV transitions gave them a pure electric quadrupole character.

For γ rays of energies above 200 keV, for which the relative γ intensities have been measured, the multipolarities were determined from the comparison of absolute K-conversion coefficients with the theoretical ones as shown in Table 2.

In the electron conversion spectrum, the K-conversion lines of most γ rays have been observed and their relative intensities were obtained as mentioned in our previous work [5]. By means of the present photon intensities and conversion electron data, we have calculated the absolute K-conversion coefficients which are presented in Table 2. Normalization between the two series of data is obtained by assuming that the 351 keV transition is a pure E2 transition.

4. Discussion of Results

The decay scheme of ^{143}Ce has been investigated in detail, and several excited states have been confirmed. From the carefully studied internal conversion spectrum of γ transitions in ^{143}Pr, more γ rays could be observed and added to our previous [5] data. There is excellent agreement between the present results and the previous ones, see Table 1. The level scheme of ^{143}Pr is given in Fig. 6. The level energies shown are derived from a consideration of our results as well as those of earlier investigations.

The proposed level scheme of ^{143}Pr is based on the studies of β and γ transitions following the decay of ^{143}Ce and coincidence measurements. In order to obtain the properties of these levels, the multipolarities of the transitions feeding and deexciting them have to be determined. The recent measurement [9] of the ground state spin of ^{143}Ce shows it to be 3/2 −. The ground state of ^{143}Pr is assigned 7/2 +, as was discussed [10]. The low lying levels in ^{143}Pr have been fully discussed in our pre-

Table 2. Conversion coefficients and multipolarities of γ transitions in ^{143}Pr.

Transition energy [keV]	Experimental α_K	Theoretical α_K						Multi-polarity
		M 1	M 2	M 3	E 1	E 2	E 3	
218	0.121 ± 0.036	0.130	0.660	2.600	0.026	0.105	0.400	M 1
232	0.100 ± 0.013	0.110	0.560	2.200	0.022	0.096	0.340	M 1 + E 2
291	0.013 ± 0.0014	0.058	0.248	0.904	0.012	0.045	0.146	E 1
293	0.052 ± 0.004	0.058	0.220	0.860	0.012	0.044	0.140	M 1 + E 2
351	0.024 ± 0.003	0.040	0.140	0.520	0.0076	0.025	0.086	E 2
371	0.033 ± 0.005	0.034	0.120	0.440	0.0068	0.022	0.074	M 1
391	0.005 ± 0.001	0.030	0.100	0.340	0.0060	0.020	0.063	E 1
408	0.005 ± 0.0008	0.027	0.085	0.280	0.0053	0.017	0.052	E 1
434	0.020 ± 0.004	0.023	0.066	0.215	0.0046	0.014	0.044	M 1
448	0.012 ± 0.005	0.021	0.063	0.190	0.0043	0.013	0.038	E 2
491	0.016 ± 0.003	0.017	0.050	0.140	0.0035	0.0098	0.028	M 1 + E 2
513	0.0027 ± 0.0005	0.015	0.043	0.120	0.0033	0.0094	0.026	E 1
555	0.010 ± 0.006	0.014	0.040	0.110	0.0030	0.0085	0.024	M 1 + E 2
588	0.008 ± 0.0009	0.011	0.030	0.080	0.0025	0.0066	0.018	M 1 + E 2
665	0.006 ± 0.0008	0.0078	0.020	0.051	0.0019	0.0047	0.012	M 1 + E 2
722	0.0063 ± 0.0006	0.0065	0.016	0.041	0.0016	0.0038	0.010	M 1
810	0.0042 ± 0.0005	0.0047	0.011	0.026	0.0012	0.0028	0.0062	M 1 + E 2
882	0.004 ± 0.0008	0.0040	0.0094	0.021	0.00104	0.0025	0.0055	M 1
939	0.0018 ± 0.0007	0.0034	0.0080	0.018	0.0009	0.0021	0.0047	E 2
1004	0.0027 ± 0.0006	0.0029	0.0070	0.0148	0.00078	0.0019	0.0041	M 1 + E 2
1032	0.0029 ± 0.0006	0.0028	0.0066	0.0135	0.00074	0.0018	0.0039	M 1
1044	0.0022 ± 0.0005	0.0026	0.0063	0.0127	0.0007	0.0017	0.0036	M 1 + E 2
1061	0.002 ± 0.0005	0.0025	0.0060	0.0120	0.0007	0.0016	0.0034	M 1 + E 2
1103	0.0018 ± 0.0004	0.0023	0.0056	0.0110	0.0007	0.0015	0.0030	M 1 + E 2

[8] L. A. SLIV and I. M. BAND, α-, β- and γ-ray, Appendix 5 (ed. by K. SIEGBAHN), North-Holland Publ. Co., Amsterdam 1965.

[9] I. MALEH, Phys. Rev. **138**, B 766 [1965].

