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THE STUDY OF THE GAMMA RAYS FROM ^{226}Ra AND ITS DERIVATIVES BELOW 1 MeV

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ABSTRACT

In this study, by using a particular spectrometer and a Ge(Li) detector with high resolution, gamma rays from ^{226}Ra and its derivatives below 1 MeV were analysed. In this energy region, in addition to the data present in the literature, 51 new transitions were determined. The energies and intensities of these gammas were measured and compared with the former data. Precision of the energy measurement is approximately 0.11 keV, and deviation of the intensity measurement is about 8 %.

ÖZET

Türevleriyle dengede bulunan radyumun 1 MeV'in altındaki enerji bölgesi gama spektrumu (özel bir spektrometrede) ayırma gücü yüksek bir Ge(Li) detektörü kullanılarak yeniden ele alındı. Sonuçlar literatür verilerine ek olarak bu bölgede 51 yeni geçişin varlığını göstermektedir. Deneylerde enerji ölçümünde şiddetli gamalar için hata sınırı 0.11 keV civarında belirlendi. Gama şiddetlerinin ölçümündeki sapma ise en az % 8 olarak saptandı.

INTRODUCTION

Gamma rays emitted from radium, in equilibrium with its derivatives, are the important sources of information dealing with ^{214}Po and ^{210}Pb.

If the counting is taken over some period of time enough to see the gamma transitions unobserved until now, the new information about the de-excitation schemes of ^{214}Bi, ^{214}Po and ^{210}Pb will be obtained.

In this work, gamma spectrum of ^{226}Ra and its derivatives was examined carefully in the region below 1 MeV where is highly complex, by paying attention to β^-

disintegration of ^{214}Pb to ^{214}Bi ($Q_{\beta} = 1024$ keV) /1/. Analyses of β^- disintegrations of ^{214}Bi to ^{214}Po and those of ^{210}Tl to ^{210}Pb will be investigated in an another study.

MATERIAL AND METHOD

A source of ^{226}Ra in equilibrium with its derivatives, prepared by Amersham Radiochemical Centre in the year 1966, had been measured for three months by using a Ge(Li) detector, GETAC, that has efficiency of % 23, at 1332 keV resolution of 2.00 keV, and the Peak/Compton ratio of 44(Fig. 1.). The source was placed at a distance of 2.5 m from detector, that is shielded by lead with thickness of 5 cm for protection from environmental radiation. The detector was connected to the preamplifier, Canberra 2001 and 2010, and multichannel analyzer, Hewlett-Packard 5401 -B. Spectrum between 0 and 1 MeV was accumulated at the first 4096 channels, and the other 4096 channels were used for the checks made twice a week.

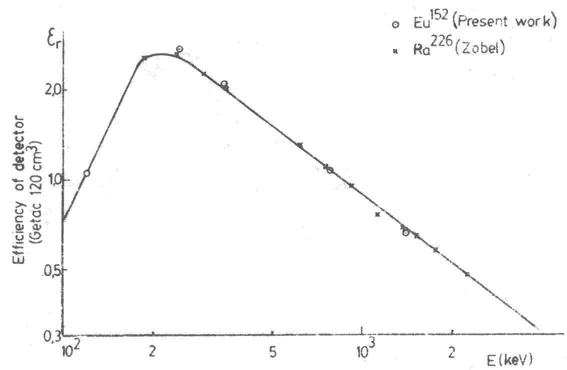

Fig. 1. Efficiency of the Ge(Li) detector (GETAC 120 cm^3, direct spectrometer).

Comparison of the spectra obtained with and without an absorbent permitted to distinguish between the peaks of the gamma rays and the escape peaks of the gamma rays with high energy. Calibration of energy was made by using two gamma rays of energy 295.13 ± 0.008 and 1120.289 ± 0.010 keV given by Zobel /2/. Energy values are calculated by using following relation: $E = 0.28879\ C - 1185.486$, Fig.2. shows that the correction for the non-linearity is lower than 0.1 keV.

