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# DETERMINATION OF THE ATOMIC ELECTRON BINDING ENERGIES IN ELEMENT 97

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The atomic electron binding energy is defined as the energy required to raise an electron from a bound atomic state to the lowest continuum state. Knowledge of the values of atomic binding energies is of importance in nuclear spectroscopy because of their application to the determination of nuclear transition energies from internal conversion electron data.

Two general methods have been used for the determination of electron binding energies. The first method utilizes a combination of X-ray absorption and emission spectroscopy; several tables of binding energies so obtained are in use.[1,2] In recent years an electron spectroscopic method has been developed by which the energies of photoelectrons ejected from suitable targets by X-radiation of known wave length are measured by means of a high-precision electron spectrometer.[3] A table of binding energies incorporating these data has recently been prepared by Hagström, Nordling, and Siegbahn.[4]

The use of either method requires that the target material contain a macro quantity of the element under study. As a consequence, the very heavy elements, not generally available in large quantities, have received inadequate study, and in fact most of the quoted binding energies for heavy elements have been extrapolations from lower atomic number. Uranium (Z = 92) is the heaviest element to have been studied with the photoelectron method;[3] with X-rays, americium (Z = 95) has received some study.[5] As pointed out by Hagström et al.,[4] the presently quoted electron binding energies obtained by extrapolation may be in error by more than 100 eV. Thus it is desirable to have measurements, wherever possible, of the binding energies of high-Z elements.

In some cases knowledge of certain properties of a nuclear level scheme makes possible the determination of the atomic binding energies in a manner independent of X-ray spectroscopy. Such a case is the simple cascade-crossover situation illustrated by the partial level scheme of Fig. 1. In this scheme, the absolute transition energy of transition A may be found from the energy difference between any two like (i.e., same subshell) conversion lines from transitions B and C. From the absolute energy of transition A one can compute the binding energies of the various subshells by subtracting the measured energies of the corresponding subshell conversion electron lines from the transition energy.

In the course of a detailed study of the decay of $Es^{253}$,[6] we have had occasion to measure with high accuracy the energies of a number of internal conversion lines in $_{97}Bk^{249}$, and from these data we can calculate the atomic binding energies of berkelium (Z = 97). In the level scheme of $Bk^{249}$ (shown partially in Fig. 2) several cascade-crossover sequences are prominent and can be used for this purpose. These are:

$$E_\gamma\ (51.9) = E_i\ (93.7) - E_i\ (41.8)$$

$$E_\gamma\ (43.0) = E_i\ (73.8) - E_i\ (30.8)$$

where i represents internal conversion in subshell i.

The internal conversion spectrum was studied with the Berkeley 50-cm $\pi\sqrt{2}$ iron-free spectrometer.[7,8] This instrument is programmed to scan automatically with pre-selected current-step intervals and counting times, and the relevant output data for each current setting were printed out by an IBM output-writer. During these measurements, it was operated on a 24-hour, 7-day per week basis. Absolute current measurements were made with use of a Leeds and Northrup Type K-2 potentiometer, by measuring the IR drop across a 0.01 Ω precision series-resistor maintained in a constant (±0.01° C) temperature bath. At the time these measurements were made the current stability of the spectrometer power supply was about 3:10,[5] and the current could be measured with comparable precision. Other limitations on the accuracy of the Bρ determinations came from the uncertainties in determining the line positions and from the spectrometer calibration error.

Calibration of the spectrometer was made with reference to the K line of the 662-keV transition in $Ba^{137}$ ($Cs^{137}$ source) which has been measured relative to the internal conversion lines of the 412-keV transition in $Hg^{198}$.[9] The $Hg^{198}$ transition energy has recently been measured with respect to annihilation radiation with high accuracy.[10] When analyzed with use of the 1963 values of the fundamental constants[11] the $Hg^{198}$ transition energy is 411.795 ± 0.009 keV,[12] the $Ba^{137}$ transition energy is 661.636 ± 0.053 keV and the K 662 line has a momentum value of 3381.28 ± 0.20 gauss cm. This Bρ value is ~ 6 parts in $10^5$ higher than the value reported earlier[9] which was based on the 1955 constants. For making momentum calibrations the "standard" source and "unknown" source were alternately moved into the electron-optical source position by means of a suitably designed holder that accomodates both sources and allows their interchange without removing the source holder from the instrument.

