CANADA

DEPARTMENT OF ENERGY, MINES AND RESOURCES

OTTAWA

MINES BRANCH INVESTIGATION REPORT IR 67-68

SCINTILLATION COUNTER PLATEAUS FOR X-RADIATION OF THE HEAVY ELEMENTS

by

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COPY NO. 19

OCTOBER 6, 1967

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ABSTRACT

Investigation of the phenomenon of double plateaus produced by the scintillation counter for the heavy elements (Z >56) has shown that the second plateau is due to the iodine escape peaks of the elements.

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INTRODUCTION

In a report on the use of the scintillation and flow counters in X-ray spectrography (1), plateaus were shown for the Ka radiation of elements from Ti (22) to Mo (42). In a later report, which discussed pulse amplitude distribution using the scintillation counter (2), these plateaus were extended to Pt (78) with a break between Ba (56) and Ta (73). This omission was made because double plateaus were found for the elements in this portion of the periodic table. At that time it was not feasible to investigate the probable cause of this phenomenon. Recently such an investigation has been possible and has shown that the counter escape peak is responsible for the second plateau.

This report is an account of the investigations carried out.

COUNTER PLATEAUS

Three typical scintillation counter plateaus - the horizontal portions of the response curves - are shown in Figure 1. The increase in intensity observed at the high voltage end of the plateau is due to electronic noise. It is customary to use a counter voltage near the centre of the plateau because any fluctuation in counter voltage will not affect the counting rate when this is done.

Plateaus for the intervening elements may be obtained by interpolation. In general, plateaus show a shift to lower counter voltages and an increase in length with increasing atomic number of the radiating element, i.e. with an increase in energy of the radiation (1,2). This is demonstrated in Figure 1. The plateau of TiKa, 4.51 keV, begins just above 900 V. That of Zn (30), 8.64 keV, at 800 V and of Sn (50), 25.27 keV, just below 700 V. The threshold voltages, where counter response begins, show corresponding shifts. KB plateaus appear at slightly lower counter voltages than the corresponding Ka ones because the KB radiation of an element has greater energy than the Ka. For individual radiations there is a shift to lower counter voltages with increasing amplifier gain (2).

COUNTER ESCAPE PEAKS

The scintillation counter consists of a thallium-activated sodium iodide crystal in front of a photomultiplier tube. When radiation reaching the crystal has energy in excess of that of the iodine K absorption edge, the iodine atoms are ionized in their K shell and the entering radiation loses the energy required to ionize the atoms. Its residual energy appears as an escape peak which is readily seen in a pulse amplitude distribution curve.

The energy of the IK_{ab} is 33.16 keV (3) and all X-radiation with energies greater than this will produce an escape peak in the scintillation counter.

DOUBLE PLATEAUS

The occurrence of double plateaus was first noted in rare earth radiation while determining the proper working conditions for their estimation. The reason for their appearance was at first obscure. When escape peaks were investigated (2), it was concluded that they were responsible for the second plateau. The first is that of the characteristic radiation.

The production of double plateaus, if due to escape peaks, should begin with the element whose characteristic radiation is just capable of producing such a peak, i.e. has energy >33.16 keV. BaKa has an energy of 32.19 keV, while KaKB has 36.37. Therefore the KB energy should show a double plateau, but the Ka should not. All elements of greater atomic number should have double plateaus.

ENERGY OF ESCAPE PEAKS

The energy of the escape peak increases with the atomic number of the fluorescing element. For BaKB it is small: 3.21 keV.

The next element in the periodic table, La (57), has just sufficient energy in its Ka radiation to produce an escape peak with an energy of 0.28 keV. Its KB escape peak has 4.64 keV.

Nd KB (60) radiation with an energy of 42.27 has an escape peak of 9.11 keV, which approximates GaKa (31) radiation with 9.25 keV. The escape peak of SmKα (62) with 6.96 keV is even closer to the CoKa (27) energy of 6.95 keV. BaKa with 32.19 and TeKB (52) with 31.70 keV are close in energy to the TaKB escape peak which has 32.05 keV. It should therefore be possible to compare the plateaus of certain elements with their escape peak equivalents.

