Auger Effect in Astatine*

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The K-capture decay of At^{211} has been studied using photographic emulsions. The number of Auger electrons per K shell vacated, defined as the Auger coefficient, has been found to be 0.106. This value is somewhat higher than that calculated from theory. Bi^{207}, which arises from the alpha-decay of At^{211}, was observed to decay by K-capture.

I. INTRODUCTION

THE Auger effect associated with orbital electron capture can be described briefly as follows. An orbital electron capture process is followed by x-rays which arise from the filling of the K shell and to a lesser extent L, M, etc. shell vacancies. However, some of these x-rays are not observed but are internally converted, producing a photo-electron within the atom which emitted the x-ray (Auger electron).

For brevity, let us define the number of Auger electrons per K shell vacated as the Auger coefficient. This quantity, which is one minus the fluorescence yield, has been found for many K-capture decays. Both experimental and theoretical results show a high Auger coefficient for elements of low atomic number, falling off with increasing atomic number.[1] However, no experimental results are quoted for $Z>60$. It is, therefore, of interest to measure the Auger coefficient for some element in this region.

It was suggested by Segrè that a study of the decay of At^{211} by impregnating photographic plates with At^{211} would offer a good opportunity for finding the Auger coefficient of its daughter Po^{211}. The decay scheme[2] at At^{211} is shown in Fig. 1. Since the alpha-decay of Po^{211}(AcC') occurs with a half-life of a few milliseconds, any At^{211} orbital electron capture is followed immediately by an alpha-emission of Po^{211}. At the starting point of this alpha-particle we know that a K or L shell of Po has been vacated. It is true that the alpha-particles of the dual decay of At^{211} will also be present and at their origin no K shell has been vacated. However, these two alpha-particles have considerably different ranges, and one can identify each alpha-particle by measuring its range. For example, in a photographic emulsion, the range of a Po^{211} alpha-particle is 37 microns while the range of an At^{211} alpha-particle is 27 microns. Thus, to measure the Auger coefficient one need only count the number of Po^{211} alpha-tracks and the number of such tracks which have at their starting point an electron track of the proper energy to have come from a K x-ray conversion. Most of the conversion electrons would be knocked out of the L shell. Therefore, they should have a kinetic energy equal to the K x-ray energy less the binding energy of the L electron. For Po this kinetic energy is 59 kev.

II. PROCEDURE

Eastman NTB-3 electron-sensitive plates were chosen for this experiment since the conversion electrons were certain to be visible in these plates. Since these plates are sensitive to particles of all energies, all particles entering the plate after the emulsion has been placed on the plate will be recorded. Thus, the plates soon acquire a considerable number of background tracks. It is desirable to remove all old background tracks before using the plates. Following a procedure recommended by the Eastman-Kodak Company,[3] the plates were placed in a high humidity atmosphere at 35°C for 20 hr. before use. About 80 percent of the old tracks were removed by this process.

At^{211} was made by bombarding Bi with 30-Mev alpha-particles from the 184-inch cyclotron. At 30 Mev, the excitation function for the formation of At^{211} by an $(\alpha,2n)$ reaction is at a maximum, while the threshold for the formation of At^{210} by an $(\alpha,3n)$ reaction[4] is also

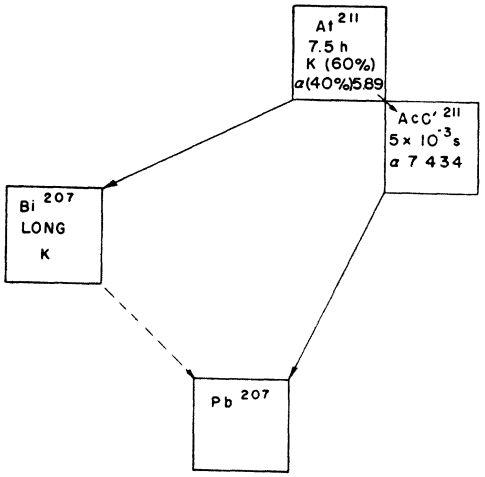

FIG. 1. Decay scheme of At^{211}.

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[2] Corson, MacKenzie, and Segrè, Phys. Rev. 58, 672 (1940).
[3] Private communication.
[4] E. L. Kelly and E. Segrè, Phys. Rev. 75, 999 (1949).

