Energy Determination of Cs^{137} K Conversion Electrons*

S. K. BHATTACHERJEE,† B. WALDMAN, AND W. C. MILLER
Department of Physics, University of Notre Dame, Notre Dame, Indiana
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The electrostatic analyzer, previously used to determine the photodisintegration thresholds of deuterium and beryllium, has been used to measure the absolute energy of the K-conversion electrons from Cs^{137}. A value of 625.2±0.9 kev was obtained, in agreement with the measurements of others.

INTRODUCTION

IN the preceding paper,[1] the determination of the photodisintegration thresholds of deuterium and beryllium is described. These thresholds are obtained by measuring the energy of the electrons producing the bremsstrahlung with a cylindrical electrostatic analyzer. As a check on the energy scale of the analyzer, we decided to measure the energy of a well-known electron line from Cs^{137}.

A 2.60-min Ba^{137} isomer results from the beta decay of (37-yr) Cs^{137}. This isomer decays to the ground state by emission of a gamma ray of 661 kev and internally converted electrons of 624 kev. Langer and Moffat[2] measured the energy of the K internal conversion electrons by comparison with the K internal conversion electrons from Au^{198} using a 180° double-focusing magnetic spectrometer. They used the value of 411.2 kev for the Au^{198} gamma ray as determined by DuMond, Lind, and Watson[3] with a curved crystal spectrometer. Their result is 623.9±0.7 kev for the K electrons and 661.4±0.7 kev for the gamma ray after adding the K electron binding energy.[4]

Muller, Hoyt, Klein, and DuMond[5] measured the gamma-ray energy of the Cs^{137} directly with a curved crystal spectrometer. Their result is 661.60±0.14 kev.

Lindstrom, Siegbahn, and Wapstra,[6] using a double-focusing magnetic spectrometer, measured this gamma ray by comparison of the photoelectrons from a uranium converter irradiated by (a) annihilation radiation, (b) the 510.85-kev gamma ray of ThC″, and (c) the Cs^{137} gamma ray. With the same instrument the energy of the Cs^{137} K conversion electrons was determined by comparison with the conversion electrons of the previously mentioned ThC″ line. The same authors measured the energy of the K conversion electrons of Cs^{137} in a small 180° magnetic spectrograph, calibrating the magnetic field with the proton magnetic resonance absorption. Their final result is 661.65±0.15 kev for the gamma ray and 624.21±0.15 kev for the K electrons.

From these determinations one sees that the energy of the Cs^{137} K conversion electron is known to within 1 part in 4000. This is an excellent electron line to check our electrostatic analyzer which has an inherent accuracy of about 1 part in 1000.

EXPERIMENTAL

The cylindrical electrostatic analyzer used in this experiment has been described by Noyes, Van Hoomissen, Miller and Waldman.[1] It is an absolute energy instrument having an accuracy of about 0.1 percent. Honnold and Miller[7] have developed the theory of this analyzer, giving special attention to the effect of the small residual magnetic field.

Since this analyzer was used originally to analyze the electron beam of our electrostatic generator, the following additional measurements and modifications had to be made for use as a spectrometer: (a) the final detection slit had to be relocated, (b) the low energy of the electrons required a more accurate mapping of the magnetic field, (c) a suitable electron detection device had to be incorporated.

Location of Detection Slit

The plan of the analyzer is shown in Fig. 1 of Noyes *et al.*[1] There are four pairs of beam and field defining slit systems. The object slit S_1 is in the object plane 30 in. from the entrance end of the analyzer. Slits S_2 and S_3, located at the entrance and exit ends of the analyzer, serve to limit the extent of the electric field. Herzog[8] has shown that for the gap width of 0.304 in., the fringe field at the ends of the analyzer can be considered zero if S_2 and S_3 have total widths of 0.150 in. and are spaced 0.060 in. from the plates P_1 and P_2. Slit S_4 is in the image plane located 11.3 in. from the exit end of the analyzer.

The process of placing slits S_1 and S_4 on the tangents to the analyzer at the entrance and exit ends respectively, is very tedious as described by Noyes *et al.* The distance l'' between S_3 and S_4 depends upon the electron energy and must be variable if one desires to use the analyzer as a beta spectrometer. After changing

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† Now at Tata Institute, Bombay, India.
[1] Noyes, Van Hoomissen, Miller, and Waldman, preceding paper [Phys. Rev. **95**, 396 (1954)].
[2] L. M. Langer and R. D. Moffat, Phys. Rev. **78**, 74 (1950).
[3] DuMond, Lind, and Watson, Phys. Rev. **73**, 1392 (1948).
[4] Hill, Church, and Mihelich, Rev. Sci. Instr. **23**, 523 (1952).
[5] Muller, Hoyt, Klein, and DuMond, Phys. Rev. **88**, 775 (1952).
[6] Lindstrom, Siegbahn, and Wapstra, Proc. Phys. Soc. (London) **B66**, 54 (1953).
[7] V. R. Honnold and W. C. Miller, Nuclear Physics Technical Report No. 2, University of Notre Dame, 1953 (unpublished).
[8] R. Herzog, Z. Physik **89**, 447 (1934).

l'' it is advisable to have a rapid and reliable means of checking the transverse location of S_4. Consequently, a point was located (to within 0.01 in.) on the surface plate at the intersection of both tangents to the median line orbit. The location of the slits S_1 and S_4 was accomplished by a telescope and plumb bobs erected at this point and at either S_2 or S_3.

