In Table IX is a summary of the results obtained from measurements on various ionic species. Values obtained from the data on different types of ions are in fair agreement. The final value for the abundance of Br^{81} relative to Br^{79} is 0.979 ± 0.004. No isotopes except 79 and 81 were detected. If isotopes 78, 80, or 82 exist, their abundance is less than 1/10,000 that of isotope 79.

The most recent figure[29] for the packing fraction of bromine is -7.4. In connection with this value the data obtained in this study give a value of 79.908 for the chemical atomic weight. The accepted international value is 79.916.

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Note on the Lifetime of Metastable States*

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The available data on approximately forty γ-emitting metastable states of isomeric nuclei has been compared with the present theories. Nearly all of the points lie near two straight lines when log λ (sec.$^{-1}$) is plotted against log E (Mev). These lines fall close to the theoretical curves of Bethe calculated for electric 2^4 and 2^5 pole radiation.

INTRODUCTION

SINCE the original proposal of the existence of metastable states by von Weizsacker,[1] several theories have been developed which relate the lifetime of a metastable state against γ-emission to the energy of this state. Included in these are the calculations on the liquid droplet model by Bethe,[2] Lowen,[3] Flügge,[4] Fierz,[5] and Koyenuma.[6] Calculations of the lifetime energy relationship have also been worked out on the basis of an alpha-particle moving in a potential well by Hebb and Uhlenbeck[7] and by Segrè.[8] Several of these theories have recently been discussed by Berthelot.[9] In addition, a correction of the earlier formulae has been proposed by Hebb and Uhlenbeck to take into account the additive decay probability brought about by internal conversion. This correction factor $[1+(N_e/N_\gamma)]$, where N_e/N_γ is the ratio of the number of conversion electrons emitted to the number of γ-rays emitted, becomes extremely important at low energies and approaches unity for high energies. It should be noted, however, that the lifetime relationships are meant merely as approximations and should, therefore, be expected to give only the order of magnitude of the lifetime as a function of the energy. In addition to this, the important ratio N_e/N_γ has been calculated only for low atomic numbers.

EXPERIMENTAL DATA

In Fig. 1 we have plotted the log of the decay constant *vs.* log of the energy of the metastable state for the states thus far studied. This includes nuclei in which the ground state is stable as well

* Some of these results have been presented at the St. Louis meeting of the American Physical Society, November 30, 1945.
** Now at the University of Michigan.
[1] C. F. von Weizsacker, Naturwiss. **24**, 813 (1936).
[2] H. A. Bethe, Rev. Mod. Phys. **9**, 226 (1937).
[3] I. S. Lowen, Phys. Rev. **59**, 835 (1941).
[4] S. Flügge, Ann. d. Physik **39**, 373 (1941).
[5] M. Fierz, Helv. Phys. Acta **16**, 365 (1943).
[6] N. Koyenuma, Zeits. f. Physik **117**, 358 (1941).
[7] M. H. Hebb and G. E. Uhlenbeck, Physica **5**, 605 (1938).
[8] E. Segrè, given by A. C. Helmholtz, Phys. Rev. **60**, 415 (1941).
[9] A. Berthelot, Ann. d. Physique **19**, 117 (1944).

as those which are unstable. Although all of the points do not fall on the lines, most points fall into two general regions about the lines which have been drawn. Such a spread should, of course, be expected on two accounts. First, the value of N_e/N_γ is a function of the atomic number Z, second, the data were obtained by many different experimenters, using various methods for determining the energy of the metastable level. From the various reports one sometimes finds considerable experimental deviations in the results obtained. Notable deviations from the two major regions may be found in the cases of 43^{99} (6.6 hr. period), Cd* (48.7 min. period), and Sr^{85} (70 min. period). These three points (dotted in diagram) fall midway between the regions. As such, they cannot be assigned to either region with any degree of certainty. The line $L=4$ corresponds to an electric 2^4 pole (or magnetic 2^3 pole) radiation and can be empirically represented by the equation:

$$\lambda = 42E^{3.67}.$$

Correspondingly, the line $L=5$ for electric 2^5 pole radiation can be represented by:

$$\lambda = 45.8\times 10^{-5}E^{3.67}.$$

Two points fall considerably below the line $L=5$ and may possibly represent transitions in which the spin change is 6 units; these are owing to Cb^{93*} (half-life $\sim$40 days) and element 61 (half-life $\sim$200 days). This is highly uncertain at the present time.

