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The β-Radiations of Uranium X_1*

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An investigation of the distribution with momentum of the β-rays of uranium X_1 has been made by analyzing them with the magnetic electron lens spectrometer. The results are recorded by an electrical counter detection and mechanical recorder in the range between $H\rho<650$ and $H\rho>1875$. The lower limit of the range is limited by the window of the detecting device. The results of the experimental records $N/H\rho$ are plotted against $H\rho$ and the plot represents the normalized energy spectrum. In the continuity of the spectrum there is a clear evidence of three distinct peaks. The energy values of these peaks which represent three groups of β-rays due to internal conversion agree with those obtained by Meitner. The spectrogram shows that the end point of the continuous UX_1 β-ray spectrum is at $H\rho$ 1617 (189.9 kev), a value which agrees with those that are obtained by absorption method but differs considerably from Marshall's value obtained by the method of the expansion chamber. The present value, unlike that of Marshall, gives a point on the Sargent diagram nearly on the curve of allowed transitions.

1. INTRODUCTION

THE disintegration of uranium X shows β-activity with an emission of soft γ-rays which give rise to a few homogeneous groups of β-rays due to internal conversion. These β-groups were investigated by von Bayer, Hahn, and Meitner.[1] Their energy spectrum, showing well-defined lines—each indicating the energy limit of one of these groups—was measured by Meitner.[2]

In the decay process of uranium X_1, of the total β-ray emission, the characteristic β-rays are only a part, the essential portion, whose emission leads to a change in the nuclear charge and thus in the atomic number of the element, being the actual disintegration β-particles. These nuclear β-rays have velocities that vary over a wide range as first demonstrated by Chadwick.[3] An investigation of the distribution of these disintegration electrons as a function of energy or $H\rho$ should prove very useful in finding the upper limit of the kinetic energy carried by them. This datum is important, since it gives the total disintegration energy of this radioactive material.

2. EARLY EXPERIMENTS WITH UX_1 BY ABSORPTION METHODS AND THEIR RESULTS

The earliest experiments with uranium X, by absorption methods, were done mainly for finding the absorption coefficients of the uranium X β-rays in different materials. From the data and the absorption curves, obtained by Levin,[4] Schmidt,[5] and Fajans and Gohring,[6] it is possible to have some information concerning the maximum energy of the UX_1 disintegration electrons. It is of course difficult to interpret these curves with the degree of certainty necessary for precisely ascertaining the range. It may, however, be estimated and this, by the range/momentum law of Marshall and Ward,[7] may give the end point half-way between $H\rho$ 1400 and 1850. The value of the absorption coefficients for UX_1 β-rays in aluminum so found, on applying the empirical relation of Chalmers,[8] gives the end point of $H\rho$ 1640. Thus in the former there is some uncertainty, while the latter result involves an empirical rule. This method is an indirect one, but the results of its application in most of the other cases used, on comparing with those obtained by magnetic analysis, are found to be satisfactory.

3. THE USE OF AN EXPANSION CHAMBER TO INVESTIGATE UX_1 β-RAYS

An expansion chamber is also employed for the study of β-rays. In this method, the tracks of the β-particles are photographically recorded and from the curvature of the tracks produced by a

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[1] von Bayer, O. Hahn, and L. Meitner, Physik. Zeits. **14**, 873 (1913).
[2] L. Meitner, Zeits. f. Physik **17**, 54 (1923).
[3] J. Chadwick, Verh. d. D. Phys. Ges. **16**, 383 (1914).
[4] M. Levin, Physik. Zeits. **8**, 585 (1907).
[5] H. W. Schmidt, Physik. Zeits. **10**, 6 (1909).
[6] K. Fajans and O. Gohring, Physik. Zeits. **14**, 877 (1913).
[7] J. Marshall and A. G. Ward, Can. J. Res. **A15**, 39 (1937).
[8] J. A. Chalmers, Proc. Camb. Phil. Soc. **28**, 319 (1932).