[10] B. BUDICK, I. MALEH, and R. MARRUS, Phys. Rev. **135**, B 1281 [1964].

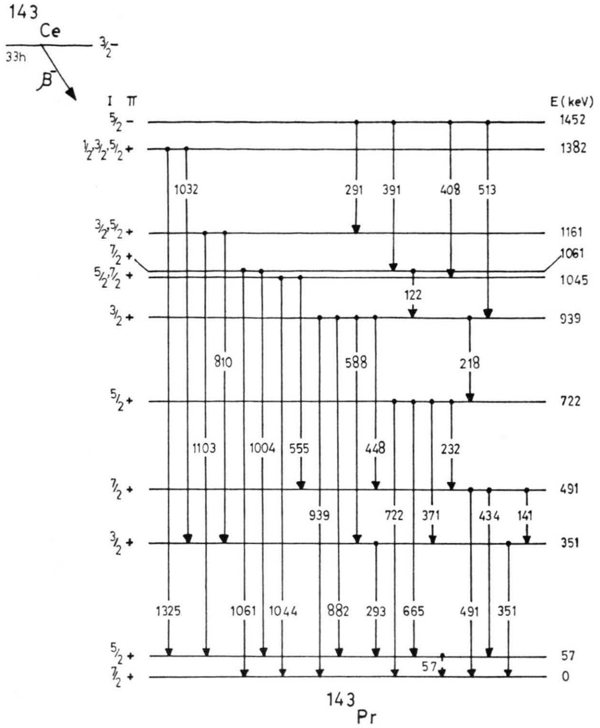

Fig. 6. Energy levels of ^{143}Pr.

vious[5] work. Also MEGLI et al.[6] have proved from their β-γ coincidence measurements that the first excited state of ^{143}Pr lies at 57 keV, the second at 351 keV, the third at 491 keV and the fourth at 722 keV. From the $\log(ft)$ value and the multipolarities of γ rays feeding and de-exciting these levels the spin and parity assignments are suggested to be $5/2+$, $3/2+$, $7/2+$, and $5/2+$ respectively.

The fifth excited state of ^{143}Pr is established at 939 keV according to γ rays measurements. From the present investigation it is proved that the 939 keV level is fed by two new γ rays of energies 122 keV and 513 keV from the 1061 and 1452 keV levels, respectively. The possible spin values $3/2+$ and $5/2+$ for the 939 keV level agree with the experimental coefficients of angular correlation for the $588-293$ keV cascade. The $3/2+$ assignment, however, is compatible with the multipolarities of γ rays feeding and de-exciting the 939 keV level.

A new level at 1045 keV is suggested which is fed by the 408 keV γ ray from the 1452 keV excited level. The decay of the 1045 keV level to the ground state is observed in our measurements as well as in ARUTYUNYAN et al.[4] work. A γ ray of energy 555 keV is also observed in all measurements, it could not, however, be placed in the decay scheme. The 555 keV γ rays is found to fit energetically between the 1045 and the 491 keV levels. For the 1045 keV level, $5/2+$ is suggested, but $7/2+$ can not be excluded.

The appearance of γ rays of energies 1061 and 1004 keV is interpreted as evidence for the presence of a seventh state in ^{143}Pr at 1061 keV. The 1061 keV level is confirmed in our present investigation due to the existence of the 391 keV γ ray exciting and the 122 keV γ ray de-exciting this level, see Fig. 6. The 391 keV γ ray was detected by MEGLI et al.[6] as well as by ARUTYUNYAN et al.[4], it was not, however, located in the decay scheme of ^{143}Pr. From the K/L conversion ratio of the 122 keV γ ray, it was found[5] that it is a pure E2 transition. The 1004 keV and the 1061 keV transitions de-exciting the 1061 keV level were found to have a dipole magnetic character with a small electric quadrupole admixture. The multipolarity assignments of γ rays feeding and de-exciting the 1061 keV level suggest it's spin and parity $7/2+$.

To explain the presence of the 1161 keV level, it is necessary to refer to the γ-γ coincidence data[6]. The 1103 keV γ ray was seen to be coincident with the 57 keV γ ray. The presence of the 1161 keV level is also consistent with the β-γ coincidence data of Ref.[6]. The 1161 keV level decays to the first excited state by the 1103 keV transition and to the second excited state by the 810 keV transition. A direct transition from the 1161 keV level to the ground state was sought for, but no γ ray could be observed. In addition to the β transition feeding the 1161 keV excited level, a new γ ray was found feeding it with an energy of 291 keV. This γ ray was detected in our previous work as well as in the present investigation as seen in Fig. 5. The spin of the 1161 keV level was supposed[6] to be either $3/2+$ or $5/2+$ from the $\log(ft)$ value of 7.0 for the β transition to this level and the observed γ transitions from this level.

