Applying, in the usual way,[2] the hypothesis of isotopic invariance, we obtain for the cross sections of processes (a) and (b) the following expressions:

$$\sigma_a = \tfrac{1}{2}\,|A_1^1|^2, \quad \sigma_b = |A_0^1|^2 + \tfrac{1}{2}\,|A_1^1|^2, \tag{2}$$

where A_t^T is the amplitude for the transition into a final state with total isotopic spin T, while the isotopic spin of the two-nucleon system is equal to t (= 0, 1). From this we only get an unequality for the cross sections:

$$\sigma_b \geqslant \sigma_a. \tag{3}$$

In reference 1 the interaction of the $\tilde{\Sigma}^+$ anti-hyperon with deuterium was discussed. The $\tilde{\Sigma}^+$ anti-hyperon has negative charge, and is thus slowed down by ionization losses. After coming to rest, it is absorbed. The following reactions take place:

$$\begin{aligned} \tilde{\Sigma}^+ + d &\rightarrow n + \pi^- + K^+, && \text{(a)} \\ &\rightarrow n + \pi^0 + K^0, && \text{(b)} \\ &\rightarrow p + \pi^- + K^0. && \text{(c)} \end{aligned} \tag{4}$$

We investigate these reactions in somewhat more detail than was done in reference 1. The amplitudes for the processes (a), (b), and (c) in Eq. (4) have, under the hypothesis of isotopic invariance, the following form:

$$\begin{aligned} F_a &= \frac{1}{\sqrt{2}}\left(-A_0^1 + \frac{1}{\sqrt{2}}A_1^1\right) = -\frac{\sqrt{3}}{2}B^1_{3/2}, \\ F_b &= -\frac{1}{\sqrt{2}}A_1^1 = \frac{1}{\sqrt{3}}\left(B^1_{1/2} + \frac{1}{\sqrt{2}}B^1_{3/2}\right), \\ F_c &= \frac{1}{\sqrt{2}}\left(A_0^1 + \frac{1}{\sqrt{2}}A_1^1\right) = \frac{1}{\sqrt{3}}\left(-\sqrt{2}B^1_{1/2} + \frac{1}{2}B^1_{3/2}\right), \end{aligned} \tag{5}$$

where A_t^1 is the amplitude for the transition into a final state, with the isotopic spin of the system K meson — nucleon equal to t (= 0, 1); $B^1_{t'}$ has the same meaning for the system π meson — nucleon ($t' = \tfrac{1}{2}, \tfrac{3}{2}$).

If we express the amplitudes for the processes by the amplitudes A_t^1, characterizing the system K meson – nucleon in the final state, we obtain the inequality

$$\sigma_a + \sigma_c \geqslant \sigma_b. \tag{6}$$

The equality sign holds for the case when the interaction amplitude for the system K meson — nucleon in the state with isotopic spin t = 1 predominates over the amplitude for the same system with t = 0. We note that the experimental data point to a strong interaction in the system N – K for t = 1. In this limiting case $\sigma(a):\sigma(b):\sigma(c) = 1:2:1$, and the ratio $K^+/K^0 = \tfrac{1}{3}$, i.e., we get the result of reference 1.

If we express the amplitudes F_i by the amplitudes $B^1_{t'}$, characterizing the system π meson – nucleon in the state with isotopic spin t′, we obtain the inequality

$$\sigma_b + \sigma_c \geqslant \sigma_a/3. \tag{7}$$

In the limiting case of a predomination of the interaction amplitude for the system π-N in the state with $t' = \tfrac{3}{2}$ we get an equality, and $\sigma(a):\sigma(b):\sigma(c) = 9:2:1$, $K^+/K^0 = 3$ (cf. reference 1).

In the general case we must be content with the inequalities (6) and (7). Their violation would indicate the absence of isotopic invariance in anti-hyperon processes.

Specific inequalities between the cross sections can also be obtained from the obvious fact that $|F_a|$, $\sqrt{2}\,|F_b|$, and $|F_c|$ may be regarded as the lengths of the edges of a triangle. This leads to the following set of inequalities:

$$\begin{aligned} |\sqrt{\sigma_a} - \sqrt{\sigma_c}| &\leqslant \sqrt{2\sigma_b} \leqslant \sqrt{\sigma_a} + \sqrt{\sigma_c}, \\ |\sqrt{2\sigma_b} - \sqrt{\sigma_c}| &\leqslant \sqrt{\sigma_a} \leqslant \sqrt{2\sigma_b} + \sqrt{\sigma_c}, \\ |\sqrt{\sigma_a} - \sqrt{2\sigma_b}| &\leqslant \sqrt{\sigma_c} \leqslant \sqrt{\sigma_a} + \sqrt{2\sigma_b}, \end{aligned} \tag{8}$$

The experimental verification of these relations is also of interest for the applicability of the hypothesis of isotopic invariance for interactions involving strange particles, and in particular, anti-hyperons.