EXPERIMENTAL RESULTS

The first experiment conducted was to establish the plateaus of BaK radiations. Those presented in Figure 2 were determined using an amplifier gain of 50. For all others a gain of 10 was used which is normal procedure in our laboratory to keep noise at a minimum. The double plateau of BaKB is evident. La radiation plateaus were then compared as Figure 3 shows. As would be expected, the KB escape peak plateau makes its appearance at a lower counter voltage than the Ka one does.

To ensure that double plateaus are due to escape peaks and not some less obvious factor, plateaus of radiation with energy equivalent to certain escape peaks, as explained above, were determined and compared with the double plateau of the element producing the corresponding escape peak. Two such comparisons are made in Figure 4. The plateau of NdKB begins at a voltage of 700, is constant for 50 or 60 volts and begins to rise as soon as the threshold of its escape peak, represented by its equivalent GaKa, is reached. The second plateau is reached at 850 volts just below the beginning of the escape peak plateau. The first plateau of TaKB is barely indicated by an inflection at 650 V and the second begins at 850 V corresponding to the escape peak plateau as represented by TeKB. This reduction of the first plateau is discussed below.

The shortening of the first plateau is more pronounced with Bi (83) which has a critical potential of 90.1 kV (4) and is the heaviest element whose characteristic radiation may be excited significantly by the 100 kV spectrograph. Bi plateaus may be seen in Figure 5.

DISCUSSION

The experimental results obtained offer sufficient proof of the assumption that the second portion of the double plateau is due to escape peaks. Double plateaus were found where such a theory predicts their appearance - with BaKB and La radiations. Escape peak energy responds to counter voltage in the same manner that the characteristic radiation of an element does and at the same voltages as that of characteristic radiation of equivalent energy.

The plateau shift to lower voltages with increasing atomic number does not continue indefinitely. With the amplifier gain of 10, which was used for most of the work reported, no response is shown below a counter voltage of 600 V even for an element as heavy as Bi. The plateaus of the escape peaks also shift to lower voltages with increasing energy and in time crowd the plateaus of the characteristic radiation to such a degree that the first plateau becomes a mere inflection in the response curve (Figures 4 and 5) and may readily be overlooked or dismissed as a counting irregularity.

In Figure 5 the appearance of a third plateau is evident in second order Bi radiation at approximately 750 V for KB and 800 V for Ka. This is due to the background radiation and is explained by the pulse amplitude distribution curves in Figure 6 which were determined using a counter voltage of 850 V.

First order radiation of Ta and heavier elements occurs at 6° 2θ or less with LiF which is the crystal normally used because it has greater reflectivity than other analyzing crystals (5). The characteristic lines of such elements thus occur where the tube continuum is highest while their intensity is low because of their high excitation potential. Frequently they may not appear above the background in a scan but do appear as second order radiation where the continuum is much lower. Second order is commonly used for this reason and also because there is better separation of neighbouring elements at second order angles. It was used for the determination of the Bi curves in Figure 5.

The second order pulse amplitude distribution shown in Figure 6 is of interest because it shows three amplitude maxima which are responsible for the three plateaus found in Figure 5. These maxima are due to BiKB at 90 V, the background and Bi escape peak at 52 V and the background escape peak at 15 V. The background of first order radiation has the same energy as the radiation. For second order it has much less. In the case of Bi, KB has 87.34 keV with an escape peak of 54.18, while its second order background has 43.72 keV with an escape peak of 10.56. The maximum at 52 V is largely due to this background as the escape of Bi would be small and the background is large. As shown by the scan inset, the background for KB has an intensity of approximately 55 chart divisions while the second order radiation has only 2 above it. The inset also shows the beginning of the rise of the continuum toward its maximum which is well over 100 chart divisions.

The pulse amplitude distribution of first order BiKB was determined to ensure the correct interpretation of the second order one. The width of the 90 V maximum, which contains both line and background, illustrates the crowding of energies at low angles. Its asymmetry indicates that the escape peak is not separated from it. There is no maximum at 15 or 52 V so both of these in the other curve are due to second order background.

