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INTRODUCTION

Perlman and McKeown[1] have found that they could improve the resolution of an iron double-focusing spectrometer of the Stockholm type by a factor of about 4 by adding shims of soft iron around the outside of the spectrometer. The shimming, however, was done to optimize the resolution for a conversion line of 624 keV (Cs^{137} *K*662). It was not at all clear whether this shimming was then also optimum for lines of other energies; differences might be expected in the low-energy region, where remanence effects and effects of the earth's field may be significant.

It is difficult to investigate the instrumental line shape of electron spectrometers at low energies, because with most sources the energy loss in the source is the principal cause, or one of the principal causes, of the line width. For such an investigation the counter window must also be thin enough to transmit low-energy electrons. In all previous work with the Brookhaven double-focusing spectrometer, the sources were thick enough to dominate the line shape at low energies, and the counter windows did not transmit electrons below 15 keV.

The availability of an electromagnetically separated source of Kr^{79} allowed the investigations reported here to be made. In the decay of Kr^{79} there is a 44-keV transition (in Br^{79}), with a *K*-conversion line at 31 keV, and there are *KLL* Auger electrons at around 10 keV.

COUNTER

The flow proportional counters used in the spectrometer had previously had Mylar windows 580 $\mu g/cm^2$ thick,[2] or even thicker, measuring 38×19 mm. They had been operated with butene-2 gas at a pressure of 25 mm Hg and at a voltage of about 1500 V.

In this work thin windows of VYNS, with an evaporated coating of gold to make them conducting, and of much smaller size (12×3 mm) were used. Films ≈ 60 $\mu g/cm^2$ thick, without support, with support on an 85% transmission tungsten mesh, and with support on a 55% transmission flat nickel foil were all tested, and the leak rates were such that the spectrometer pressure was up to about 10^{-3} mm Hg when the counter gas pressure was up to 15 mm Hg.

It was then decided to determine (1) whether the pressure of the counter gas could be reduced, and (2) whether the higher gas pressure in the spectrometer due to the leaks affected the resolution and transmission of the spectrometer. It was found that good plateaus could be obtained at a counter pressure of 10 mm Hg and even at 7 mm Hg. It was also found that, at an energy of 31 keV and a resolution of 0.19%, the line shape was the same at a spectrometer pressure of 4.2×10^{-4} mm Hg and at 3.5×10^{-6} mm Hg. Comparison plots are shown in Figures 1 and 2.

Finally, gold-coated VYNS films of 100 $\mu g/cm^2$, with a very slow leak rate, were produced, and the final measurements were made with an unsupported window of one of these films.[2] Some plateau curves taken with this counter are shown in Figure 3.

SOURCE QUALITY

The standard source used for aligning and testing the spectrometer was a vacuum-evaporated Cs^{137} source. The line width (full width at half-maximum) at 624 keV is 0.05% in momentum with a 3-cm-wide entrance baffle. There is a tail on the low-energy side of the line which may be due to aberrations and may be partly due to source thickness.

An electroplated Te^{121} source was used in the spectrometer. The line widths found (with 3-cm entrance baffle, 0.65-mm counter slit) were 0.05% at 500 keV, 0.08% at 100 keV, and 0.3% at 30 keV. The source thickness is very important at low energies.

The Kr^{79} source was electromagnetically separated in the Stockholm isotope separator and collected on an electropolished aluminum plate with a retarding field such that the ions entered the plate with ≈ 1.5-keV energy. The source was in-

