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ABSTRACT

An electron-sensitive Ilford K5 emulsion was exposed in a permanent-magnet spectrograph to the small energy region from 312 to 324 kev of the beta spectrum of Pa^{233}. Comparison of this detection method with that of exposing an x-ray photographic film indicated an increase in sensitivity by a factor of eight. Also, there were four possible new lines observed. The techniques and advantages of this method are considered.

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INTRODUCTION

Semicircular spectrographs have long proved valuable in beta spectroscopy because they are easy to operate, dependable, multichannel, and have high resolution. Probably the most common method of detection is the exposing of an x-ray photographic film, but with this method one is confronted with the difficulty of visual determination of relative line intensities in a spectrum by comparison of the relative blackening of the film. Also, there is often enough background due to scattered electrons to obscure weak lines.

During the past decade there have been a few attempts made to expose electron-sensitive emulsions in a spectrograph and then to determine the relative line intensities directly by electron-track counting.

Antonova, who investigated the spectrum of Cs^{137} by using a spectrograph of about 1% resolution, reported that by using freshly prepared NIKFI type R emulsion (Russian) lines weaker by a factor of 300 to 500 could be observed.[1]

Kleinheins investigated the spectra of Cs^{137}, Co^{60}, and Te^{137} by using Ilford G5 emulsion, and was able to make quite accurate determinations of relative line intensities and maximum energies of the beta decays.[2]

Faler, who also used Ilford G5 emulsion, observed an increase in sensitivity by a factor of two for low-energy electrons ($\approx$30 kev) and by a factor of four for higher energy electrons ($\approx$280 kev) in observing the spectra of Pa^{233} and Np^{237}.[3] In the case of the low-energy electrons, background proved to be a primary limiting factor.

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DISCUSSION

In considering the method of detection described in the above reports, one might expect it to have some potential value in beta-spectroscopy, if the limiting factors were minimized. Because of this, our investigation of some of the weaker lines of Pa^{233} was carried out, and the limiting factors involved were considered.

Since the time when the aforementioned investigations were carried out, Ilford has marketed a K5 emulsion that has a smaller grain diameter and increased sensitivity.

This newer emulsion was used for our investigation. The mean grain density in this emulsion parallel to the surface, is about 14 per 10 μ at 40 kev, and about 5 per 10 μ at 300 kev. Because the emulsion shrinks in thickness by a factor of approximately two during development, the grain density in the direction perpendicular to the surface of the emulsion is increased by a factor of two. Therefore, electrons entering normal to the emulsion with high enough energy, so that scattering is small, will be observed as a string of grains running through the emulsion. These are easily observable at 1,000 to 1,500× magnification. Also, the background may be reduced to some extent by neglecting those electrons entering at angles other than perpendicular to the emulsion.

At about 250 kev the mean scattering of an electron perpendicular to the initial direction is about 3 μ per 10 μ. This quantity is inversly proportional to the energy of the electron.[4]

For very slow electrons, where the path length is not great, it may be best to count electron-track ends which are characterized by the high grain density.

Background is always a limiting factor for sensitivity. Background in the form of latent images in the emulsion prior to exposure to the electrons may be eliminated by an erradication process. For our investigation the plates were placed in an atmosphere saturated with water vapor and warmed to 48 °C for 12 hr. A plate that was developed immediately after the eradication showed the emulsion to be completely free of all tracks other than rare α-particle track remnants. The eradication process usually reduces the sensitivity of the emulsion, but there have been cases in which there seemed to be an enhancement. This change was tolerated in our investigation. The sensitivity of an emulsion could be increased, in any case, by hypersensitization. This can be done by placing the emulsion in solution of 1% triethanolamine (2, 2', 2'' nitrilotriethanol) and 5% glycerine in water for about 20 min.

The 50-μ emulsion was processed as follows:

Developer (D 19 dil. 1:6)	≈ 15 min
Wash (distilled water)	≈ 30 sec
Fix	20 min (Until emulsion clears)
Wash (tap water)	2 min
Alcohol + 5% glycerine	2 min
Dryer	5 min

The fix is:

1000 cm^3 water,
300 g sodium thiosulfate, and
22.5 g sodium bisulfate
(at about 20 °C).

EXPERIMENTAL PROCEDURE

In order to test the sensitivity of our method of electron-track counting, the small energy region between 312 and 324 kev of the Pa^{233} spectrum was scanned. This region includes the 340 L_I, L_{II}, and L_{III} lines—the first two of which have been observed to have the intensity ratio L_I/L_{II}=0.5/0.065 (in percent beta decay).[5] The L_{III} line was not observed. Since the L_{II}/L_I intensity ratio indicates a M1+E2(≈ 10%) decay mixture, one can calculate $L_{III}/L_I \approx 0.044$.

The emulsion plate was exposed in a permanent-magent spectrograph of 125-gauss magnetic field for a period of 1 hr; an x-ray film was also exposed for 1 hr in order to compare the sensitivities of the two methods. The emulsion plate was scanned by using 1500X magnification and by counting over an area of 75 μ by 750 μ, with the longer dimension extending across the plate near its center. This area was moved 50 μ along the plate for each new measurement.

