# X-Ray Absorption Coefficients of the Elements with $Z=1$ to 17 for Mo $K\alpha$ Radiation*

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The x-ray absorption coefficients of the elements with $Z=1$ to 17 (excluding helium and neon) have been determined for Mo $K\alpha$ radiation. The values found in the present work are in better agreement with the earlier experimental data of Allen than with the semitheoretical values given in the *Internationale Tabellen*.

## INTRODUCTION

In the preceding paper[1] the author investigated the x-ray absorption coefficients of thorium, uranium, and plutonium. It was found that between absorption edges the mass absorption coefficients could be represented by an equation of the form

$$\mu_m = C\lambda^n. \quad (1)$$

The value of $n$ was determined to be 2.44, 2.47, and 2.82 for thorium, uranium, and plutonium, respectively. These elements, therefore, do not obey the general $\lambda^3$ law. The results are consistent, however, with the observation of Compton and Allison,[2] who note that for high $Z$ numbers or long wavelengths, or both, the value of $n$ is reduced from the "ideal" value of 3.

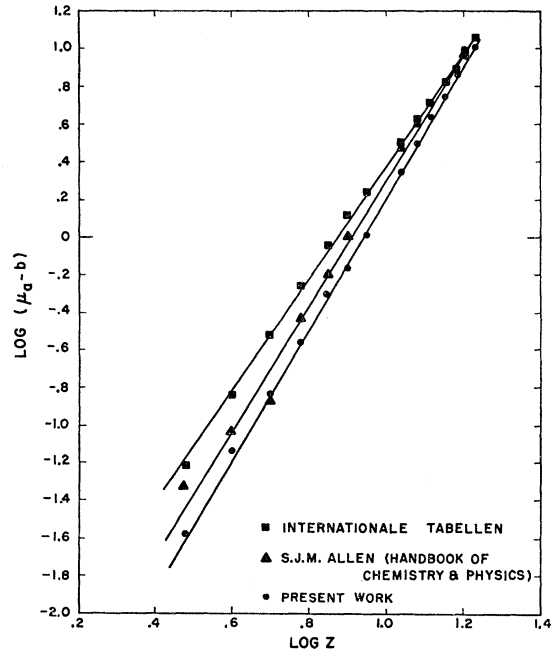


FIG. 1. The variation of $(\mu_a - b)$ as a function of $Z$ (a graphical presentation of the data of Table I).

The mass absorption coefficient of a material is usually considered to be the sum of a true absorption coefficient and a scattering coefficient, i.e.,

$$\mu_m = \mu_a + \mu_s. \quad (2)$$

For thorium, uranium, and plutonium the scattering coefficient, $\mu_s$, is negligible and the measured mass absorption coefficient represents the true absorption coefficient with sufficient accuracy for most purposes.

The departure from the general $\lambda^3$ law for thorium, uranium, and plutonium raises a question as to the validity of a general $Z^m$ law where $m$ is a whole number.

TABLE I. Experimental x-ray absorption coefficients for $Z=1$ to 17 for Mo $K\alpha$ radiation.

| Element | Experimental absorber | $\mu_m$, cm$^2$g$^{-1}$ | $\mu_s$, cm$^2$g$^{-1}$ | $\mu_a$, cm$^2$g$^{-1}$ |
|---|---|---|---|---|
| H | $H_2O_2$ in $H_2O$ | 0.57±0.10 | 0.38 | 0.19±0.10 |
| He | | | | |
| Li | LiCl in $H_2O$ | 0.375±0.122 | 0.16 | 0.215±0.122 |
| Be | Be foil | 0.43±0.24 | 0.17 | 0.26±0.24 |
| B | $H_3BO_3$ in $H_2O$ | 0.51±0.06 | 0.18 | 0.33±0.06 |
| C | $HC_2H_3O_2$ in $H_2O$ | 0.64±0.02 | 0.19 | 0.45±0.02 |
| N | $NH_3$ in $H_2O$ | 0.86±0.02 | 0.19 | 0.68±0.02 |
| O | $H_2O_2$ in $H_2O$ | 1.02±0.02 | 0.19 | 0.83±0.02 |
| F | LiF plate | 1.37±0.04 | 0.18 | 1.19±0.04 |
| Ne | | | | |
| Na | $NaNO_3$ in $H_2O$ | 2.36±0.03 | 0.18 | 2.18±0.03 |
| Mg | $Mg(NO_3)_2$ in $H_2O$ | 3.29±0.05 | 0.19 | 3.10±0.05 |
| Al | Al foil | 4.58±0.21 | 0.18 | 4.40±0.21 |
| Si | Fused $SiO_2$ | 5.86±0.09 | 0.19 | 5.67+0.09 |
| P | $H_3PO_4$ in $H_2O$ | 7.38±0.03 | 0.18 | 7.20±0.03 |
| S | $(NH_4)_2SO_4$ in $H_2O$ | 9.38±0.04 | 0.19 | 9.19±0.04 |
| Cl | $NH_4Cl$ in $H_2O$ | 10.67±0.02 | 0.18 | 10.49±0.02 |

Thorium, uranium, and plutonium cannot be used to test this law due to an insufficient number of experimental points and the absorption edge discontinuities of these elements for x-rays.