CONCLUSIONS

Double plateaus found for elements of atomic number >56 consist of a first plateau due to the characteristic radiation and a second from the escape peak.

At atomic number 72 the first becomes a mere inflection in the voltage response curve due to the crowding of energies as the plateaus shift towards 600 V.

ACKNOWLEDGEMENT

A number of plateaus were determined by Miss C. I. Macdonald, a summer student with the Mineral Sciences Division.

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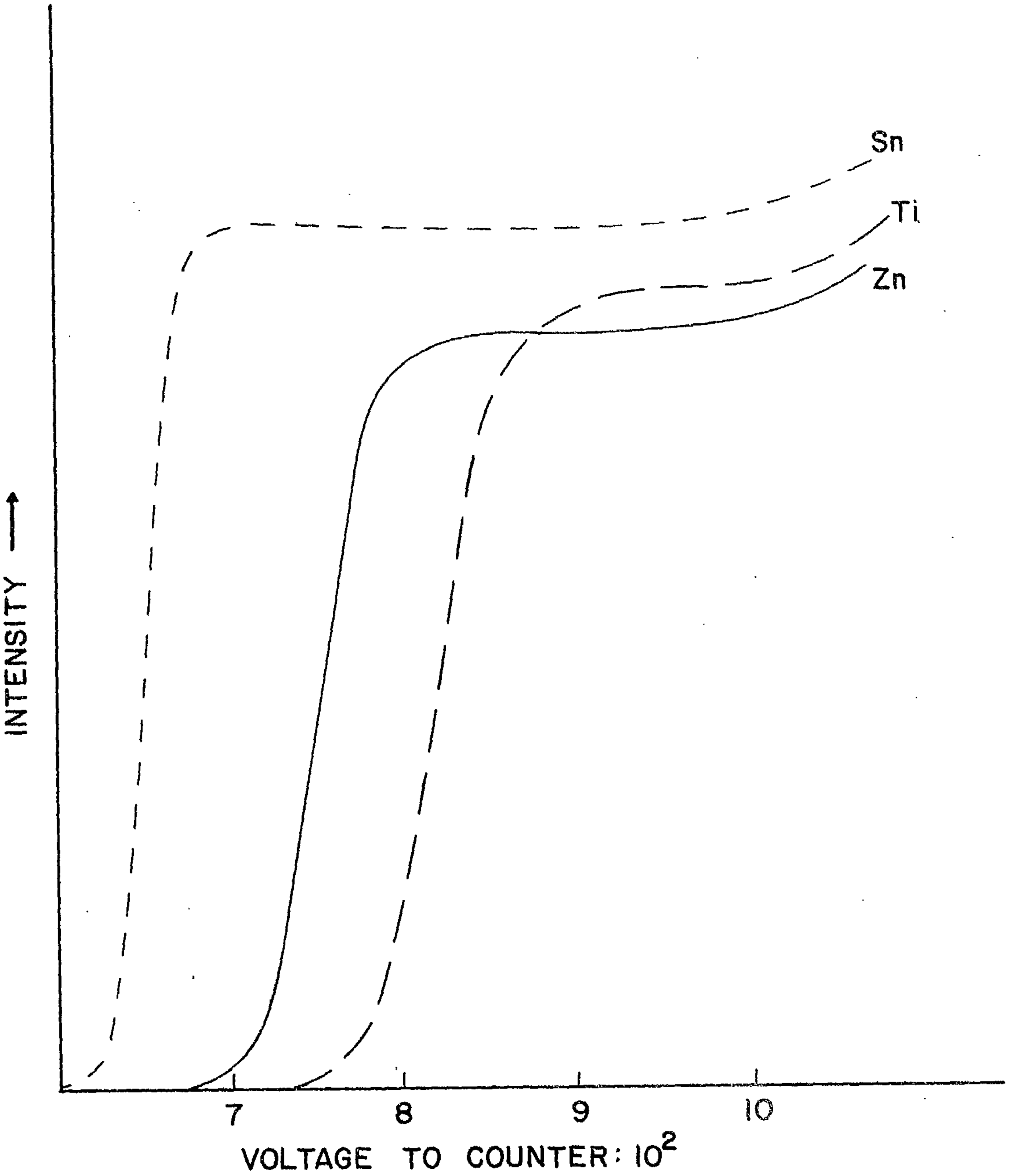

Figure 1. Scintillation Counter Plateaus for Three Ka Radiations.

