The present work substantiates the conclusion of Lawson and Cork that the 45–50-day period is to be attributed to In^{114}, since it has been shown here to go with slow neutrons on indium. Furthermore, the relative activity of the 50-day period compared with the 54-min. period, produced by slow neutrons, is about what one would expect from the relative abundances of In^{113} and In^{115}.

From the evidence presented by Lawson and Cork it seems very probable that the 4.1-hour period is due to In^{114} since it was obtained with deuterons on Cd and quite strongly with fast neutrons on In. It is isomeric with the 50-day period. In the present investigation no 4.1-hour period was observed when slow neutrons bombarded indium. Lawson and Cork found this period to be produced only weakly with slow neutrons. It is not impossible that the weak activity observed by them was due to residual fast neutrons not slowed down by the paraffin. From the above, it appears that the 4.1-hour period is due to In^{114}, that it is produced by fast neutrons on In^{115}, but that it is not readily produced by slow neutrons on In^{113}. Since the two periods 4.1 hours and 50 days are isomeric, one must conclude, from the nonappearance of the 4.1-hour period with slow neutrons that the formation of this state is forbidden due to energy considerations or to the action of a selection rule.

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Note on *K* Electron Capture and Isomerism in Radiosilver

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From radioactivity data a tentative energy-level diagram is constructed for the isomeric nucleus Ag^{106}. These data indicate that, for the 8.2-day period, the relative probabilities of K electron capture: negative β-emission: positive β-emission $=640:40:1$. The 24.5-min. Ag^{106} level is metastable and 0.3 Mev above the 8.2-day Ag^{106} ground state. Theory requires that the difference in angular momentum associated with these two levels be at least 5 nuclear units.

INTRODUCTION

The capture of orbital electrons as an alternative to positron emission by radioactive nuclei has been considered theoretically by several investigators.[1] For heavy radioactive nuclei the probability for K electron capture has been calculated to be comparable to, or even a thousand times greater than that of the corresponding positron emission. It is also probable that some radioactive nuclei which are stable with respect to positron emission may be unstable with respect to K electron capture.[2]

The x-rays following K electron capture have been found by Alvarez[3] in the comparatively light element V^{48}, which emits positrons and has a half-life of 16 days. The possibility of K electron capture in potassium has been discussed by Weizsäcker[4] and Bramley.[5] Various observations on radiosilver Ag^{106} have been made which suggest that K electron capture plays an important role in the radioactive transformation of this nucleus.[6]

RECAPITULATION OF DATA

The 8.2-day period in silver was determined by the γ as well as by the $\beta+\gamma$ activity; 447

[1] Möller, Physik. Zeits. Sowjetunion **11**, 9 (1937); Uhlenbeck and Kuiper, Physica **4**, 601 (1937); Yukawa and Sakata, Phys. Rev. **51**, 677 (1937); Hoyle, Nature **140**, 235 (1937).
[2] Sizoo, Physica **4**, 467 (1937).

[3] Alvarez, Phys. Rev. **52**, 134 (1937).
[4] Weizsäcker, Physik. Zeits. **38**, 623 (1937).
[5] Bramley, Science **86**, 424 (1937).
[6] Pool, Phys. Rev. **53**, 116 (1938).

β-tracks were measured and gave by inspection an upper limit of 1.3 Mev. The number of γ-quanta per β-ray was about 35. The γ-ray spectrum was complex but probably consisted of at least lines at 0.3, 0.7 and 1.0 Mev. Out of 600 negative β-tracks, 15 positron tracks were measured; the maximum energy observed was 0.41 Mev.

The 24.5-min. period was also measured by the γ and $\gamma+\beta$ activity; 847 positron tracks gave by inspection an upper limit of 1.9 Mev. The number of γ-quanta per positron was about 2.

Both periods were best obtained by fast neutron bombardment of silver. The branching ratio of the 8.2-day to the 24.5-min. period is about 20.

K Electron Capture

Uhlenbeck and Kuiper[1] have calculated a set of curves which show the dependence of the ratio of capture probability to that of positive β-emission as a function of atomic number and of the energy W_0 available for the transition. The above data give the relative probability of K electron capture: negative β-emission: positive β-emission $=640:40:1$. Using the ratio 640/1 one obtains from the curves a value of $W_0=2.2\,mc^2$ which corresponds to 0.6 Mev for the upper limit of the positron spectrum. Since 0.41 Mev was the maximum energy observed from such a limited number of tracks, 0.6 Mev or even more might easily be expected for the upper limit. To obtain more positron tracks a very much stronger source is necessary. The sample of silver used was irradiated six hours with neutrons from Li bombarded with 7μA of 6.3 Mev deuterons.

These data with interpretations are presented in Fig. 1. Since the 8.2-day period is determined by the probabilities of three processes, the total decay constant $\lambda=\lambda_k+\lambda_-+\lambda_+$. It appears from the Sargent diagram, when the intrinsic decay constants λ_- and λ_+ are used, that the negative β-emission is doubly forbidden while the positron emission is approximately singly forbidden.