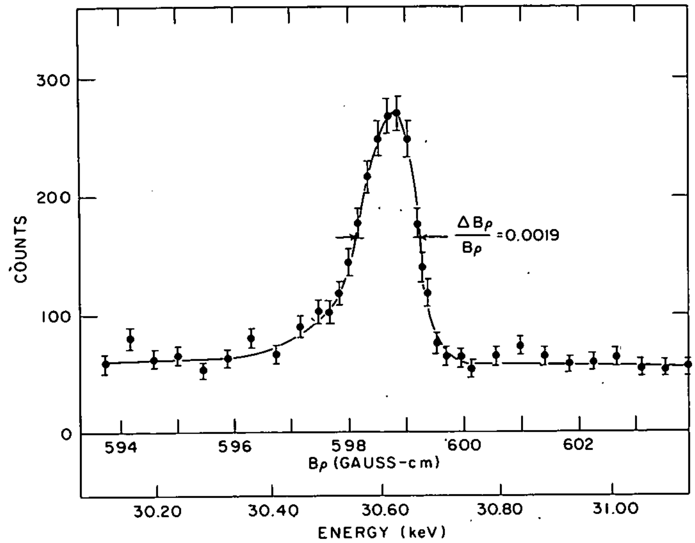

Figure 1. K-conversion electron line of the 44-keV transition in Br^{79} measured with the spectrometer pressure $=4.2\times10^{-4}$ mm Hg.

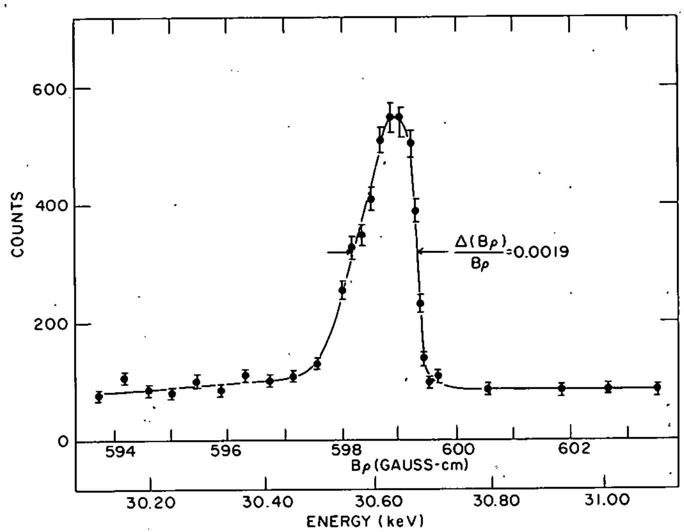

Figure 2. K-conversion electron line of the 44-keV transition in Br^{79} measured with the spectrometer pressure $=3.5\times10^{-6}$ mm Hg.

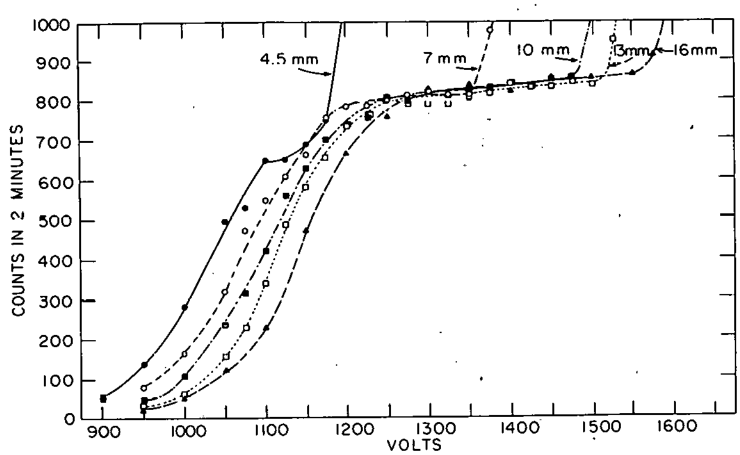

Figure 3. Plateaus of the proportional counter measured with different butene-2 gas pressures.

visible. Autoradiograms showed it to be about 0.3 mm wide. Measurements[3] of the range of krypton ions in aluminum lead to an expected median penetration depth of $\approx$0.5 $\mu g/cm^2$.

When the entrance-baffle openings were reduced to give a line width of 0.08% at 10 keV, the satellite peaks due to plasmon excitation in the aluminum were clearly visible. The experimental spectrum of the KLL Auger group will be discussed in the next section.

SPECTROMETER

With the standard Cs^{137} source the line width with 3-cm-wide entrance baffle and 0.65-mm counter slit is $\approx$0.05%. The vertical baffle opening is about 9 cm high in normal operation.

The Kr^{79} source was aligned with the help of autoradiograms. Initial runs with the standard baffle openings showed a line width of 0.18% at 31 keV and 0.34% at 10 keV.

