Precision Measurement of K X-Ray Spectrum of Hg

OLOF BECKMAN AND PÄR BERGVALL
Institute of Physics, Uppsala, Sweden
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The K x-ray spectrum of Hg has previously not been measured with the same accuracy as nearby elements because of the difficulty of obtaining a good anticathode. A wavelength determination of Hg$K\alpha_1$, α_2, β_1, β_3 is herewith reported with an accuracy of less than 40 ppm. Using these data an earlier measurement of the weaker Hg lines is recalculated to give higher accuracy.

IN a previous report,[1] Beckman has published wavelength values for 9 lines in the K x-ray spectrum of Hg. These measurements were made with a curved crystal spectrometer in the Cauchois mounting where it was necessary to use reference lines from a nearby element, separately recorded. In this case the Au spectrum, as measured by Ingelstam,[2] was used. The wavelength positions of the Hg lines relative to each other were established with high accuracy, but the absolute accuracy was diminished by the precision with which the Au and Hg spectra could be related, and the error limits given by Ingelstam. The large limits of accuracy, ± 0.05 xu which had to be adopted, has caused other investigators[3] to use interpolations in order to obtain more accurate values for the Hg lines, rather than referring to the above measurements.

With use of a newly built precision curved crystal spectrometer,[4] Bergvall has made a redetermination of Hg$K\alpha_1\alpha_2\beta_1\beta_3$, reported here. The spectrometer is of the DuMond mounting and the measurements are absolute in the sense that Bragg angles are measured on a precision scale. No screws or mechanical link systems are involved in the construction. The angular scale, which is the scale from the Siegbahn "tube" spectrometer, is known to be of high quality and has been checked to give an accuracy of $\pm 0.2''$ in the angle measurements. The x-ray tube, which has exchangeable anticathode, is provided with sufficient voltage from a 500-kv electrostatic generator.

The anticathode of silver-amalgam is the same as that described by Beckman.[1] The detector is a scintillation counter with a differential discriminator, which gives a very low background. The resolution of the spectrometer is the same as illustrated by Beckman[1] or less than 0.2%.

The spacing of the atomic planes employed (quartz

TABLE I. Spectrometer calibration. Mo$K\alpha_1$ 707.831 xu.[a] Bragg angles are corrected to 18°C with use of a thermal expansion coefficient for quartz in the 1340 direction of 14.5×10^{-6}.[b]

θ_{18}	t°C
17° 29′ 25.5″	22.2
17° 29′ 25.5″	22.3
17° 29′ 24.7″	23.1
17° 29′ 26.3″	23.0
17° 29′ 25.6″	22.6
17° 29′ 25.5″±0.5″	

[a] A. E. Sandström, *Encyclopedia of Physics*, edited by S. Flügge (Springer-Verlag, Berlin, 1957), Vol. 30, p. 161.
[b] A. H. Jay, Proc. Roy. Soc. (London) **142**, 237 (1933).

TABLE II. Hg measurements.

$K\alpha_2$ θ_{18}	t°C	$K\alpha_1$ θ_{18}	t°C	$K\beta_3$ θ_{18}	t°C	$K\beta_1$ θ_{18}	t°C
4° 22′ 23.7″	22.4	4° 15′ 14.8″	22.9	3° 46′ 25.0″	23.6	3° 45′ 12.1″	23.6
4° 22′ 23.0″	23.0	4° 15′ 14.7″	23.0	3° 46′ 24.5″	23.5	3° 45′ 11.5″	23.5
4° 22′ 23.5″	22.6	4° 15′ 14.9″	23.1	3° 46′ 25.0″	22.4	3° 45′ 11.6″	22.4
4° 22′ 23.4″	22.8	4° 15′ 14.7″	23.3	3° 46′ 24.3″	23.4	3° 45′ 11.5″	22.7
4° 22′ 23.4″±0.4″		4° 15′ 14.8″±0.4″		3° 46′ 24.7″±0.4″		3° 45′ 11.7″±0.4″	

TABLE III. Wavelength values and relative intensities of the K x-ray lines of Hg.