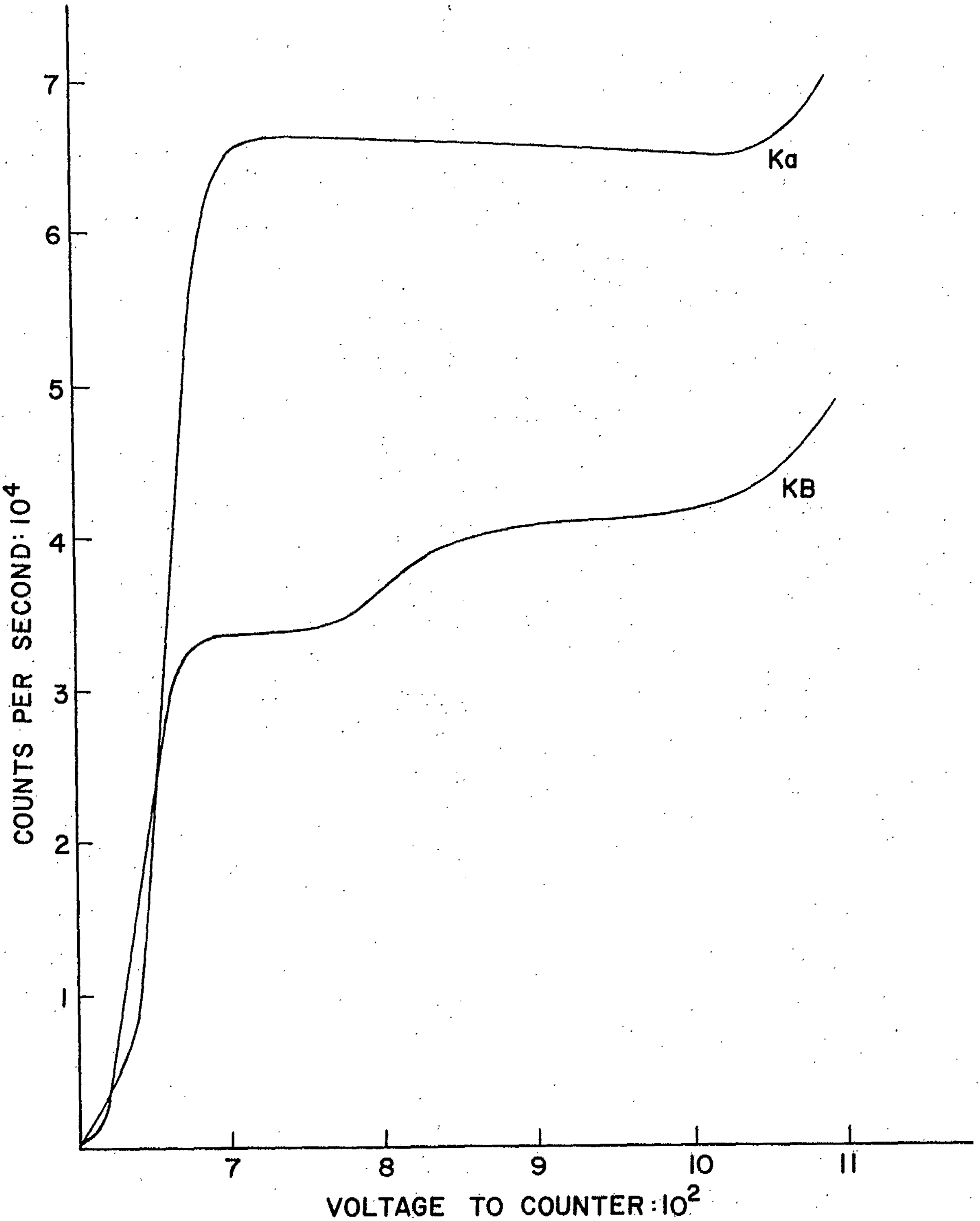

Figure 2. Plateaus for Barium Radiation.

