to the X-ray tube is raised, the rays can penetrate deeper into the crystal and consequently affect a larger volume of the semiconductor, so that we observe a larger value of the negative photoconductivity.

When X-rays and visible light are both applied, the observed effects depend on the order of application. When X-rays are applied to a crystal which is already illuminated with visible light so as to give a maximum of negative photoconductivity, we observe a decrease in the negative photoconductivity, or even the appearance of a positive effect. When visible light is applied to a crystal already irradiated with X-rays, we observe an increase in the negative photoconductivity. A satisfactory simple explanation of these observations is obtained if we assume that visible light is absorbed throughout the whole volume of the crystal, while the soft X-rays are absorbed only in a very thin layer. If the X-ray and visible radiation are both sufficiently intense to produce saturation of their individual negative photoconductivities—the visible light in the whole crystal, and the X-rays in their own thin layer—then the addition of X-rays to light and light to X-rays must lead to different effects, as is actually observed.

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The Alpha Decay of Pu^{239}

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The α-spectrum of Pu^{239} has been investigated. Three new lines with energies 5064 ± 2, 4999 ± 5 and 4917 ± 5 kev and intensities (0.037 ± 0.005), (0.013 ± 0.005), and (0.005 ± 0.002) percent have been detected. It is shown that the principal α-line of Pu^{239} is related to the decay to an excited level of U^{235} having a spin of ½. Three previously detected lines and two of the newly detected lines belong to the rotational band of this level. The existence of a metastable state of U^{235} with an excitation energy of $\sim$ 3 kev is predicted. A doublet splitting parameter equal to $a = -0.276$ has been found.

THE PRINCIPAL LINES in the α-spectrum of Pu^{239} are well-known[1,2]. These lines have energies 5.147, 5.134 and 5.096 Mev. The intensities of the corresponding transitions are 72, 16.8 and 10.7 percent. From the data presented it is seen that the transition to the lowest of the known levels takes place with great probability. The decay coefficient for this transition is equal to 0.3 (*cf.* Ref. 3), *i.e.*, this transition is allowed. As is known, the spin of the nucleus must not change in an allowed transition. Direct measurements of the spins lead however to $I = ½$ for Pu^{239} [4] and to $I = 7/2$ for the daughter nucleus U^{235} [5]. Such difference in spins of the ground states of the parent and daughter nuclei made it necessary to assume[6] that the most intense transition is not to the ground state of U^{235}.

This hypothesis received supporting evidence in experiments on Coulomb excitation[7,8]. The Coulomb excitation of the U^{235} nucleus has led to the observation of a system of levels starting naturally from the ground state of U^{235} and having nothing in common with the levels observed in the α-decay of Pu^{239} (see the level scheme below).

Bohr, Froman and Mottelson[3] have stated the hypothesis that the lowest most intense level known from α-decay has $I = ½$ and is the first level starting the rotational spectrum.

As is known, the excitation energy for the rotational levels with $K = \frac{1}{2}$ are determined from the two-parameter formula suggested by Bohr[9]

$$E_{\mathrm{rot}} = (\hbar^2/2J)\,[I\,(I+1) + a\,(-1)^{I+1/2}\,(I+1/2) - 3/4 - a]. \tag{1}$$

Assuming that the levels with excitation energies of 13.2 and 52 kev have spins $\frac{3}{2}$ and $\frac{5}{2}$, Bohr, Froman and Mottelson have computed, according to formula (1), the excitation energy of the next level with spin $\frac{7}{2}$. It turned out to be equal to 83 kev.

The investigation of $\gamma-\gamma$ coincidences in the decay of Pu^{239} carried out by Asaro's group (see reference given in Ref. 10) did not confirm the existence of a level with such an excitation energy in the α-spectrum of plutonium. From the data obtained by this group it was concluded that the levels present have energies 172, 379, and 430 kev and α-decay intensities 0.02, 0.006 and 0.006 percent (see the level diagram). It is not difficult to convince oneself that these levels do not fit into the rotational system predicted by Bohr.

We carried out an investigation of the alpha spectrum of Pu^{239} with the help of a magnetic alpha-spectrometer[11] in the energy region 4.850–5.120 Mev. The measurements were carried out with a source, prepared by vacuum evaporation of the element, and containing Pu^{239} and Pu^{240} in ratio 100 : 0.7*.

The alpha spectrum in the energy region from 5.025 to 5.120 Mev is shown in Fig. 1, and displays clearly a line corresponding to an 84-kev level. The intensity of this line is only equal to (0.037 ± 0.005) percent.† In order to resolve a line with such an intensity at a distance of ~ 30 kev from a line with an intensity 300 times larger, it was necessary to consider very carefully the choice of the optimal thickness of the source. The half width of our peak was ~ 13 kev.