In a few cases several γ-ray energies are reported for a given activity. These may arise from a cascade process in the decay of the metastable state to an intermediate level. As such, it is not immediately possible to determine which is the metastable transition energy. These energies are thus plotted on the same horizontal line in Fig. 1. In fact, Columbium might well belong to the group $L=5$ since two γ-ray energies are reported; namely, 0.15 Mev[10,11] and 0.94 Mev.[10] A second case of interest is Cobalt^{60} (half-life 10.7 minutes) which emits γ-rays of energy 0.056 and 1.5 Mev. The first of these points falls on the curve for $L=4$ while the second falls on the curve $L=5$.

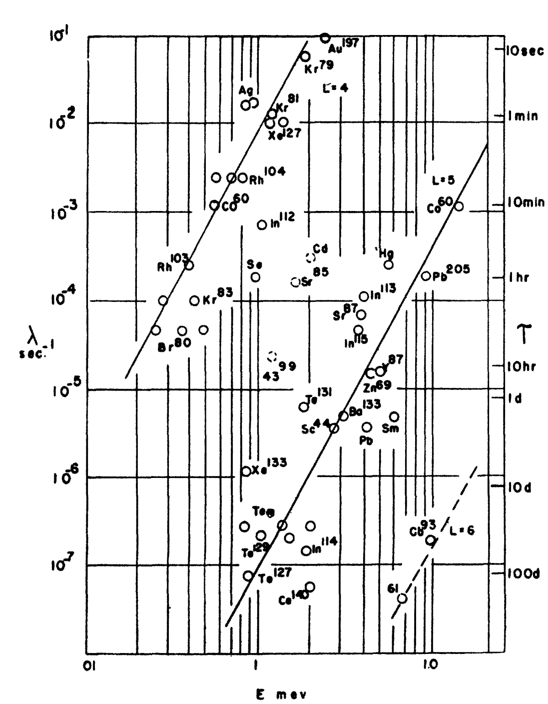

FIG. 1. Log λ *vs.* log E. $L=4$ and $L=5$ correspond to electric 2^4 and 2^5 pole radiation, respectively.

COMPARISON OF EXPERIMENTAL DATA WITH THEORY

In Fig. 2 we have plotted several of the lifetime-energy relationships along with the experimental line $L=4$ from Fig. 1. Line 1 represents Bethe's uncorrected formula for a spin change $L=3$; line 2—Bethe's value with $L=4$ corrected for internal conversion; line 3—experimental; line 4—Bethe's uncorrected value with $L=4$; line 5—Lowen's value corrected for internal conversion; line 6—Lowen's uncorrected value; line 7—Flügge's value; line 8—Hebb and Uhlenbeck's value calculated on the alpha-particle model; line 9—Bethe's uncorrected value for $L=5$.

Figure 3 shows similar relationships for a spin change of 5 units.

From these diagrams one can clearly see that the corrected values of Bethe and Lowen correspond to the data most closely. It may also be noted that the internal conversion correction of

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[11] R. Sogane, S. Kojima, G. Miyamoto, and M. Ikawa, Phys. Rev. **57**, 1180 (1940).