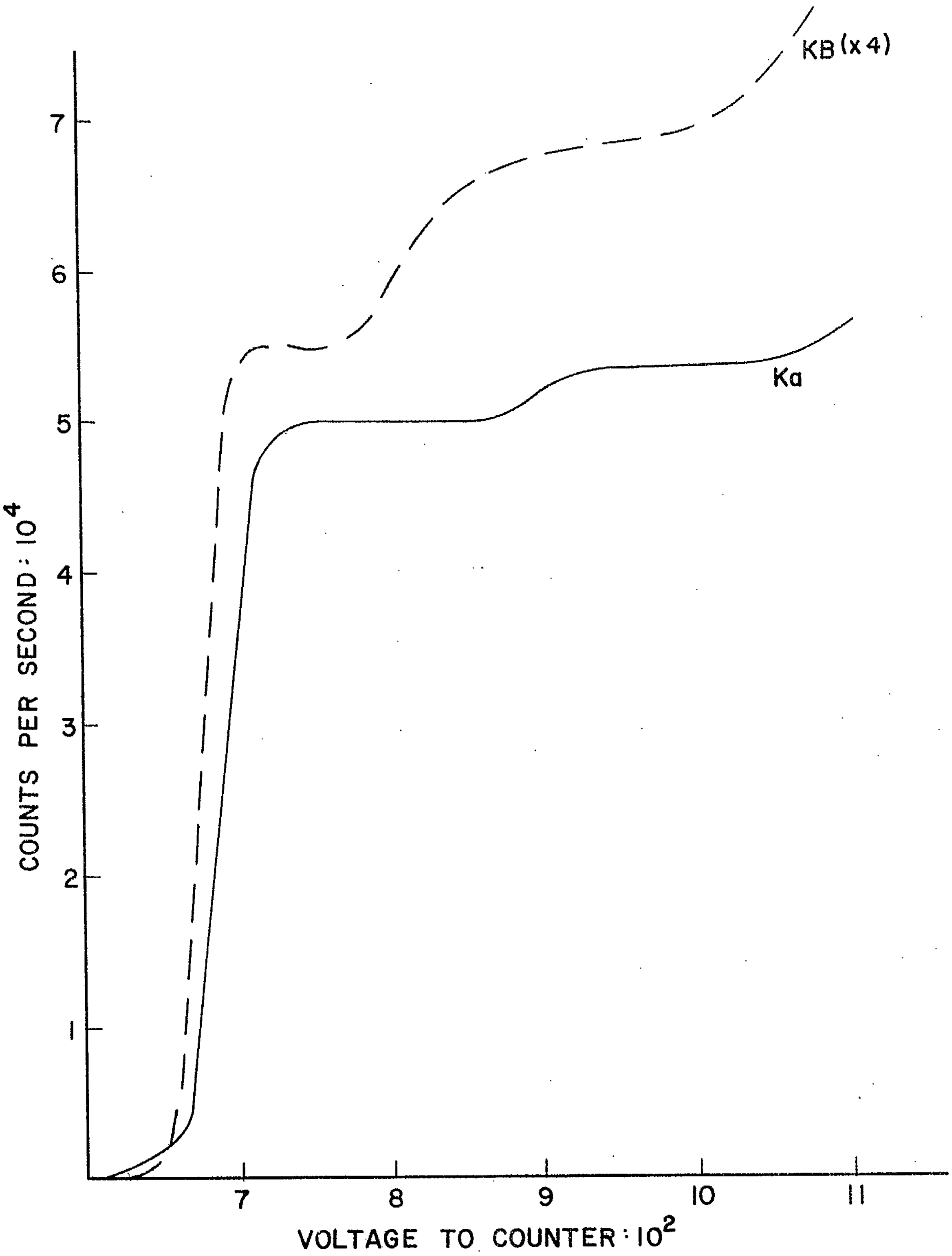

Figure 3. Plateaus for Lanthanum Radiation.