30 Mev. The At was separated chemically upon the conclusion of the bombardment. The At, in a water solution, was placed on the surface of several plates which were then dried within an hour. It is necessary that nearly all of the decays occur in a dry plate. In the first place, wet plates suffer from a loss of sensitivity. Furthermore, it was found that it was impossible to distinguish Po^{211} alpha-particles from At^{211} alpha-particles if many of the decays occurred when the emulsion was wet. Wet plates are considerably swollen, and the range of the decay particle is longer than it would be in a dry emulsion. Since the experiment depended upon being able to distinguish these alpha-particles, the plates had to be dry before an appreciable number of decays occurred. Measurement of the ranges of the alpha-particles found in the plates showed two well-defined groups of particles with ranges of the Po^{211} and the At^{211} alpha-particles. The absence of particles of greater ranges showed that the drying had been accomplished in a sufficiently short time. The plates were allowed to rest eight hours before being developed.

III. RESULTS

In the process of scanning the At loaded plates, fields of view were selected at random and each alpha-track which was completely in the field of view was examined and counted provided that another alpha-track did not obscure one of the ends of the alpha-track. A total of 1849 Po^{211} alpha-tracks were examined and 171 of these were found to have Auger electrons at one end. This would lead one to a value of $171/1849=0.0925$ for the Auger coefficient. However, Rose and Jackson[5] have calculated that for an element in this region of the periodic table the ratio of L-capture to K-capture is 0.15. Correcting for the cases of L-capture one obtains a value of 0.106 ± 0.005 for the Auger coefficient, and the fluorescence yield is 0.894 ± 0.005. The error stated is the probable error based on the number of counts taken.

IV. DISCUSSION

Theoretical calculations[1] predict about 0.06 for the Auger coefficient for an element of atomic number 84. However, the calculations do not consider all of the possible transitions in an exact manner, and are made with hydrogen-like eigenfunctions; a deviation of 50 percent from the theoretical results is not out of the question.

Let us consider the activities present in an At loaded plate to see whether any of them can cause any confusion in the measurement of the Auger coefficient. The chemical separation should rule out all activities other than those of astatine. At^{210}, At^{211}, and At^{212} may be formed during the bombardment. However, At^{212} decays with a 0.25-sec. half-life and would all decay in the short time between the bombardment and the separation. A small amount of At^{210} was present because of a spread in the cyclotron beam energy giving some alpha-particles with an energy greater than 30 Mev, the threshold for the formation of At^{210}. At^{210} decays by K-capture with an 8.3-hr. half-life giving Po^{210}, a 140-day alpha-emitter. The Po^{210} alpha-particles can be easily distinguished from the Po^{211} alpha-particles because of their different ranges, and any Auger electron background which may be present will cause little trouble since, in order to be counted, the end of the Auger electron must coincide with the end of a Po^{211} alpha-particle track. The probability for such an event to occur by chance is negligible. Bi^{207} is also produced in the plate by the alpha-decay at At^{211}. While the activity of Bi^{207} has not been reported it is expected that it decays by K-capture and has a long half-life. None of these activities interfere with observations of the Auger effect in the decay at At^{211}.

V. ACTIVITY OF Bi^{207}

Since the activity of Bi^{207} has not been reported, it was considered worth while to attempt to detect the activity with photographic plates. NTB-3 emulsions loaded with the At solution 10 days after the bombardment and chemical separation showed many Auger electrons. After 10 days, the activities of At^{210} and At^{211} would be only 10^{-10} of the original activities. Thus, these Auger electrons must have come from a daughter activity. The possible daughters are Pb^{207}, Po^{210}, and Bi^{207}. It is known that Pb^{207} is stable and Po^{210} is an alpha-emitter. Therefore, these Auger electrons in all probability have come from the K-capture decay of Bi^{207}. Furthermore, the only alpha-particles found on the plate were those of Po^{210} (these coming from the decay of At^{210}). Therefore, one can conclude that Bi^{207} decays by K-capture and its half-life is very long, probably several years. This follows not only from the fact that past experiments failed to detect its activity but also from the fact that the activity was allowed to decay in the plate for a week before a workable number of tracks grew in the plate.

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[5] M. E. Rose and J. L. Jackson, Phys. Rev. **76**, 1540 (1949).