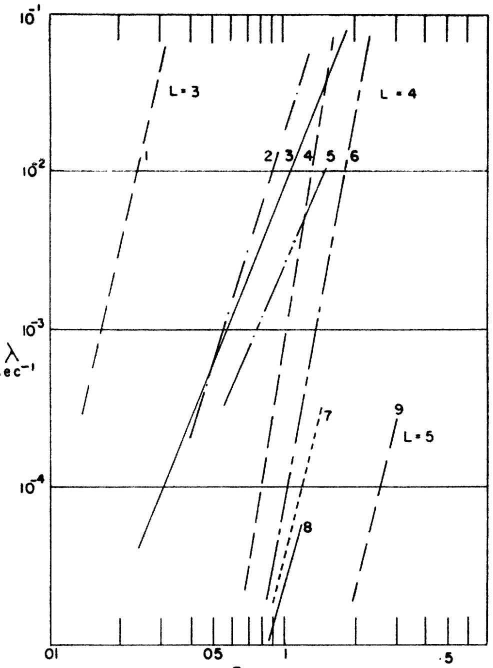

FIG. 2. Comparison of experimental data with several of the theories.

1. Bethe—uncorrected with $l=3$.
2. Bethe—corrected with $l=4$.
3. Experimental.
4. Bethe—uncorrected with $l=4$.
5. Lowen—corrected with $l=4$.
6. Lowen—uncorrected with $l=4$.
7. Flügge with $l=4$.
8. Hebb and Uhlenbeck with $l=4$.
9. Bethe—uncorrected with $l=5$.

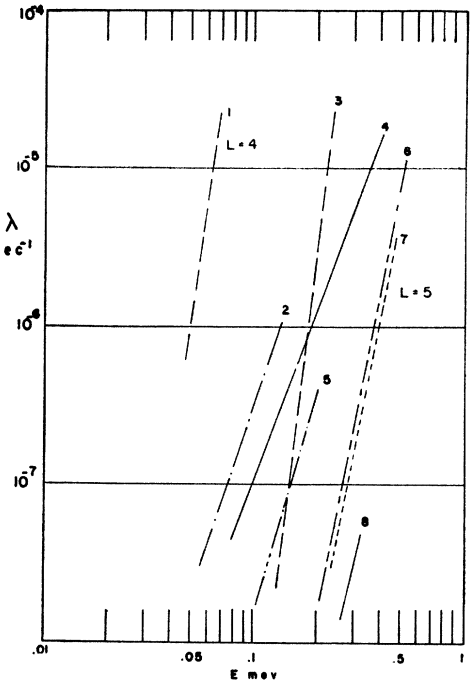

FIG. 3. Comparison of experimental data with theory.

1. Bethe—uncorrected with $l=4$.
2. Bethe—corrected with $l=5$.
3. Bethe—uncorrected with $l=5$.
4. Experimental.
5. Lowen—corrected with $l=5$.
6. Lowen—uncorrected with $l=5$.
7. Flügge with $l=5$.
8. Hebb and Uhlenbeck with $l=5$.

Hebb and Uhlenbeck not only increases the agreement in absolute value but also changes the directions of the curves so as to make the experimental and theoretical curves nearly parallel.

The spin change in such a transition can be obtained independently in some cases by determining the conversion coefficient[12–14] and the ratio of K conversion to L conversion. This has been done for several such transitions by Helmholtz.[15]

It has been possible to determine the multipole order of the transitions with a good degree of accuracy for four isotopes ($Zn^{69}(L=5)$, $Kr^{83}(L=4)$, $Sr^{87}(L=5)$, $Ag^{*}(L=4)$). In four other cases the transition order can only be assigned as probable ($Sc^{44}(L=5)$, $Te^{127}(L=5)$, $Te^{129}(L=5)$, $Te^{131}(L=5)$). In all cases these isotopes fall on the correct line in Fig. 1. However, it is not possible to distinguish between electric 2^l pole and magnetic 2^{l-1} pole radiation.

Thus far, no metastable state with $L=3$ has been studied. One might expect, however, that they should occur quite frequently. If such metastable states of reasonably long lifetime exist, it is seen that their energy is extremely low ($\sim$10 to 20 kv) and hence will not be accompanied by conversion. With the extension of techniques to study periods of 10^{-2} second and less, one could obtain conversion electrons which could easily be detected.

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