magnetic field, a continuous distribution with velocity is found. For the investigation of the UX β-radiations, this method has been applied by Lecoin[9] and subsequently by Marshall.[10] Lecoin in his experiment used a thin UX source in an expansion chamber and as he found no UX peak in the distribution he obtained, he came to the conclusion that the end point was below $H\rho$ 1115 (100 kev). Marshall,[10] employing an expansion chamber containing hydrogen or helium at atmospheric pressure with ethyl alcohol vapor, with particular regard to momentum values below $H\rho$ 2000, has investigated the distribution with momentum of the UX_1 β-rays. He has found that these rays extend at least to $H\rho$ 1950, a value which differs very much from the one obtained from the mass absorption coefficient for UX_1 β-rays in aluminum by Chalmer's relation.[8]

In the cloud-chamber experiments, the measurements involve the selection of the tracks unaffected by scattering and in the absence of definite and strictly quantitative criterion for rejecting those β-ray tracks whose curvatures have been appreciably affected by scattering, the precision of the results is probably somewhat questionable. With high energy β-particles, an experiment employing a cloud chamber with air replaced by light gas may give satisfactory results provided a large number of particles are registered and the selection of the tracks which have not been appreciably affected by scattering is not faulty. The evidence obtained from the cloud-chamber experiment is liable to be less reliable, especially when the variation of the efficiency of registration of tracks with velocity during the time of expansion is not carefully investigated.

4. DIRECT METHODS OF ANALYSIS AND THE UX_1 ENERGY SPECTRUM

An investigation of the UX_1 β-rays by one of the two direct methods in vogue which gives the entire energy spectrum, showing the end point, should therefore prove very fruitful. Of these two, the first consists in analyzing the β-rays with the usual semi-circular focusing in a magnetic field and detecting the results by an electrical method. The second consists in analyzing them with the magnetic electron lens or with the electrostatic lens selective focusing and recording the results by the devices of detection and automatic registration.

A detailed and reliable record of the energy spectrum of UX_1 is important for considering its actual form and end point which gives the total disintegration energy. With improved data obtained in this way, the form of the continuous spectrum can be ascertained and the position of the end point on the original Sargent[11] diagram can be determined to test the other results and especially the latest one obtained by the cloud-chamber method[10] which has given an end point far to the right of the curve of allowed transitions.

5. EXPERIMENTAL ARRANGEMENT

In the present experiment, a thick magnetic electron lens β-ray spectrometer has been employed with a source of UX_1 of adequate strength and purity to investigate the energy spectrum from $H\rho < 650$ to $H\rho > 1875$, the lower end of the region being limited by the window of the detecting device.

The spectrometer, as explained elsewhere in detail,[12] is designed on the geometrical model of electron trajectories in a standard field, obtained from the determinants of their parameters and radial displacements. The design admits about 5 percent of 4π in solid angle of β-rays from the source into the field of the selective focusing action. The spectrometer, with a source holder on one end and an electrical counter on the other and with different component parts assembled together, is mounted in the body of a magnetic electron lens system, as shown in Fig. 1. This system is comprised of seven air-core, multi-layer straight solenoids, each 5 cm long, connected together in series and mounted on a cylindrical brass tubing about 12 cm in diameter and 50 cm in length. The spectrometer is fixed in the part of the lens body where the magnetic field is nearly homogeneous and axially symmetrical so that the lens system and the spectrometer are perfectly coaxial. The electron lens system with the spectrograph mounted in it is so adjusted as to let its axis be in alignment with the earth's magnetic lines of force.

[9] M. Lecoin, J. Phys. Rad. **9**, 81 (1938).
[10] J. S. Marshall, Proc. Roy. Soc. **A173**, 391 (1939).
[11] B. W. Sargent, Proc. Roy. Soc. **A139**, 659 (1933).
[12] S. Jnanananda, Liverpool University, Ph.D. thesis, 1943.