A portion of the measured conversion spectrum is shown in Fig. 3. The data used for calculation of the absolute transition energies of the 51.9- and 43.0-keV transitions are shown in Table I. The following contributions to the errors in the absolute values of the subshell-conversion-line energies were considered:

1) Irreproducibility of source holder during interchange of unknown with standard sources, 1:$10^4$, as determined from independent experiments.

2) Uncertainty in establishing the peak position current of the conversion lines. This error was taken as 1.5:$10^4$ for all lines. The peak positions were determined by extrapolating the locus of midpoints of the conversion line to its intersection with the top of the line (see Fig. 3).

3) Potentiometer inaccuracy, estimated to be 5:$10^5$.

4) Uncertainty in the calibration constant; estimated to be 8:$10^5$.

The first three errors were assumed to be statistical while the fourth was assumed to be systematic. In Table I only the statistical errors were considered and therefore the errors in the Difference column were added quadratically.

From the absolute transition energies given in Table I, the various subshell binding energies were calculated from the measured energies of the individual conversion lines of these transitions. The results are given in Table II.

The calibration error is included only in the last column and is added linearly. All of the other errors in Table II were added quadratically.

It is not possible to calculate the K-binding energy in the same manner as the others because the transition energies used (51.9- and 43.0-keV) are lower than the K-edge and do not produce K-lines. Therefore, use was made of the carefully measured energy difference between the K and $L_I$ lines of the 389.2-keV transition, which is very prominent in the $Es^{253}$ decay. These results are also included in Table II. It is interesting to note that the absolute value of the K-binding energy so obtained is higher by 150 eV and ~ 300 eV than the extrapolated values quoted by Hagström et al.,[4] and by Hyde,[2] respectively.

Table I. Determination of absolute transition energies of 51.9- and 43.0-keV transitions from $Es^{253}$ decay.

A. $E_\gamma(51.9) = E_i(93.8) - E_i(41.8)$

| Subshell i | $E_i(93.8)$ | $E_i(41.8)$ | Difference |
|---|---|---|---|
| $L_{II}$ | 69.366 ± 0.042 | 17.404 ± 0.010 | 51.962 ± 0.043 |
| $L_{III}$ | 74.302 ± 0.044 | 22.340 ± 0.013 | 51.962 ± 0.045 |
| $M_{II}$ | 87.585 ± 0.053 | 35.638 ± 0.021 | 51.947 ± 0.056 |
| $M_{III}$ | 88.757 ± 0.053 | 36.807 ± 0.022 | 51.950 ± 0.056 |
| | | $E_\gamma$ = | 51.956 ± 0.025 |

B. $E_\gamma(43.0) = E_i(73.8) - E_i(30.8)$

| Subshell i | $E_i(73.8)$ | $E_i(30.8)$ | Difference |
|---|---|---|---|
| $M_{II}$ | 67.657 ± 0.040 | 24.688 ± 0.015 | 42.969 ± 0.042 |
| $M_{III}$ | 68.839 ± 0.041 | 25.851 ± 0.016 | 42.988 ± 0.043 |
| | | $E_\gamma$ = | 42.979 ± 0.030 |

Table II. Atomic electron binding energies in element 97 (berkelium).