Reducing the entrance-baffle width to 1 cm gave a line width of 0.09% at 31 keV and 0.19% at 10 keV. Moving the location of the entrance-baffle opening radially 1 cm in and out gave little or no improvement. Reducing the baffle width to 0.5 cm gave no improvement at either 10 or 31 keV. Moving the source 2 cm nearer the entrance baffle seemed to give a slight improvement.

Reducing the vertical entrance baffles to an opening of 3.7 cm reduced the line width at 10 keV to 0.08%, which corresponds to $\approx$16 eV. A plot of a section of the KLL Auger spectrum at 10 keV is shown in Figure 4.

The natural widths of the K, L_2, and L_3 levels in bromine are each about 2.0 eV.[4] The L_1 level width is less accurately known, but the data of Geiger, Graham, and Merritt[5] suggest that it is about 6 eV. Thus the KL_2L_2, KL_2L_3, and KL_3L_3 lines are expected to have the smallest natural width, and the KL_1L_1 line is expected to have the largest natural width. The KL_1L_1 line did indeed appear to be significantly broader than the others; a run with better statistics will be needed to confirm this.

The structure on the low-energy sides of the lines (see Figure 4) is expected from the discrete nature of the predominant energy losses for low-energy electrons (see ref. 5, for example). The characteristic peak in the energy-loss spectrum for Al_2O_3 is at about 20 eV.[6] For aluminum metal, it is only about 15 eV, but the surface of the source was un-

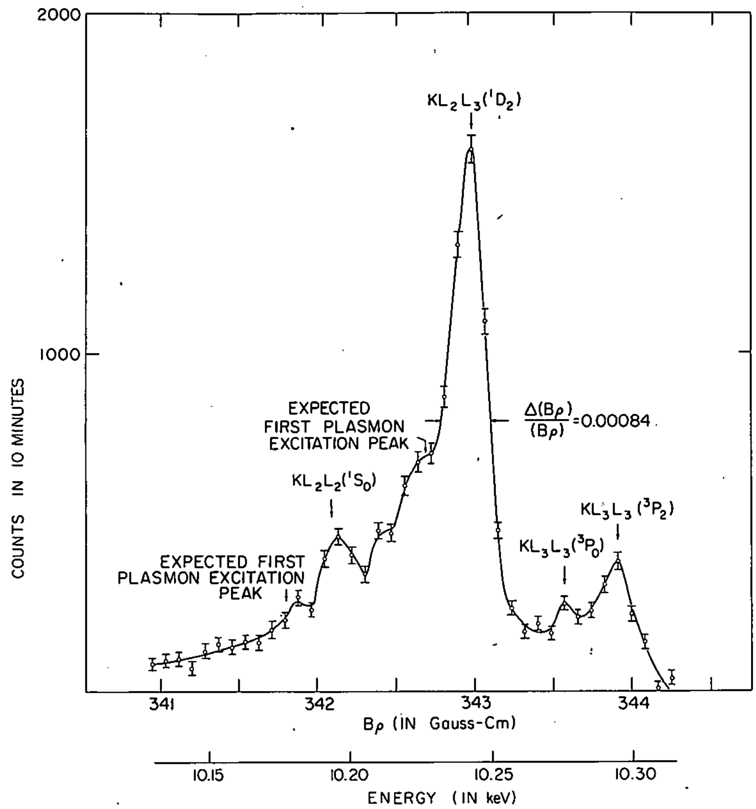

Figure 4. A section of the measured *KLL* Auger electron spectrum of Kr^{79}.

doubtedly well oxidized at the time the data were taken.

The final part of the investigation of the Kr^{79} Auger spectrum was done in Stockholm. The Stockholm spectrometer (of the same design) was finally adjusted to give comparable resolution but with a transmission which was about ten times larger than in the Brookhaven experiments. The Stockholm spectrometer was, however, not shimmed. The field was corrected by empirical adjustment of the coils.[7] P. Erman found that, with a proper demagnetization, it is possible to achieve a resolution as good as 0.1% or better, even at an electron energy of 2 keV.[8] The final report on the relative intensities of the *K* Auger lines will be published in *Nuclear Physics.*

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