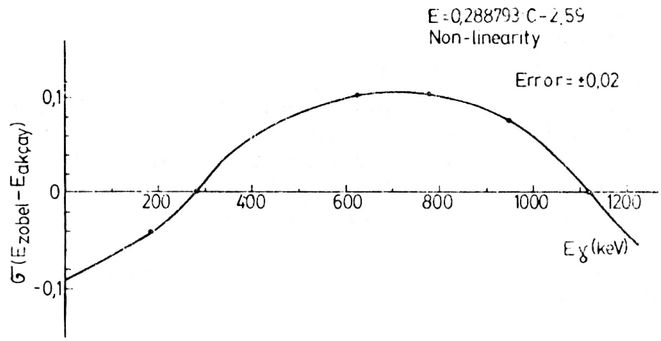

Fig. 2. Variation of the energy with the correction of non linearity.

The analysis of such complex spectrum requires the knowledge of heights of escape peaks as well as their exact positions. The heights of those, for the detector and geometrical conditions used, could be predicted by using the curves which give variations of the energy with the ratios of photoelectric peak to those which are single escape, double escape, Compton scattering and backscattering peaks (Fig. 3.). Since measurement in region above 1 MeV was not made in the present study, intensity values of escape peaks for gamma rays between 1 MeV and 2.3 MeV were taken from the literature /2,3/. To do this, following relation,

$$h(\text{peak height}) = \frac{I(\text{intensity}) \times \varepsilon(\text{efficiency})}{\text{FWHM}(\text{full width at half maximum})}$$

and curves that give relations between E and ε and also E and FWHM were used.

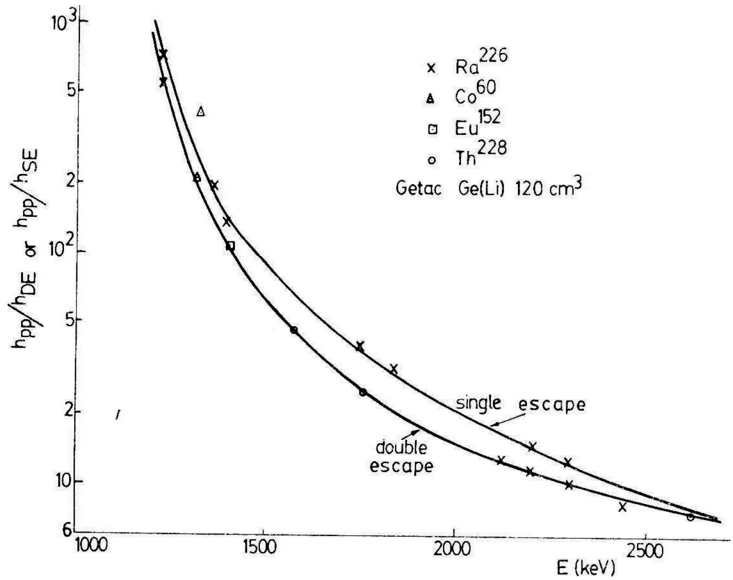

Fig. 3. **Variation of the ratios h (photopeak/h (double escape) and h (photopeak) / h (single escape) with the gamma energy values.**

RESULTS AND DISCUSSION

Table-2 shows the relative energy and intensity values, newly obtained in this study, of the gamma rays. The error in the energy calculation includes following components: the error reference due to peaks 295 and 1120 keV (~0.01 keV), the error of fitting (~0.02 keV), the error of superposition of the standard and experimental peaks (~0.02 keV), the error of correction for non-linearity (~0.04 keV). The error in the energy values of the principal rays is 0.11 keV. The relative intensities of these gamma rays are given by normalizing them such that of the gamma ray of energy 609.21 keV is set equal to 100. The error in the determination of the intensity is 8 % for the intense simple rays, and includes following components: the error due to statistical fluctuations, the error due to plotting the curve, the error present in the function E (FWHM), the error in the efficiency, and above all, the error due to the manual graphical analysis, therefore, it must be determined after every plotting.