| Shell | Transition Energy (keV) | Conversion Line Energy (keV) | Difference (keV) | Selected Value | |
|---|---|---|---|---|---|
| $L_I$ | 51.956 ± 0.025 | 26.682 ± 0.021 | 25.274 ± 0.033 | $L_I$ | 25.275 ± 0.026 |
| | 42.979 ± 0.030 | 17.704 ± 0.014 | 25.275 ± 0.033 | | |
| $L_{II}$ | 51.956 | 27.574 ± 0.022 | 24.382 ± 0.034 | $L_{II}$ | 24.385 ± 0.026 |
| | 42.979 | 18.592 ± 0.015 | 24.387 ± 0.033 | | |
| $L_{III}$ | 51.956 | 32.506 ± 0.026 | 19.450 ± 0.036 | $L_{III}$ | 19.452 ± 0.030 |
| | 42.979 | 23.525 ± 0.019 | 19.454 ± 0.040 | | |
| $M_I$ | 51.956 | 45.399 ± 0.036 | 6.557 ± 0.044 | $M_I$ | 6.556 ± 0.031 |
| | 42.979 | 36.424 ± 0.029 | 6.555 ± 0.041 | | |
| $M_{II}$ | 51.956 | 45.809 ± 0.037 | 6.147 ± 0.045 | $M_{II}$ | 6.147 ± 0.046 |
| $M_{III}$ | 51.956 | 46.979 ± 0.037 | 4.977 ± 0.045 | $M_{III}$ | 4.977 ± 0.046 |
| $N_I$ | 51.956 | 50.193 ± 0.040 | 1.763 ± 0.048 | $N_I$ | 1.755 ± 0.033 |
| | 42.979 | 41.232 ± 0.033 | 1.747 ± 0.045 | | |
| $O_I$ | 51.956 | 51.571 ± 0.041 | 0.385 ± 0.049 | $O_I$ | 0.398 ± 0.033 |
| | 42.979 | 42.568 ± 0.034 | 0.411 ± 0.045 | | |
| K | 389.2 | $K-L_I$ = 106.32 ± 0.05 | | K | 131.59 ± 0.06 |

REFERENCES

†On leave from Faculty of Sciences, University of Belgrade, Belgrade, Yugoslavia.

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1. Hill, Church, and Mihelich, Rev. Sci. Instr. 23, 523 (1952).
2. E. K. Hyde, UCRL-9642 (May 1961).
3. C. Nordling and S. Hagström, Arkiv för Fysik, 15, 431 (1959).
4. S. Hagström, C. Nordling, and K. Siegbahn, "Alpha, Beta, and Gamma Ray Spectroscopy" editor K. Siegbahn, North-Holland Publishing Co., Amsterdam, 1964.
5. J. J. Merrill, Ph. D. Thesis, California Institute of Technology (1960).
6. M. D. Holtz, J. M. Hollander, R. L. Graham, and T. Novakov, Nucl. Phys. (to be published).
7. K. Siegbahn, C. Nordling, and J. M. Hollander, UCRL-11023 (1962).
8. J. M. Hollander and R. L. Graham, UCRL-10624 (1963).
9. R. L. Graham, G. T. Ewan, and J. S. Geiger, Nucl. Instr. Methods, 9, 245 (1960).
10. G. Murray, R. L. Graham and J. S. Geiger, Nucl. Phys. 45, 177 (1963).
11. E. R. Cohen and J. W. M. DuMond, Proc. Second Int. Conf. on Nuclidic Masses, Vienna (1963) and see also the National Bureau of Standards Technical News Bulletin 47, No. 10 (October 1963).
12. Reanalysis of the $Hg^{198}$ transition energy on the basis of the 1963 constants is discussed in G. Murray, R. L. Graham and J. S. Geiger, Nucl. Phys. (to be published).

## FIGURE CAPTIONS

Figure 1. Example of cascade-crossover situation in a nuclear level scheme.

Figure 2. Partial level scheme of $_{97}Bk^{249}$ slowing levels used for binding energy determinations.

Figure 3. Portion of the $Es^{253}$ internal conversion spectrum measured with the 50-cm $\pi\sqrt{2}$ iron-free spectrometer.