Figure 2 shows a plot of the spectrum in the 4.850–5.080 Mev region taken with another source of greater intensity. The peak related to the 84-kev level is hardly noticeable here. However, an α-line corresponding to a level with excitation energy of 151 kev appears clearly. The intensity of the transition is (0.013 ± 0.005) percent. A small part of the intensity of this line comes from the 4^+ level of Pu^{240} (the energy of this level and the intensity

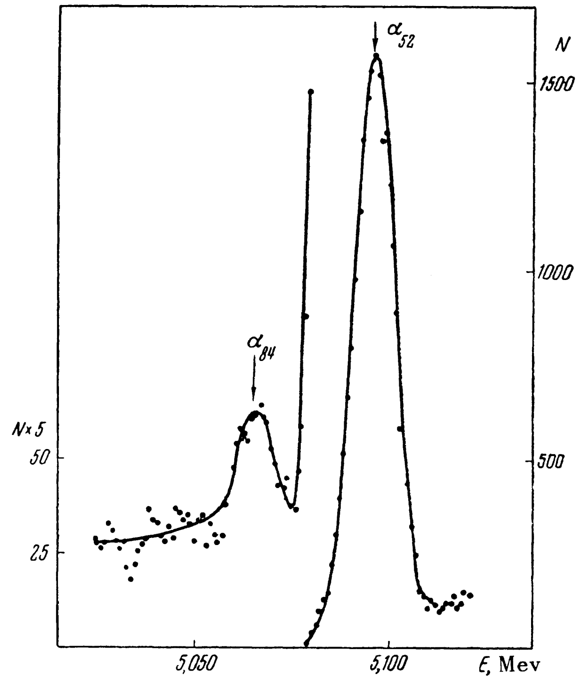

FIG. 1. The alpha spectrum of Pu^{239} in the 5.025–5.120 Mev region.

of the corresponding transition are well known[12]). The corrected curve is shown dashed.

It is not difficult to calculate, from Eq. (1), that the excitation energy of the level belonging to the rotational band with $K = \frac{1}{2}$ and having $I = \frac{9}{2}$ is 153 kev, that is, that it coincides with the energy of the level observed by us. The level with 171 kev energy and 0.02 percent intensity, indicated in Ref. 9, was not observed by us. If this level does exist, its intensity is in any case less than 0.005 percent.

The energies of five consecutive levels are thus well described by Eq. (1). Therefore the lowest level has indeed a spin $\frac{1}{2}$ and is the first of the evolved system of rotational levels with $K = \frac{1}{2}$ (see Fig. 3).

From the separation of the levels it is possible to calculate the ground state characteristics of the nucleus: $\hbar^2/2J = 6.1$ kev and $a = -0.276$ [see Eq. (1)].

A line with 0.005 percent intensity, 230 kev away from the most intense line, is also seen on Fig. 2. This line does not fit into the rotational scheme. One should mention that this line cannot be attributed to any admixture of a known α-active isotope in the material used to prepare the source. It re-

*The Pu^{240} content was determined by a mass spectroscopic method using a double isotope source.

†Bohr predicted an intensity ten times larger for this level.

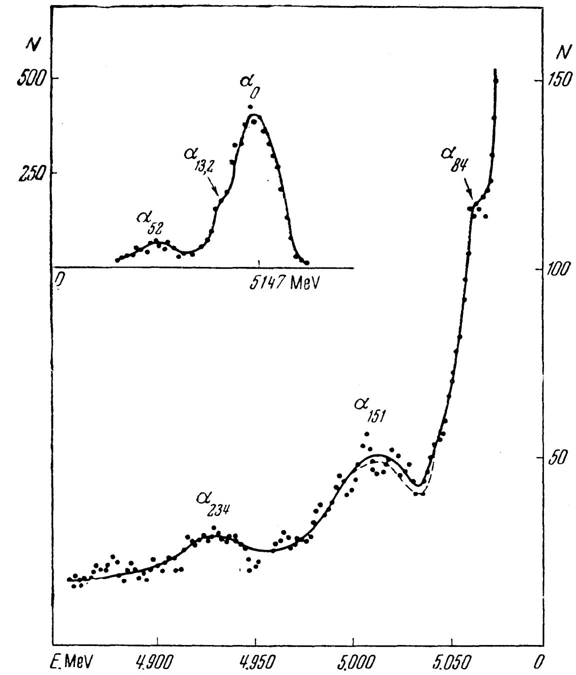

FIG. 2. The alpha-spectrum of Pu^{239} in the 4.850–5.080 Mev region.

mains to assume that this line corresponds to a single transition to a U^{235} level with 234 kev excitation energy.

Data on the investigation of γ-rays observed in the α-decay of Pu^{239} are shown in the work of Refs. 13–17. Several of the known γ-rays (E_γ = 39, 53 and 100 kev) fit in well with the U^{235} level scheme; however, it is not yet possible to find corresponding transitions in this scheme for several of these γ-rays (for instance, with E_γ = 124 kev).