Because of the complexity of the spectra, it does need the delicate decompositions for some peaks; nevertheless, this gives rise to great errors. Table-1 compares the most intense gamma rays of the present study with those of Zobel /2/ and Hachem /3-5/. When the agreement between our results and those of Zobel (deviation lower than 4 %) is considered, the results of Hachem show a systematic difference (deviation 7 through 19 %). By using the results of Mouze /6/ it is concluded that there is disagreement between Zobel and Hachem below the energy 1238 keV.

TABLE-1. Comparison of intensities of the principal gamma rays from ^{214}Bi.

E (keV)	Iγ Ref /2/	Iγ Ref /7/	Iγ Present work(PW)	Iγ/2/ / Iγ/PW/	Iγ/2/ / Iγ/7/	Iγ/PW/ / Iγ/7/
186,27±0,14	70± 9	83,6± 0,9	86,2± 6,4	0,81	0,84	1,03
242 ±0,20	141± 14	149,1± 1,7	149,3± 14,7	0,94	0,95	1,00
295,21±0,11	325± 32	390,1± 3,9	399,5± 31,1	0,81	0,83	1,02
351,97±0,14	695± 70	746,7± 7,5	777,0± 63,1	0,89	0,93	1,04
609,31±0,11	808±(80)	928,5±(8,5)	928,5±(73,3)	0,87	0,90	1,00
768,35±0,14	92± 10	101,2± 1,3	102,1± 9,0	0,83	0,91	1,01
934,05±0,11	59± 6	64,3± 0,9	65,0± 6,7	0,91	0,92	1,01
1120,29±0,17	275± 28	303,8± 3,6	305,9± 25,1	0,90	0,91	1,01

It is difficult to decide, without doing chemical separations and γ-γ or x-γ coincidence measurements for all the family, that to which element a gamma belongs. However, when the branching and the origin of different energy levels in the family are considered, the major part of the gamma rays from ^{226}Ra and its derivatives corresponds to the deexcitation of ^{214}Bi and ^{214}Po. Thus, principal question is to distinguish between gamma rays from ^{214}Pb. In order to solve this problem, there are such possibilities: the study of the gamma rays above 1 MeV for this family, which is made by Mouze /6/, brought to light the existence of the new energy levels for ^{214}Po; values of these are 2604.7, 2869.7, 2880.1, 2928.8 and 3014.4 keV. Moreover, they were confirmed by coincidence measurements. Each of coincidence energies, that corresponds to the differences between energy levels of ^{214}Po, indicates that those gammas belong to ^{214}Po. New gammas cited in Table-2 are related to this type. On the other hand, the measurement of gamma rays from lead and bismuth fractions, that were chemically separated from the family by Lingemann et al. /7/, support this attributions. Gamma intensities observed in the fractions of lead and bismuth are lower than 2 % of the intensity of 609.21 keV gamma ray.

TABLE-2. Energy and intensity values of the gamma rays from ^{226}Ra and its derivatives, except for known literature data (reference $I_{609,21}$=100). Gammas belong to ^{214}Po.