The purpose of this paper is to examine the coefficient $m$ in an equation of the form

$$\mu_a = CZ^m + b, \quad (3)$$

for elements at the opposite end of the periodic table. The mass absorption coefficients of some of the elements from $Z=1$ to 17 were experimentally determined. Then the scattering coefficient (calculated from the formulas of Klein-Nishina[3]) was subtracted from the measured

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[1] R. B. Roof, Jr., Phys. Rev. **113**, 820 (1959), preceding paper.

[2] A. H. Compton, and S. K. Allison, *X-rays in Theory and Experiment* (D. Van Nostrand Company, Inc., Princeton, New Jersey, 1935), p. 542.

[3] O. Klein and Y. Nishina, Physik **52**, 853 (1928).

mass absorption coefficient to yield the true absorption coefficient, Eq. (2). The true absorption coefficient was then analyzed according to Eq. (3).

## EXPERIMENTAL METHOD AND METHOD OF ANALYSIS

A description of the general experimental method employed and the general method of analysis of the experimental data is given in the preceding paper[1] under these headings.

## EXPERIMENTAL RESULTS

In order to use Eq. (3), the mass absorption coefficients of a number of elements must be determined at a constant wavelength, and Mo $K\alpha$ radiation was chosen for this purpose. The mass absorption coefficients obtained for the elements with $Z=1$ to 17 are given in Table I. Table I also contains the scattering coefficients calculated from the Klein-Nishina formulas and the true absorption coefficients obtained by application of Eq. (2).

## ANALYSIS AND CONCLUSIONS

Equation (3) can be transformed to

$$\log(\mu_a-b)=m\log Z+\log C. \tag{4}$$

A plot of $\log(\mu_a-b)$ *vs* $\log Z$ will result in a straight line, the intercept of which is equal to $\log C$ and the slope of which is equal to $m$. The quantities $b$ and $C$ can be estimated from the data in the following manner. For hydrogen ($Z=1$) the quantity $m\log Z$ is zero and $(\mu_a-b)=C$. Since $C$ is a very small number, then to the first approximation let $C$ be zero. Then $b=\mu_a$ of hydrogen. Successive applications of least-squares fitting of points of Eq. (4) will refine the numerical values of $b$ and $C$ to any desired degree of accuracy. Figure 1 is a presentation of the data of Table I according to Eq. (4). For comparison, the experimental work of Allen[4] and the semitheoretical values of the *Internationale Tabellen*[5] are also shown in Fig. 1. The numerical constants of Eq. (4) for the three sets of data are collected in Table II.

TABLE II. Numerical constants for $\mu_a=CZ^m+b$.

| | Present work | Allen[a] | *Internationale Tabellen*[b] |
|---|---|---|---|
| $b$ | 0.1859 | 0.0542 | 0.0100 |
| $C$ | $5.0\times10^{-4}$ | $8.8\times10^{-4}$ | $22.8\times10^{-4}$ |
| $m$ | 3.52 | 3.36 | 3.02 |

[a] See reference 4.
[b] See reference 5.

From an examination of Fig. 1 and Table II, the author concludes that the present work is in good agreement with the earlier experimental work of Allen. Both sets of experimental data, however, are in disagreement with the semitheoretical values of the *Internationale Tabellen*. It is interesting to observe that the values of $m$ obtained from the experimental data approach more closely the "ideal" value of 4 proposed by Bragg,[6] Richtmyer,[7] and Walter[8] than does the value of $m$ obtained from the *Intrenationale Tabellen*.

In deriving the mass absorption coefficients listed in Table I it was assumed that the chemical combination or bonding of the element under investigation would be of negligible importance for Mo $K\alpha$ radiation. Several types of bonding are evident in an examination of the experimental absorbers: metallic bonding for beryllium and aluminum, ionic bonding for fluorine, covalent bonding for silicon, and normal oxidation states for the other elements. The successful application of the experimental points to a straight line analysis tends to confirm the validity of the original assumption.

[4] S. J. M. Allen, compilation of mass absorption coefficients for the *Handbook of Chemistry and Physics* (Chemical Rubber Publishing Company, Cleveland, 1952), thirty-fourth edition.
[5] *Internationale Tabellen zur Bestimmung von Kristallstrukturen* (Gebrüder Brontraeger, Berlin, 1935), Vol. II.
[6] W. H. Bragg, Phil. Mag. **29**, 407 (1915).
[7] F. K. Richtmyer, Phys. Rev. **18**, 13 (1921).
[8] B. Walter, Fortschr. Gebiete Röntgenstrahlen **35**, 929, 1308 (1927).