Metastable States

The subject of metastable states in nuclei has been reviewed by Bethe.[7] He gives an expression

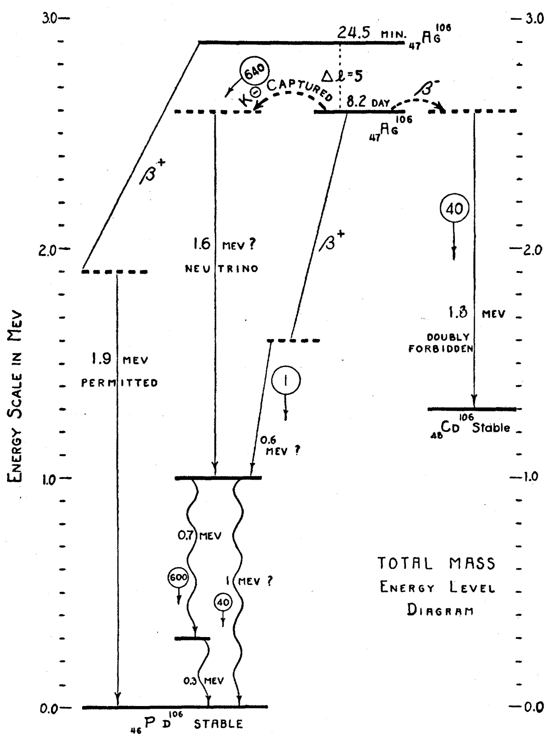

FIG. 1. Tentative energy-level diagram for the isomeric nucleus Ag^{106}. The relative transition probabilities are inscribed in circles. Total mass includes the rest mass of the orbital electrons.

for the lifetime of a state with respect to γ-emission and shows that the lifetime may be of the order of ordinary β-ray periods (seconds or days) provided that a large change Δl of the angular momentum is involved in the transition or that the levels between which the transition occurs lie very close together. Since the upper limit of the 24.5-min. positron spectrum is known to be 1.9 Mev, the difference in energy between the 24.5-min. level and the 8.2-day level is calculated to be 0.3 Mev as is shown in Fig. 1. One may then calculate that the condition $\Delta l \geqslant 5$ is necessary in order that the upper level should have a lifetime with respect to γ-emission long compared to 24.5 min. Since the 24.5-min. positron period is a permitted transition and since the nuclear spin of stable Pd^{106} is probably zero (even Z, even A) one would expect the 24.5-min. level of silver also to have zero angular momentum and the 8.2-day level to have an angular momentum of 5. This very high angular momentum should not be too disconcerting insofar as several stable

[7] Bethe, Rev. Mod. Phys. **9**, 226 (1937).

nuclei are known whose angular momentum is 9/2 in the ground state.

Discussion

In order to avoid the large Δl calculated above, the 8.2-day period might be assigned to Ag^{105}. If this new assignment be made, a n-$3n$ reaction would be involved instead of the n-$2n$ process. Since neutrons of 6 to 10 Mev are more abundant in the $Li+d$ source than those of higher energies, the number of n-$2n$ reactions should in general, on purely energetic grounds, exceed the number of n-$3n$ reactions.[8] But the observations show that the 8.2-day silver is formed at a much greater rate than the 24.5-min. silver. Therefore the assignment to Ag^{105} seems unlikely. The most serious obstacle of all to this assignment is that the negative β-spectrum, which shows a normal energy distribution, would have to be attributed to Compton recoil electrons or that a new stable isotope Cd^{105} would have to be postulated.

Instead, the 24.5-min. period might be assigned to Ag^{105}. This period, however, has been obtained with neutron bombardment at energies as low as 10 Mev and the n-$3n$ reaction necessary in this case would be quite unlikely. Furthermore, one must assume that the 24.5-min. period is obtained from the reactions Cd-n-d and Rh-α-$2n$ instead of the suggested reactions Cd-n-p and Rh-α-n. Reactions of the types α-$2n$ and n-d have not so far been experimentally established.

Consequently, the data at present suggest more strongly that both the 24.5-min. and the 8.2-day periods should be assigned to Ag^{106}. If a very much stronger source were available, the 8.2-day γ-ray and positron spectra could be more accurately measured. The branching ratio of 20, obtained from the reactions Ag-n-$2n$, could then be checked by the following reactions: Cd-n-p, Pd-d-p and Rh-α-n. In the latter three reactions the 24.5-min. period and a long period (presumably the 8.2-day period) have been found but the intensity of the long period was too small to permit a reliable estimate of the branching ratio. However, the experiments are not in disagreement with the hypothesis that the branching ratio is about the same in all three reactions as would perhaps be required for the two periods to be isomeric.

The authors wish to thank Professor L. H. Thomas and Professor H. A. Bethe for helpful discussions regarding the theoretical aspects of this work.

[8] Pool, Cork and Thornton, Phys. Rev. **52**, 41 (1937); Walke, Phys. Rev. **52**, 669 (1937).

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X-Ray Spectroscopic Data in Regard to the Electronic Energy Bands in Potassium and Sodium Chlorides

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The wave-lengths of several lines in the $K\beta$ group of Cl in NaCl and KCl, and of K in KCl, have been measured in the secondary radiation from pressed blocks of the salts. The results are discussed in terms of the electronic energy bands in these crystals. It is shown that certain of the weaker lines arise from transitions of valence electrons belonging to one of the ions into a K shell vacancy in the other ion. Some of the residual nondiagram lines seem to be related to the excited levels in irradiated crystals.

Recent discussions of the electronic energy bands in crystals, of which NaCl has been treated in greatest detail,[1] make it of interest to examine the x-ray spectrum of compounds more closely in the light of these results. One obtains in this way supplementary information on the locations of the principal energy bands and the transitions which take place. There are, however,

[1] Pauling, Phys. Rev. **34**, 954 (1929); Slater and Shockley, Phys. Rev. **50**, 707 (1936).