Energy (keV)	Intensity (I)	Interpretation	Energy (keV)	Intensity (I)	Interpretation
95.00±0.14	0.33 ±0.03	2922.0 → 2827.1	575.09±0.14	0.021±0.002	2113.7 → 1543.4
100.31±0.14	0.17 ±0.01	2293.4 → 2192.8	576.12±0.14	0.021±0.002	2694.7 → 2118.7
102.90±0.14	0.092±0.007	1377.8 → 1275.0	646.80±0.11	0.012±0.001	2940.6 → 2293.4
156.82±0.11	0.14 ±0.01	2662.4 → 2505.4	658.70±0.11	0.052±0.004	?
160.65±0.11	0.023±0.002	2017.3 → 18.47.7	677.53±0.14	0.009±0.0008	2694.7 → 2017.3
170.95±0.17	0.016±0.01	2940.6 → 2770.1	700.98±0.11	0.049±0.004	2694.7 → 19.94.8
213.89±0.17	0.017±0.01	3000.1 → 2786.0	704.63±0.17	0.118±0.009	2699.2 → 1994.8
220.63±0.17	0.017±0.01	2728.9 → 2507.7	744.83±0.11	0.053±0.004	2508.7 → 1764.7
221.66±0.20	0.014±0.01	2940.6 → 2719.4	746.44±0.14	0.018±0.002	2940.6 → 2192.8
252.65±0.17	0.033±0.002	2017.3 → 1764.7	775.68±0.11	0.011±0.009	2505.4 → 1729.8
254.49±0.17	0.020±0.001	2447.4 → 2192.8	780.66±0.14	0.018±0.002	2545.1 → 1764.7
268.65±0.11	0.032±0.002	1543.4 → 1275.0	788.51±0.17	0.052±0.004	2204.4 → 1415.7
281.87±0.17	0.035±0.002	2827.1 → 2545.1	798.04±0.14	0.02 ±0.002	3064.5 → 2266.4
308.28±0.17	0.055±0.005	2662.4 → 2354.0	846.13±0.14	0.026±0.002	3269.7 → 2433.2
419.26±0.11	0.016±0.001	2266.7 → 1847.7	849.98±0.11	0.020±0.001	3054.2 → 2204.4
435.28±0.11	0.009±0.001	2940.6 → 2505.4	872.89±0.14	0.051±0.004	3082.0 → 2208.7
436.75±0.14	0.011±0.009	2747.7 → 2011.0	877.89±0.17	0.024±0.002	2293.4 → 1415.7
439.53±0.14	0.029±0.002	2204.4 → 1764.7	880.40±0.11	0.021±0.002	2770.1 → 1890.2
451.26±0.14	0.009±0.001	1994.8 → 1543.4	911.14±0.17	0.012±0.001	2922.0 → 2011.0
452.88±0.14	0.068±0.005	2447.7 → 19.94.8	917.70±0.11	0.010±0.008	2928.8 → 2011.0
460.94±0.17	0.065±0.005	2204.4 → 1743.2	929.37±0.14	0.072±0.006	2204.4 → 1275
463.51±0.11	0.009±0.001	2192.8 → 1729.8	938.59±0.11	0.032±0.003	2786.0 → 1847.7
467.39±0.14	0.023±0.002	2011.0 → 1543.4	949.90±0.11	0.016±0.001	3142.8 → 2192.8
496.87±0.11	0.015±0.001	2979.0 → 2482.6	961.59±0.11	0.045±0.004	2979.0 → 2017.3
528.37±0.14	0.031±0.002	2293.4 → 1764.7	991.79±0.14	0.015±0.001	2266.7 → 1276.0
531.33±0.17	0.014±0.001	2979.0 → 2447.7			

However, the knowledge of gamma rays from these fractions has a great advantage. In Table-3, energy and intensity values of gamma rays from ^{214}Bi given by Lingemann /7/ are compared with the results of Nuclear Data Sheets /8/ and of ours. In respect to this table, following points are remarkable: in the present work, gamma rays of 137.45 and 141.3 keV were not determined. The latter overlaps the peak which is the wide backscatter of the Compton edge belonging to 295.21 keV gamma ray. The intensities of the gamma rays from ^{214}Bi are in good agreement with the results of Lingemann, except for 839.00, 258.96 and 274.76 keV gamma rays. It is probable that Lingemann had mistaken for the different value of 839 keV gamma ray due to the summing effect. Our conclusion is confirmed by the measurement recently realised by Ythier and Pravikoff /9/. The other two differences between the gamma intensity values cannot be explained. In Table-3, for 487.31 and 544 keV gamma rays, disagreement between the values of gamma intensities obtained in this work and those given in Nuclear Data Sheets /8/ can be seen. For the first gamma ray, in NDS, all the intensities are ascribed to it with great probability, but Lingemann points out that there is a complex peak in this energy region, and in the present work it is determined that there are two gamma peaks of energy 486.45 and 487.31 keV in the region mentioned. For the second one, it appears that Ref. /8/ did not pay attention to the data of Lingemann. Although Fig. 2B in Ref. /7/ indicates that there is a gamma at 775 keV, this is 775.68 keV gamma present in this study.