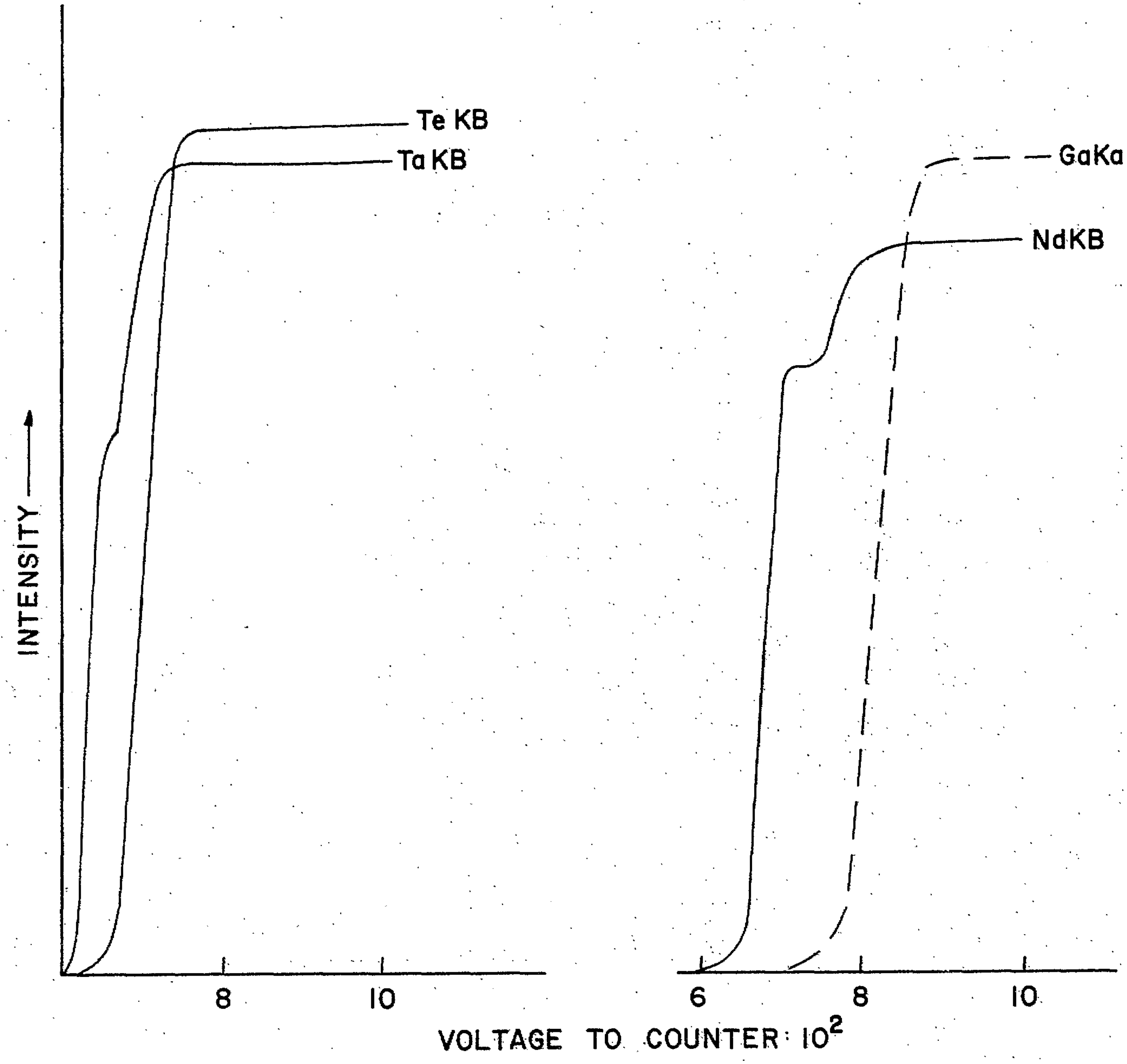

Figure 4. Plateaus for Two Radiations and Their Escape Peak Equivalents.