Shliagin[17], studying the decay of Pu^{239}, observed a very intense group of conversion electrons with an energy of approximately 2 kev. However the interpretation of these electrons proposed by him seems rather unconvincing to us. We think that this group of electrons is related to the γ-rays corresponding to the transition of the lowest level of the rotational band with $I = \frac{1}{2}$ to the ground state of U^{235} with $I = \frac{7}{2}$.

Returning to the system of rotational levels in the α-spectrum of Pu^{239} (see Fig. 3) it is necessary to note the regularity which appears in the intensities of these levels.

The intensities of the transitions to states with $I = \frac{3}{2}$ and $I = \frac{5}{2}$ differ little from each other but are 5–7 times smaller than the intensity of the transition to the $I = \frac{1}{2}$ level. The intensities of the transitions to the $I = \frac{7}{2}$ and $I = \frac{9}{2}$ levels again differ little from each other but they are several hundred times less intense than the transitions to to the two levels mentioned earlier.

From the doublet structure one can deduce that the α-particles corresponding to the transition between the ground state of Pu^{239} and the $I = \frac{1}{2}$ level of U^{235} carry off $l = 0$, which means that the ground state of Pu^{239} and the lowest level of the rotational band have the same parity (which confirms also the large value of the decay coefficient for this transition). The transitions to the levels with energies 13.2 and 52 kev take place with $l = 2$, while the transitions to levels with energies 84 and 151 kev involve $l = 4$. It is interesting to note that the wide separation of the doublets (the 13.2-kev level, for instance, is closer to the ground state than to its pair member level with 52-kev energy) does not disturb the pronounced doublet character of the intensity of the lines.

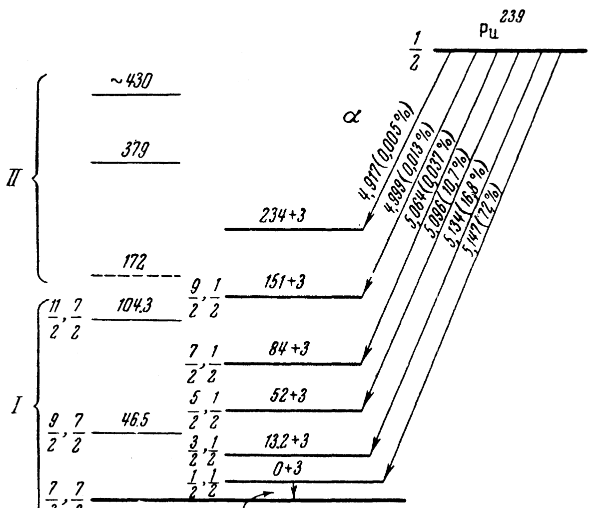

FIG. 3. α-decay scheme of Pu^{239} and the levels of U^{235}. I denotes the levels determined from the Coulomb excitation[8], and II the levels determined from the $\gamma-\gamma$ coincidences[10].

Let us discuss in greater detail the γ-transition between the $I = \frac{1}{2}$ and $\frac{7}{2}$ levels. As L. Peker has shown (private communication), one should expect the ground states of Pu^{239} and U^{235} to have even parity. Thus the parities of the $I = \frac{1}{2}$ and $I = \frac{7}{2}$ levels of U^{235} are the same. The corresponding γ-transition must be of the $M3$ type with an energy of approximately 3 kev. The $I = \frac{1}{2}$ level must therefore be isomeric and must have a long lifetime.

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Note added in proof (April 19, 1957). Later measurements with a thinner source force one to believe that the level with 172 kev energy apparently exists. The intensity of the α-decay to this level lies within the stated limits.

In the 4.675–4.850 Mev region, levels with excitation energies 373 kev ($\sim$ 0.002%), 426 kev ($\sim$ 0.005%), 497 kev ($\sim$ 0.0015%) and, apparently, 336 kev (0.0035%) have been discovered. The first two of these levels correspond to states observed in $\gamma - \gamma$ coincidences.

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Reactions Involving Polarized Particles

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The statistical tensors of particles produced in reactions of the types $a + b \rightarrow c + d$ and $a \rightarrow c + d$ have been obtained in the most general case, when the incident beam and the target particles are in definite spin states. New selection rules are deduced which supplement the general selection rules of Simon and Welton[1,2]. The first of these rules can be regarded as a generalization of the rule according to which the polarization vector of the particles produced in the reaction is perpendicular to the plane of the reaction if the incident and target particles are unpolarized. The second rule states that the statistical tensor of a particle produced in the reaction, defined relative to the direction of its momentum, is either purely real or purely imaginary if the incident and target particles are unpolarized. As a particular case, the decay of an unstable particle into particles of spins ½ and 0 is considered, and it is shown that the polarization and angular distribution of these particles depend only on the spin and spin state of the decaying particle.

THE GENERAL THEORY of nuclear reactions has already been broadly developed in the papers of Simon and Welton[1, 2]. In the present paper a new method is proposed for obtaining the statistical tensors (for definition see Appendix I) of particles produced in a reaction. It has been given brief-