It is of interest to note that this location of S_1 was identical (within the accuracy of our observation) with the original location determined by triangulation.[1] During the course of the experiment, slit S_4 was moved transverse to the trajectory in order to study the intensity distribution in the image plane. It was found that the maximum height of the K peak occurred when S_4 was located on the previously determined tangent line.

Magnetic Field Mapping

Noyes *et al.*[1] measured the magnetic field in the electrostatic analyzer using a flip coil and ballistic galvanometer. Due to the limitation of the size of the flip coil the deflections were only a few millimeters. Consequently, the more sensitive peaking strip[9] method was used in this experiment.

A strip ($\frac{1}{16}$ in.$\times\frac{3}{8}$ in.$\times$0.005 in.) of Delta-max was inserted into the center of a 1000 turn coil of No. 40 copper wire wound on a Lucite spool (0.40 in.$\times$0.15 in.). This probe was small enough to clear the plates of the analyzer and was mounted on the arm pivoted at O for the mapping between O' and O''.

The probe was used as one of the arms of a Maxwell bridge. The oscillator was a Hewlitt Packard 200-C and the detector was a Hewlitt Packard 300-A Wave Analyzer. It can be shown that any even order harmonic generated in such a probe is practically a linear function of the external magnetic field. Consequently, the oscillator was set at 5 kc/sec and the analyzer at 10 kc/sec. The bridge is balanced with the probe in zero field with both oscillator and detector at 10 kc/sec. The oscillator is then set at 5 kc/sec and its second harmonic remains balanced. Since the Maxwell bridge is frequency independent (for linear elements) the fundamental is almost balanced and thus does not saturate the detector.

This device was calibrated in the field of a standard solenoid for an oscillator voltage of 10 volts at 5 kc/sec. The calibration curve is linear up to 1.5 gauss (the largest field used) and has a slope of 5.6 milligauss/millivolt.

The direction of the magnetic field was determined by superposing a small field of known direction on the probe. An increase in output voltage indicates parallel fields, a decrease indicates antiparallel fields. This small field was obtained by a dc current (from a high impedance source to maintain bridge balance) through the coil of the probe.

The distribution of the magnetic field in the regions between S_1 and S_2, between S_2 and S_3 (0° to 90°), and between S_3 and S_4 is shown in Fig. 1. These measurements agree with the preliminary measurements made by Noyes *et al.* using the small flip coil and ballistic galvanometer.

Honnold and Miller[7] have used these results in their analysis of the effect of this small residual magnetic field on the energy determinations made with this electrostatic analyzer. For the case of the Cs^{137} conversion electrons the energy determined from Eq. (2) of Noyes *et al.* must be decreased by 2.9 kev.

Electron Detection

Due to the high source strength, a directional detector must be used to reduce the background. Preliminary experiments with two Geiger counters in coincidence proved satisfactory. A dual Geiger counter was machined from a brass block and was filled with the conventional argon-ethyl alcohol mixture. Both halves of the counter had the same characteristics and were operated at 1150 volts. The coincidence background counting rate was 100 per 10 minute interval and remained constant throughout all the experiments.

Source

The electrostatic analyzer subtends a very small angle and consequently necessitates a strong source. A distilled water solution of Cs^{137} chloride was evaporated on a one-mil aluminum foil, 0.04 in.$\times$0.5 in., depositing a source of approximately 2 to 3 millicuries. The source, on its aluminum foil backing, was mounted directly behind slit S_1 and grounded electrically to avoid charging effects.

RESULTS AND DISCUSSION

Figure 2 (Experiment I) is a plot of the net coincidence rate *versus* potentiometer reading of voltage across the electrostatic analyzer plates. Slits S_2 and S_3, which act as guard slits at the entrance and exit of the analyzer, were set at 0.15 in., a value which made the fringe field zero.

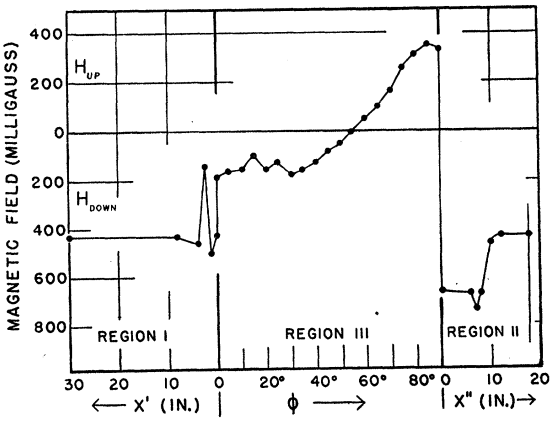

FIG. 1. Vertical component of magnetic field along the electron trajectory.

[9] Adams, Dressel, and Towsley, Rev. Sci. Instr. **21**, 69 (1950).