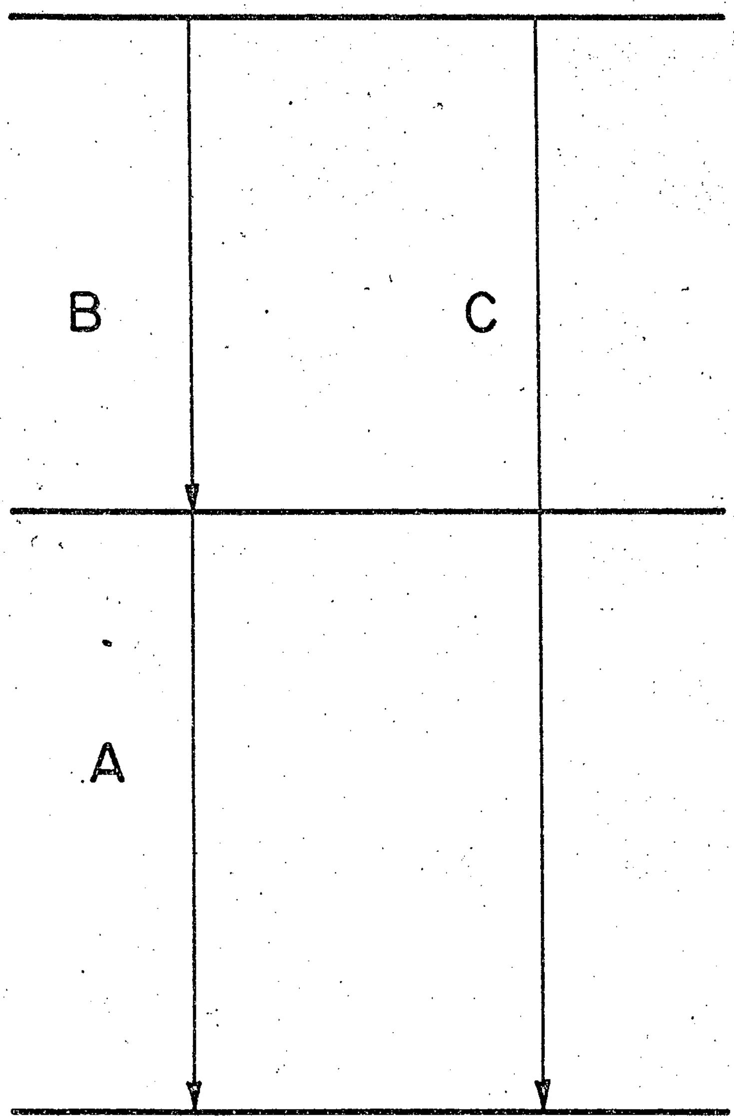


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Fig. 1.

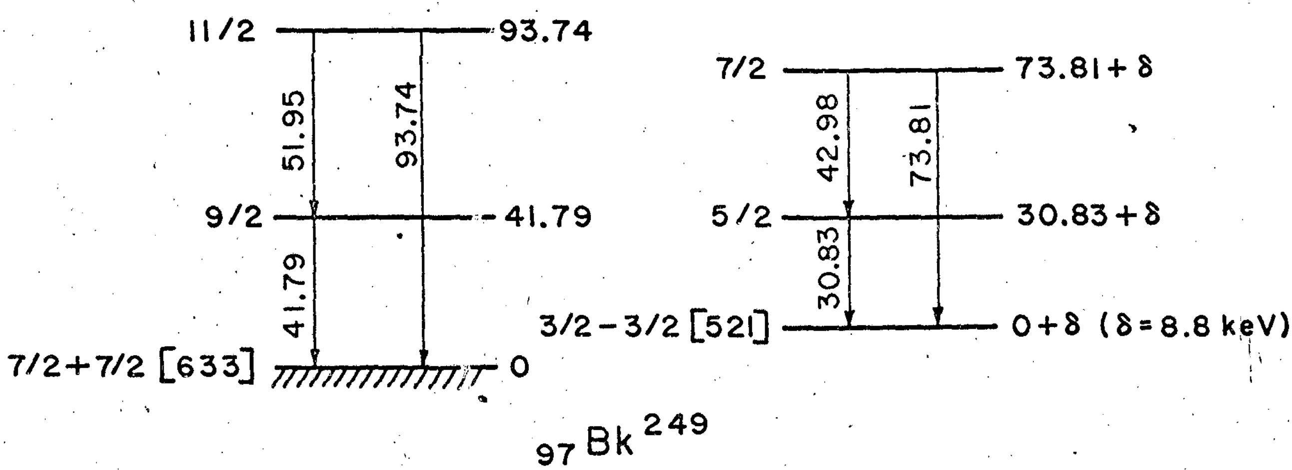


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Fig. 2.