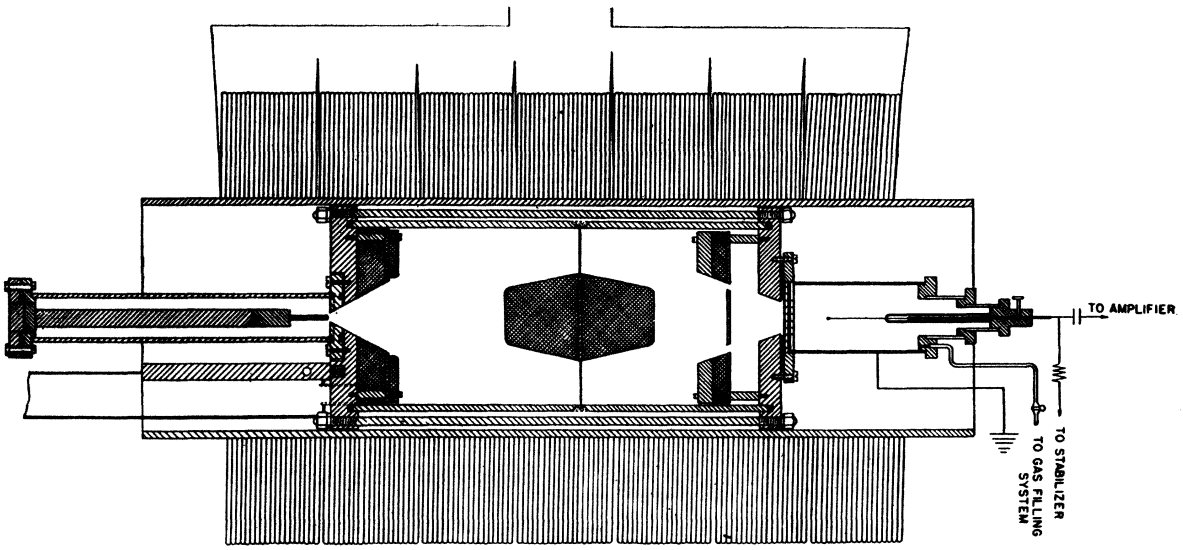

FIG. 1. Thick magnetic electron lens beta-ray spectrometer.

The spectrometer and the source chamber are exhausted to a pressure of nearly 10^{-5} mm of mercury by means of a single stage apiezon oil diffusion pump backed by a rotary pump.

Electrical power for the solenoids is supplied from 110-volt accumulators. The variation of the magnetizing current is effected by potentiometer control and the current at each variation is measured by a calibrated shunt connected to an ammeter. The current is constant to within one in at least two thousand parts during each short interval of operation at the end of which the necessary records are made.

The electrical counter, fixed at the end of the spectrometer, opposite to the source holder chamber, is used to detect the β-ray spectrum. Power necessary for the operation of the counter is applied from a neon valve stabilizer. This counter is provided with an amplifier, a scale of sixteen, and a thyratron operated mechanical recorder. This equipment is provided with H.T. of 230 volts from an eliminator.

6. CALIBRATION OF THE MAGNETIZING COIL CURRENT IN TERMS OF $H\rho$

In a magnetic electron lens β-ray spectrometer, the position of the source and that of the focal region, where an electrical counter is placed, are fixed so that β-rays of a particular velocity are focused at the effective region of the counter by the action of its corresponding field of force of the magnetic electron lens. This definite field of force can be determined by calibrating the magnetizing current in terms of $H\rho$ of a measured β-line. The calibration has been done by experimentally determining the magnetizing coil current which corresponds to the peak of the accurately measured[13] F-line of thorium B. It has been found that a magnetizing current of 2.4 amp. corresponds to the peak of the chosen reference line at $H\rho$ 1385.6.

7. EXPERIMENTAL PROCEDURE

A circular foil of platinum, 3 mm in diameter, with one of its surfaces having a deposit of uranium X_1 uniformly spread on it, is mounted and fixed on the tip of a brass rod. This brass rod, with its source carrying end, is screwed on a holder which is fixed in the source chamber so that the center of the foil lies on the axis of the spectrometer and the platinum surface with the

TABLE I. Relative strengths of the source used for different energy ranges.