An excited state of ^{143}Pr has been placed at an energy of 1382 keV, because γ rays at 1325 and 1032 keV appear in the spectrum, differing in energy by 293 keV. Since the 1382 keV excited state is fed[6] by first-forbidden β spectra and no 1382 keV γ ray is present with observable intensity, possible values of the spin-parity would be $1/2+$, $3/2+$, $5/2+$ or $7/2+$, the multipolarity of the 1032 keV γ ray, however, excluding the $7/2+$ assignment.

The level at 1452 keV is proposed according to the appearence of γ rays of energies 291, 391, 408, and 513 keV in our measurements. The 391 and 513 keV γ rays have been observed [4, 6] before, but they could not be placed in the ^{143}Pr decay scheme. The electric dipole nature of the transitions de-exciting the 1452 keV level indicate a negative parity and a probable spin 5/2 of this level.

^{143}Pr with 59 protons is considered a nearly spherical nucleus with the ^{142}Ce even-even core susceptible for quadrupole vibrations. Since the excited states of the even-even ^{142}Ce show vibrational character, the low lying energy levels of ^{143}Pr could be explained [11] as due to the coupling of the odd proton with its available single-particle states $g_{7/2}$ and $d_{5/2}$ to the quadrupole vibrations of the even-even core. One can expect various levels in the low energy region with spins $1/2+$ to $11/2+$. In other words, a collective character of excitation was to be expected in the energy spectrum of ^{143}Pr. KISSLINGER and SORENSEN [12] have predicted several states with these spins in this energy region. However, as they pointed out, their method may not give accurate results when even a few neutrons are added to the 82 neutron shell because of the approaching deformed region.

[11] A. DE SHALIT, Phys. Rev. **122**, 1530 [1961].

[12] L. S. KISSLINGER and R. A. SORENSEN, Rev. Mod. Phys. **35**, 853 [1963].

Streumessungen am System LiCs und das Singulett-Potential dieses Moleküls

H. KANES und H. PAULY

Max-Planck-Institut für Strömungsforschung, Göttingen

und E. VIETZKE *

Physikalisches Institut der Universität Freiburg

(Z. Naturforsch. **26 a**, 689—692 [1971]; eingegangen am 20. Januar 1971)

Total scattering Cross Section Measurements for LiCs and the Singlet Potential of this Molecule

The velocity dependence of the total collision cross section has been measured for the system LiCs in the energy range from 15—1000 eV. Using the observed glory undulation together with spectroscopic data a potential for the singlet ground state of LiCs is proposed.

I. Einleitung

In vorausgegangenen Arbeiten [1, 2] wurde die Geschwindigkeitsabhängigkeit des totalen Streuquerschnitts für das Stoßpaar NaCs gemessen. Hieraus wurde unter Mitverwendung spektroskopischer Daten und theoretischer Überlegungen das Potential für den Singulettzustand dieses Systems angegeben [3]. In der vorliegenden Arbeit werden analoge Messungen am Stoßpaar LiCs mitgeteilt und das Potential für den Singulettzustand dieses Systems in entsprechender Weise bestimmt.

II. Apparatur und Meßergebnisse

In der Meßanordnung, deren Einzelheiten in vorausgegangenen Arbeiten [2, 4] beschrieben sind, wird durch Umladung eines Ionenstrahls ein schneller Alkaliatomstrahl erzeugt [5]. Dieser Strahl kreuzt einen thermischen Alkaliatomstrahl und wird anschließend durch Oberflächenionisation nachgewiesen [6]. Durch eine magnetisch betätigte Blende kann der Targetstrahl an- und abgeschaltet werden, so daß die ungestreute Intensität I_0 und die abgeschwächte Intensität I des Primärstrahls in rascher Folge gemessen werden können. Aus diesen Intensitäten wird durch ein Analogrechensystem direkt der totale Streuquerschnitt gebildet. Einzelheiten des

Sonderdruckanforderungen an Dr. H. PAULY, Max-Planck-Institut für Strömungsforschung, Abt. Molekularstrahlen I, *D-3400 Göttingen*, Böttingerstr. 6/8.

* Jetzt: Center of Research in Experimental Space Science, Cress York University, Toronto (Kanada).

[1] W. NEUMANN u. H. PAULY, Phys. Letters **20**, 357 [1968].

[2] W. NEUMANN u. H. PAULY, J. Chem. Phys. **52**, 254 [1970].

[3] CH. SCHLIER u. E. VIEZKE, Chem. Phys. Letters **3**, 250 [1969].

[4] M. HOLLSTEIN u. H. PAULY, Z. Phys. **201**, 10 [1967].

[5] Die Geometrie der Meßanordnung und damit das Auflösungsvermögen ist dasselbe wie bei den in der vorausgegangenen Aubeit [2] beschriebenen Messungen am System LiHg.

[6] M. HOLLSTEIN u. H. PAULY, Z. Phys. **196**, 353 [1966].