We note that these considerations are immediately generalized for the case of light nuclei with isotopic spin zero (He^4, C^{12}, etc.).

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[2] S. G. Matinian, J. Exptl. Theoret. Phys. (U.S.S.R.) **31**, 528 (1956); Soviet Phys. JETP **4**, 431 (1957).

Translated by R. Lipperheide
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LOWER EXCITED STATES OF Th^{231}

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Submitted to JETP editor May 26, 1958

J. Exptl. Theoret. Phys. (U.S.S.R.) **35**, 548-549 (August, 1958)

A considerable fraction of the Th^{231} produced in the alpha decay of U^{235} is in excited states. Up to recently it was assumed that the gamma transitions between the levels of Th^{231} occur at energies of 74, 110, 184, 200, 289, and 382 kev.[1] The multiplicity of the transitions remained unknown.

In the present work we investigated the γ-ray spectrum of Th^{231}, using a scintillation spectrometer with a NaI(Tl) crystal. The resolution of the spectrometer on the Cs^{137} was 7%. We counted the gamma quanta in coincidence with the alpha particles of the U^{235}. The spectrum obtained is shown

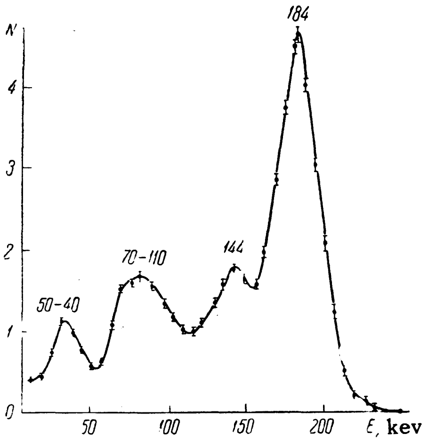

FIG. 1

in Fig. 1. The most intense line of the spectrum corresponds to 184-kev gamma quanta. The intensity of the 144-kev line is 25 to 30% of that of the 184-kev line. In the region of the spectrum from 110 to 70 kev, there are several unresolved lines: 92 kev — the characteristic thorium x-rays that accompany the internal conversion of the gamma quanta, and 95 kev — the characteristic uranium x-rays produced by slowing down the alpha and beta particles in the source. It is possible that lines corresponding to gamma transitions in Th^{231} are also present. The 40-kev line is connected with the gamma transition during the α decay of the U^{234} present in the specimen. It is also possible, however, that a transition of like energy occurs during the decay of U^{235}.

It was established in control experiments with sources of various thickness and in investigations of the gamma spectrum of a Te^{123m} reference that no 144-kev gamma quanta can result from backward scattering of gamma rays with energies of 184 to 200 kev. We must assume that these quanta are emitted by Th^{231} during the transition from 184-kev to the 40-kev excited level. The latter may be the first excited level of the rotation band.

On the basis of the Nielson scheme, the spin of the ground state of Th^{231} must be assumed to be $^5/_2$. The second excited level of the rotation band should then have an approximate energy of 93 kev and a spin of $^9/_2$.

The intensity of the unresolved lines in the spectrum region from 70 to 110 kev is approximately 40% of the intensity of the 184-kev line. If we assume that this region contains only the characteristic x-radiation of thorium, the K-shell coefficients of internal conversion (i.c.c.) of the 184- and 144-kev gamma quanta cannot exceed unity. The presence of other gamma quanta, with energies from 70 to 110 kev, reduces still further the upper limits for the i.c.c. Such a limitation of the value of the i.c.c. makes it possible to exclude the possibility of magnetic gamma transitions, for even in M1 transitions with energies of 184 and 144 kev, the values of the i.c.c. are ~3 and 5 respectively.

By assuming the 40-kev excitation level to be rotational, we can classify the transitions with energies of 184 and 144 kev only as E1 or E1 + M2. The existence of an E1 + M2 radiation with 184 kev energy is confirmed by measuring the angular correlation between these quanta and the 4.4-Mev alpha particles for U^{235}. The angular correlation were measured with a pulsed ionization chamber and a scintillation spectrometer. The distribution function obtained is of the form

$$W(\theta) = 1 + (0.109 \pm 0.020) P_2(\cos\theta) - (0.055 \pm 0.018) P_4(\cos\theta).$$

The scheme proposed for the Th^{231} levels was reported at the Conference on Nuclear Spectroscopy[2] and is shown in Fig. 2.