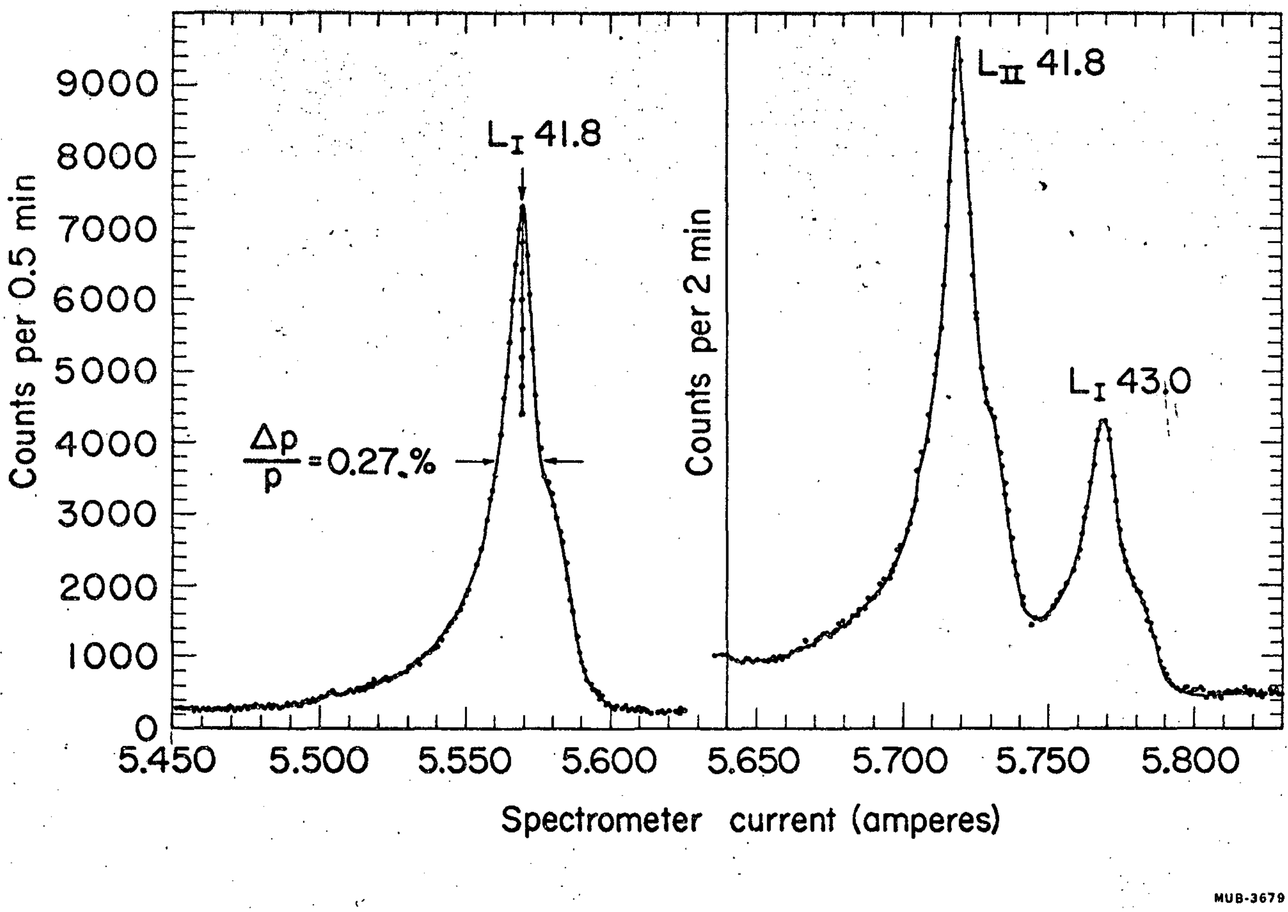
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Counts per 0.5 min
Counts per 2 min
L_I 41.8
Δp/p = 0.27 %
L_II 41.8
L_I 43.0
5.450
5.500
5.550
5.600
5.650
5.700
5.750
5.800
Spectrometer current (amperes)
MUB-3679

Fig. 3.

[illegible]