By means of the knowledge of gammas in lead and bismuth fractions, it is shown that some of the new gamma sources in the region from 839.0 to 1024 keV (Q_β of ^{214}Bi) in the spectrum may belong to ^{214}Bi.

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TABLE-3. Comparison of the intensities of the gamma rays from ^{214}Bi.

Eγ(keV) Present work	Eγ(keV) Lingeman /7/	Iγ(*) Present work	Iγ(*) Lingeman /7/	Iγ(*) N.D.S. /8/	Commentary on Iγ
	137.45±0.3	0.03	0.14	0.09	
	141.3 ±0.3	0.03	0.09	0.09	
196.31±0.14	196.3 ±0.5	0.14 ±0.01	0.12 ±0.05	0.11 ±0.04	
242.00±0.20	(241.92)	16.08 ±0.60	17.76 ±1.87	16.18 ±1.90	
258.96±0.11	258.82±0.10	1.20 ±0.12	1.87 ±0.47	1.19 ±0.04	disagreement with ref.7;see text
274.76±0.14	274.80±0.10	0.57 ±0.06	1.64 ±0.47	0.70 ±0.11	idem
295.21±0.11	(295.22)	43.03 ±3.36	44.16 ±4.67	41.58 ±0.64	
305.35±0.30	305.4 ±0.5	0.096±0.025	0.07 ±0.02	0.05 ±0.03	may be contribution from
314.41±0.11	314.2 ±0.4	0.18 ±0.02	0.19 ±0.05	0.17 ±0.04	3000.1 → 2694.7
323.79±0.14	324.3 ±0.5	0.073±0.011	0.05 ±0.02	0.04 ±0.02	may be contribution from
351.97±0.14	(351.99)	83.69 ±6.80	84.81	80.38 ±0.85	2088.4 → 1764.6
461.97±0.17	462.1 ±0.2	0.45 ±0.04	0.40 ±0.07	0.36 ±0.06	may be contribution from
469.85±0.14	470.0 ±0.3	0.31 ±0.04	0.023±0.012	0.02 ±0.01	2728.9 → 2266.7
480.53±0.14	480.50±0.20	0.73 ±0.08	0.79 ±0.07	0.73 ±0.04	
487.31±0.17	487.25±0.20	0.80 ±0.08	0.77 ±0.07	0.95 ±0.03	disagreement with ref.1; see text
(* *)	511.00±0.04	(* *)	0.07 ±0.02	0.07 ±0.02	
533.73±0.14	533.80±0.20	0.42 ±0.04	0.40 ±0.05	0.41 ±0.03	
538.50±0.17	538.7 ±0.4	0.038±0.007	0.012	0.011	
543.92±0.17	544.0 ±0.3	0.12 ±0.01	0.14 ±0.05	0.05 ±0.02	disagreement with ref.1, see text
580.08±0.11	580.30±0.20	0.83 ±0.09	0.84 ±0.09	0.79 ±0.03	
766.10±0.15	766.0 ±0.4	0.28 ±0.05	0.10 ±0.05	0.17 ±0.04	
785.91±0.17	785.95±0.20	2.38 ±0.20	2.01 ±0.21	2.37 ±0.06	
839.00±0.17	839.20±0.20	1.05 ±0.12	1.38 ±0.14	1.27 ±0.05	disagreement with ref.7, see text

(*) Intensities were reported by referring $I_{609.21} = 100$

(**) In this work, the peak of energy 511 keV (annihilation) was not analyzed.

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