Relative strength	Momentum range ($H\rho$)
11.9	From 600 to about 860
10.0	From 860 to about 1000
1.4	From 1000 to about 1150
1.3	From 1150 to about 1300
1.1	From 1300 to about 1560
1.0	From 1560 to about 1875

[13] C. D. Ellis, Proc. Roy. Soc. **A138**, 318 (1932); K. C. Wang, Zeits. f. Physik **87**, 633 (1934).

active deposit of UX_1 at the very threshold in front of the entrance aperture. After these arrangements, the spectrometer with the source chamber is exhausted to the limiting pressure.

Then the effect in the counter without the focusing action of the magnetic electron lens has been recorded. The counter record has been taken as a measure of the intensity of the source. With such counter records, the relative intensities of the source used at different times have been estimated. Also for a magnetizing coil current of 1.5 amp., the different sum total effects in the counter, for the different times the active source is used for investigation, have been recorded to verify the results obtained by the former method. There has been a fair agreement between the estimations of the intensities of the source obtained by these two methods. The mean value of the results of these two kinds of estimations is taken as the actual relative strength of the source, each time it is used for investigation. In this way, accidental errors and those arising out of statistical fluctuations are minimized in the determination of the relative intensities of the source. After the estimation of the relative intensity of the source, the magnetizing current has been applied and has been gradually raised at precisely regular intervals in steps of 12.5 ma from the lower limit up to the upper limit of the momentum range. At each step of the coil current and at the end of each interval, the counter reading corresponding to the magnetizing current applied during that interval has been recorded. In this way the spectrum of UX_1, with the source in different strengths at various ranges, has been measured by means of counter records (Table I).

Each one of the series of counter records which corresponds to one of the ranges, given in Table I, has been individually corrected for decay. The different spectrometrical data thus obtained with different relative strengths of the source have been reduced to those of the intensity of the source which is arbitrarily taken as a standard.

TABLE II. Data on three line groups.

Number of the line	Origin	Relative intensity	log $H\rho$	$H\rho$	Energy (kev)
I	L_1	10	2.96561	924	70.3
II	M_1	6	3.01069	1025	85.3
III	N_1	1	3.01977	1047	89.9

From these corrected series of counter impulse frequency records of the source of standard strength and their corresponding values of the magnetizing coil current in terms of $H\rho$, obtained by the experimental determination of the coil current corresponding to the F-line of thorium B at $H\rho$ 1385.6, the $N/H\rho$ values have been obtained for the entire measured momentum range $(600 < H\rho - 1875 < H\rho < 2000)$ of the β-particles of this source of the chosen standard strength. These values of $N/H\rho$ are plotted against those of their corresponding $H\rho$.

8. THE SECONDARY AND THE PRIMARY β-RAY SPECTRUM OF UX_1

The plot shown in Fig. 2 represents the curve of the distribution with momentum of the UX_1 β-rays. In the continuity of the spectrum there is a clear evidence of three distinct β-groups. The data of these three groups are given in Table II and for comparing them with those that are obtained by Meitner,[2] the two data are given in Table III.

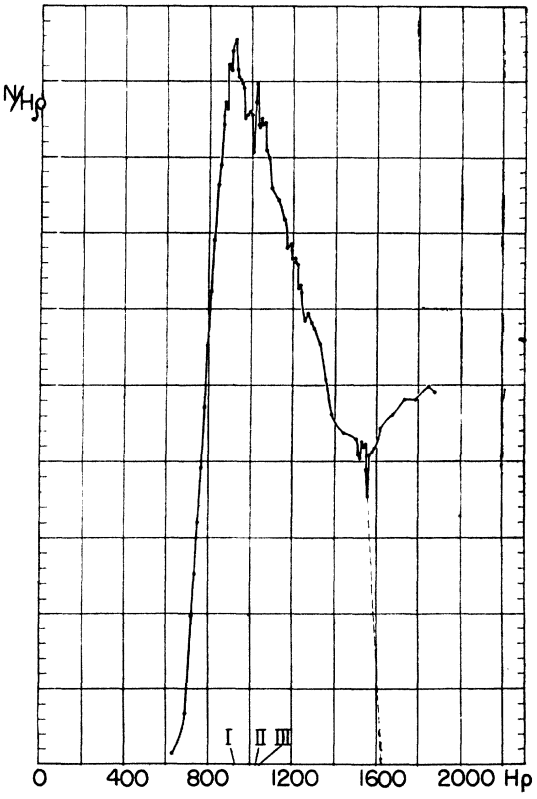

FIG. 2. Energy spectrum of uranium X_1.