RESULTS

The results of one scanning run are shown in Fig. 1. N/A is the number of electrons counted in the area covered at each setting, (in this case 56, 250 μ^2). The horizontal scale is in millimeters along the emulsion plate. The intensities (underlined in the figure) are normalized to that of the L_I line being 0.50 in units of percent beta decay. As can be seen, there are two additional lower energy lines and a possible doublet of higher energy lines, none of which have been reported before. Also, the L_{III} line did not show, its intensity being near the detection limit for the statistics involved.

A 24-hr exposure of the spectrum on x-ray film was closely scrutinized after the track count was made. There seemed to be a slight intensity plateau on the tail of the L_I line, which could be one or both of the lower energy lines detected. No indication of the doublet was seen.

The comparison of line intensities is often best made visually in using x-ray film. The weakest line visible on the x-ray plate would be about 0.4 the intensity of the 340 L_I line. This indicates about an eightfold increase in sensitivity when using our track-counting example. (Here relative sensitivity is defined as the ratio of the intensity of the weakest line detectable by the x-ray film exposure to that of the weakest line detectable by the emulsion exposure.) This figure can, of course, be improved with better statistics. The time required to obtain each point on the graph was about 5 min, which does not seem unreasonably great for the results obtained. The counting itself however, is tedious and very tiring.

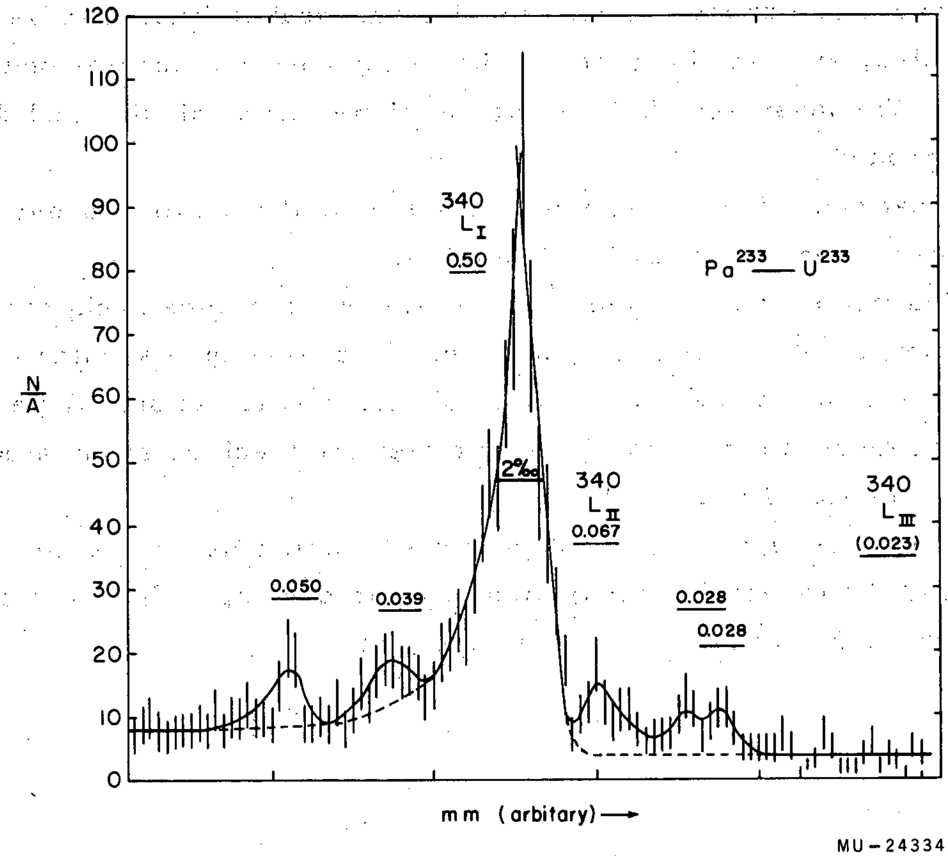

Fig. 1. Results of one scanning run between energies 312 and 324 kev, where N/A is the number of electron tracks per 56, 250 μ^2.

IMPROVEMENTS AND EXTENSIONS

Because of the considerable increase in sensitivity, the resolution may be improved, and shorter-lived isotopes and weaker lines may be investigated. Also, an emulsion plate might be exposed in a double-focusing spectrometer, the advantages here being the higher transmission and the reduced background.

The treatment of the emulsion could also be altered to improve sensitivity and to ease electron-track identification.

Eradication of emulsion plates is necessary to reduce background, if very freshly poured plates are not available. Of course they should be exposed in the spectrograph as soon as possible after eradication. Hypersensitization can increase the sensitivity of either the fresh or eradicated emulsions by a factor of two.

The electron tracks can be made more conspicuous by overdeveloping, perhaps even to the extent that the grains begin to overlap. This will certainly decrease the tedium involved in scanning the plate.

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