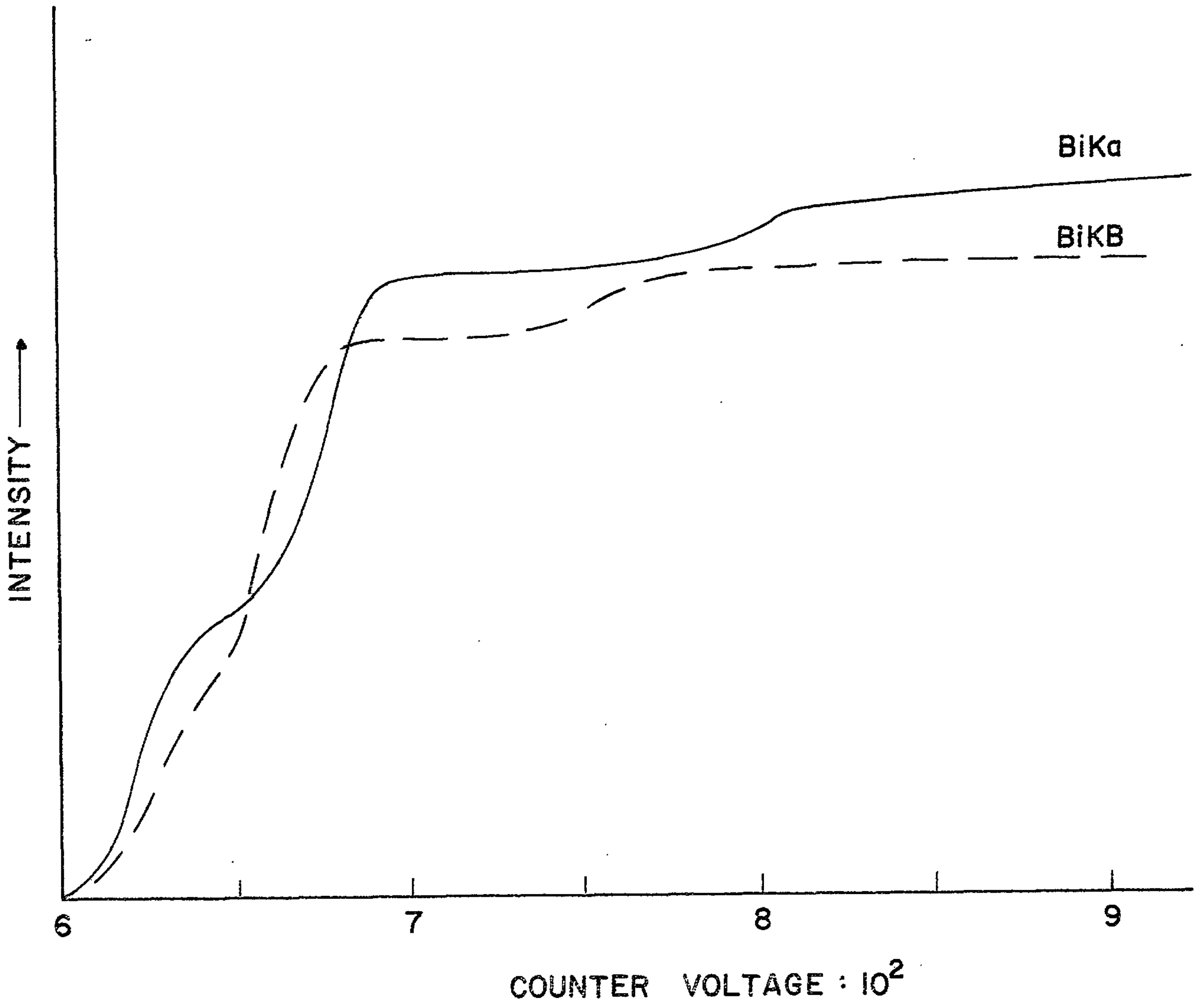

Figure 5. Plateaus for Second Order Bismuth Radiation.