From Table III, it is obvious that the present energy values of the β-lines agree with those of the same lines obtained by Meitner. The $N/H\rho$-values, plotted in the graph (Fig. 2), are not corrected for the relative absorption of the β-particles by the counter window. The β-particles of below $H\rho$ 650 are greatly cut off by the counter window. So, the low energy end-point of the continuous spectrum cannot be ascertained. The influence of the counter window on β-particles of over $H\rho$ 900 is, in consideration of the thickness of the window, so trivial that the values of the relative intensities of the β-lines given in the Table II, within the limits of experimental errors, may be regarded as being inappreciably affected.

An inspection of the distribution curve in Fig. 2 shows that it rises up to a maximum with three distinct off-shoots, representing three homogeneous groups of β-rays due to internal conversion. It then falls down at first abruptly, then gradually with a series of kinks beginning from $H\rho$ 1170 to $H\rho$ 1270 which indicates groups of weak energy lines. The curve then sinks down abruptly to a minimum, representing the end point of UX_1, from whence it rises again first abruptly and then gradually. The first part of the curve up to the second minimum represents the energy spectrum of UX_1 β-rays with its upper end point overlapped by the low energy part of the (UX_2+UZ) continuous β-spectrum. A line projected in the direction of the upper end at the second minimum intersects the momentum axis. This point of intersection indicates the upper limit of the continuous UX_1 β-ray spectrum at $H\rho$ 1617 (189.9 kev).

The value of the end point at $H\rho$ 1617, obtained thus by the present spectrometric method, agrees with the mean value of $H\rho$ 1625, obtained from effective range measurements in aluminum of Levin,[4] Schmidt,[5] and Fajans and Gohring[6] by the range/momentum law of Marshall and Ward.[7] It also agrees with the value of $H\rho$ 1640 obtained

TABLE III. Comparison with Meitner's data.

Number of the line	Meitner's data $H\rho$	Meitner's data Kev	Present data $H\rho$	Present data Kev
I	927	71.0	924	70.3
II	1028	86.2	1025	85.3
III	1057	90.7	1047	89.9

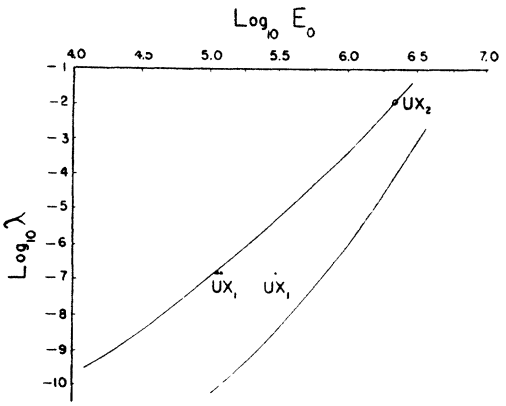

FIG. 3. The Sargent diagram.

from absorption coefficient found for the UX_1 β-rays (about 500 cm Al) by the empirical relation of Chalmers.[8] The present value, however, differs very much from the value $H\rho$ 1950 (265 kev) of Marshall obtained by expansion chamber method.

In this connection it is interesting to note that in almost all cases where the upper end points of continuous spectra have been measured by the three methods, there has been agreement between the values obtained by absorption measurements and those obtained by the magnetic spectral analysis while in most of the cases the results from cloud-chamber measurements have differed from those obtained by the other mentioned methods.

The present value of the end point of the continuous UX_1 β-spectrum, unlike Marshall's value, gives a point on the Sargent diagram, shown in Fig. 3, nearly on the curve of allowed transitions. The present value of UX_1 on the Sargent diagram is indicated by ▲ and the value obtained by absorption measurements by a dot. Marshall's value for the same is indicated also by a dot which is definitely away from the curve of allowed transitions.

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