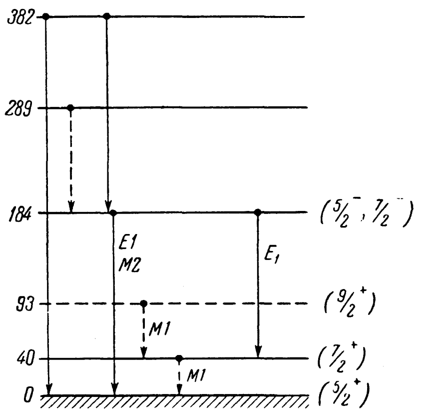

FIG. 2

The existence of rotational levels in Th^{231} was indicated independently by Pilger et al.[3]

The authors thank Professor L. I. Rusinov for constant attention to this work.

[1] S. A. Johansson, Ark. f. Fysik **10**, 97 (1956).

[2] Program and Topics of the Eighth Annual Conference on Nuclear Spectroscopy in Leningrad,

January 27 — February 3, 1958.
[3] Pilger, Stephens, Asaro, and Perlman, Bull. Phys. Soc. **2**, 394 (1957).

Translated by J. G. Adashko
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THE SATURATION MAGNETIZATION OF NICKEL-COPPER ALLOYS AT LOW TEMPERATURES

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Submitted to JETP editor May 28, 1958

J. Exptl. Theoret. Phys. (U.S.S.R.) **35**, 549-550 (August, 1958)

THE aim of the present investigation was to check the $^3\!/_2$-law, $I = I_0(1 - CT^{3/2})$, for the saturation magnetization at low temperatures, and to determine the constant C in that law for nickel-copper alloys with copper content of up to 50%.

The measurement was carried out on a setup which made it possible to follow directly the change in the saturation magnetization of the sample while its temperature was changed. The temperature of the specimen was varied by pumping out vapors of boiling liquids (oxygen, nitrogen, hydrogen, and helium) in which the specimen was placed. The temperature was determined by the vapor pressure in the cryostat. The change in the magnetization was determined by a photoelectric flux meter. The sensitivity of the flux meter was equal to 20 μsec-v for one division of the scale, which made it possible to measure a magnetization of the order of 10^{-3} gauss.

In the table we have given the values of the magnetization I_0 of nickel and nickel-copper alloys in a field H = 3500 Oe at different temperatures, the value of

$$n = \ln(\Delta I_1/\Delta I_2)/\ln(T_1/T_2) + 1,$$

where ΔI_1 and ΔI_2 are the change in magnetization found respectively at the temperatures T_1 and T_2 for the same lowering of the temperature (for a change of the temperature by the same small amount ΔT). In the table is also given the value of C evaluated by means of the Bloch equation for

Cu content (%) in the alloys	Magnetization, gauss				n	$C \cdot 10^6$	Θ', °K	J/k	$2S^*$	J^*/k
	4.2° K	20°K	77°K	286°K						
0	512	512	510	496	1.6 ±0.2	9	2300	217	0.606	485
10	423	422	420	369	1.55±0.1	17	1500	144	0.502	475
20	348	347	342	272	1.43±0.2	32	990	94.5	0.412	440
30	255	253	246	124	1.53±0.2	67	610	58	0.302	445
44	124	121	97.5	—	1.56±0.2	320	215	20	0.147	470
50	82.5	77.5	35.5	—	1.48±0.2	780	118.5	11.5	0.098	495

an observed value of $\Delta I/\Delta T$ and the value $\Theta' = C^{-2/3}$. One sees easily that the difference $n - {}^3\!/_2$ lies within the limits of the errors, assumed in the determination of n. Hence it follows that, within the limits of the errors, the experiments observe the $^3\!/_2$ law for all alloys which were investigated.

From the value of C from the Bloch-Møller equation

$$C = (0.1174/2S\alpha)\left(\frac{k}{2SJ}\right)^{3/2},$$

in which S is the spin, α = 1, 2, 4 for simple, body-centered, and face-centered cubic lattices, respectively, one can evaluate the exchange integral J for pure metals. To evaluate the exchange integral of iron we take[1-3] 2S = 2; for nickel we take 2S = 1. However, for nickel and its alloys the average magnetic moment for one atom is not equal to an integral number of Bohr magnetons, and the above expression for C loses its meaning. We can, however, by considering J as a parameter characterizing the alloy, attempt to determine its value substituting for 2S the number 2S* of Bohr magnetons per atom of the alloy obtained from the experimental values for the magnetic saturation.

The results of these calculations are given in the table.

The exchange parameter J* evaluated in this way stays constant for all the copper-nickel alloys investigated within an accuracy of 10 to 15%.

[1] E. M. Lifshitz, J. Exptl. Theoret. Phys. (U.S.S.R.) **15**, 97 (1945), J. Phys. (U.S.S.R.) **8**, 337 (1944).