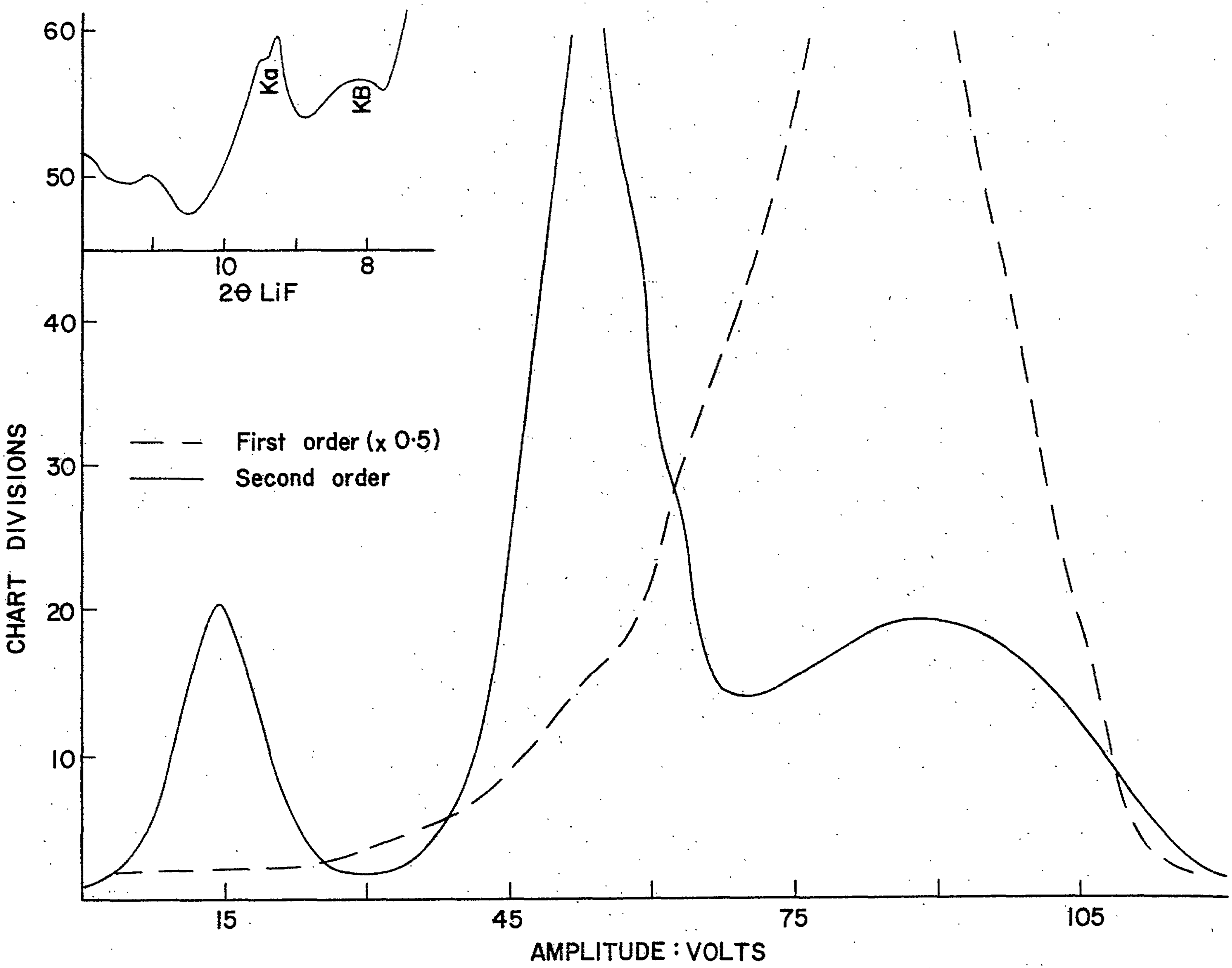

Figure 6. Bismuth KB Pulse Amplitude Distributions.