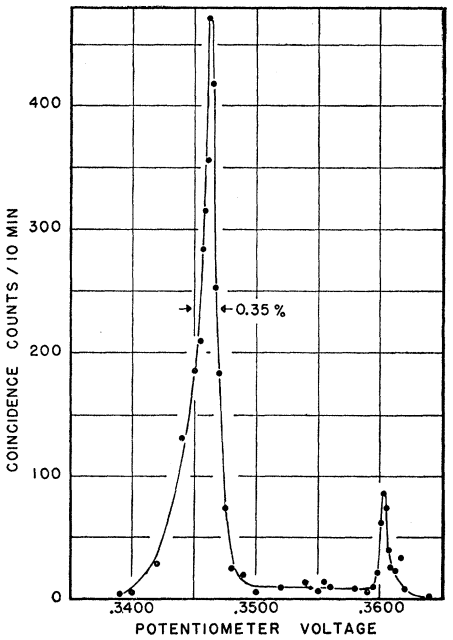

FIG. 2. Experiment I, Conversion electron spectrum. Guard slits S_2 and S_3 set at 0.15 in.

In order to obtain a greater intensity slits S_2 and S_3 were widened to 0.20 in. Figure 3 (Experiment II) is a plot of the data. The increased width of S_2 and S_3 resulted in an increased analyzer angle but this correction is too small to be considered.

Since the sources were relatively thick, the high energy edges of the lines were extrapolated to the abscissas. The potentiometer readings measure the voltage across the analyzer plates and can be converted into the energy of the electrons by Eq. (2) of Noyes *et al.* Table I gives the results of the K and L line energies as determined above.

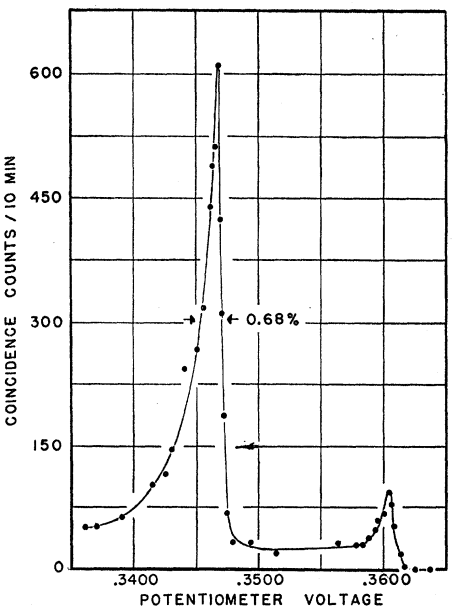

FIG. 3. Experiment II, Conversion electron spectrum. Guard slits S_2 and S_3 set at 0.20 in.

The energy resolution of the analyzer for the slit widths used can be calculated from Eq. (3) of Noyes *et al.* For the K line of Cs^{137} it is 0.9 kev. This means the energy spread admitted by the last slit (S_4) is ± 0.9 kev and is the limiting factor in determining the accuracy of this experiment.

TABLE I. Experimental energy values of K and L lines of Cs^{137}.

Exp.	Line	Potentiometer reading	Electron energy (kev)	Average electron energy (kev)	Magnetic field correction (kev)	Corrected electron energy (kev)	K and L electron binding energies (kev)	Gamma ray energy (kev)
I	K	0.3465	627.77	628.10	2.90	625.2	37.43	662.6
II	K	0.3468	628.44					
I	L	0.3606	658.72	659.06	2.80	656.3	5.99	662.3
II	L	0.3610	659.41					
						E_L-E_K =31.10	$K-L_I$ =31.44	

The L lines were not resolved from the M lines in either Experiments I or II, so that the energy determinations were made by extrapolating the high energy edges of the L peaks at their half-widths. As stated above, the slit-width of S_2 and S_3 in Experiment II had an effect of increasing the fringe field and hence of effectively increasing the analyzer angle. This requires a correction of less than a tenth of a kilovolt. Therefore, arithmetic means were taken for the K-electron and L-electron energies corresponding to these two experiments. The difference between E_K and E_L is 31.10 kev and is to be compared to the binding energy difference between the K and L shells of Ba^{137}. From the data of Hill, Church, and Mihelich[4] this is 31.44 kev. Table II lists the results of this investigation along with those of other workers.

TABLE II. Cs^{137} electron and gamma ray energies.

References	K-conversion electron energy (kev)	Gamma ray energy (kev)
Langer and Moffat[a]	623.9 ±0.7	661.4 ±0.7
Muller, Hoyt, Klein, and DuMond		661.60±0.14
Lindstrom, Siegbahn, and Wapstra	624.21±0.15	661.65±0.15
Present investigation	625.2 ±0.9	(662.6 ±0.9)[b]

[a] May be adjusted for more recent Au^{198} value by adding 0.9 kev.
[b] Calculated with Ba^{137} K binding energy of 37.43 kev (see reference 4).

CONCLUSION

The agreement between the results of the present investigation and those of other investigators is satisfactory. One may now have increased confidence in the absolute energy determinations by our electrostatic analyzer.

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