Line	xu	kev	Int.
α_2	179.585±0.006	68.895±0.003	51.0
α_1	174.705±0.006	70.819±0.003	100.0
β_3	154.999±0.006	79.823±0.003	13.1
β_1	154.167±0.006	80.253±0.003	26.6
β_5	153.21 ±0.03	80.76 ±0.02	0.72
β_2^{II}	150.09 ±0.03	82.43 ±0.02	10.0
β_2^{I}	149.89 ±0.03	82.54 ±0.02	
β_4	149.47 ±0.05	82.78 ±0.03	0.3
$O_{II,III}$	149.00 ±0.03	83.04 ±0.02	1.8

[1] O. Beckman, Phys. Rev. **109**, 1590 (1958).
[2] E. Ingelstam, Nova Acta Regiae Soc. Sci. Upsaliensis **5** (1937).
[3] Bäckström, Bergman, and Burde, Nuclear Phys. **7**, 263 (1958).
[4] Beckman, Bergvall, and Axelsson, Arkiv Fysik **14**, 419 (1958).

$1\bar{3}40$) has been determined with use of the $K\alpha_1$ line of Mo. This determination is reported in Table I. The results of four separate runs for the above four x-ray lines are given in Table II. Using these new data, the measurements of the weaker lines by Beckman are recalculated, the wavelength values given in Table III. The accuracy of these wavelengths is now increased as the reference lines are to be found within the Hg spectrum. The error given for the $\alpha_1\alpha_2\beta_1\beta_3$ lines is the probable error for the mean Bragg angle, including allowance for nonlinear systematic errors. Energy values are computed from $E\lambda_s = 12\,372.44$ kev xu.[5]

The K x-ray spectrum of Hg is herewith known with the same accuracy as for nearby elements.

[5] E. R. Cohen and J. W. M. DuMond, *Encyclopedia of Physics*, edited by S. Flügge (Springer-Verlag, Berlin, 1957), Vol. 35, p. 1.

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$B^{11}(He^3,p)C^{13}$ and $B^{11}(He^3,d)C^{12}$ Reactions

H. D. Holmgren, E. A. Wolicki, and R. L. Johnston
United States Naval Research Laboratory, Nucleonics Division, Washington, D. C.

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The differential cross sections for the $B^{11}(He^3,p)C^{13}$ and the $B^{11}(He^3,d)C^{12}$ reactions have been measured at 4.5 and 5.4 Mev. Yield curves for these reactions have also been obtained over the energy region extending from 3.00 to 5.40 Mev. The angular distributions for the deuteron groups are strongly peaked in the forward direction and indicate that the simple stripping interaction is the predominant mechanism of these reactions. The angular distributions of the proton groups are more complex and more difficult to interpret; however the yield curves change rather slowly with energy suggesting that direct interaction mechanisms may be important.

I. INTRODUCTION

A PROGRAM was established a few years ago at the U. S. Naval Research Laboratory to study the interactions of He^3 particles with light nuclei. The main purpose of this progarm has been to investigate the nature of the mechanism involved in these interactions. This paper is one in a series,[1–5] and reports the experimental results of the study of He^3 interactions with B^{11}.

The differential cross sections for 7 proton groups from the $B^{11}(He^3,p)C^{13}$ reaction and 2 deuteron groups from the $B^{11}(He^3,d)C^{12}$ reaction have been measured at a bombarding energy of 4.5 Mev. The differential cross sections of several of these groups have also been determined at 5.4 Mev. In addition, the yield curves for 3 proton groups and the ground-state deuteron group have been investigated over the energy region extending from 3.00 to 5.40 Mev.

The Q value for the $B^{11}(He^3,d)C^{12}$ reaction[6] is 10.456 Mev, which is the second highest (He^3,d) Q value in the light nuclei. It is of considerable interest to see if this reaction proceeds by a simple stripping mechanism.

[1] Holmgren, Bullock, and Kunz, Phys. Rev. **104**, 1446 (1956).
[2] H. D. Holmgren, Phys. Rev. **106**, 100 (1957).
[3] Holmgren, Geer, Johnston, and Wolicki, Phys. Rev. **106**, 102 (1957).
[4] Illsley, Holmgren, Johnston, and Wolicki, Phys. Rev. **107**, 538 (1957).
[5] Johnston, Holmgren, Wolicki, and Geer, Phys. Rev. **109**, 884 (1958).
[6] Moak, Galonsky, Fraughber, and Jones, Phys. Rev. **110**, 1369 (1958).

II. PROCEDURE

A thin evaporated B^{11} target ($\sim$50 kev of 99.8% B^{11} on a 40-microinch nickel foil) was bombarded with a beam of singly ionized He^3 particles from the 5-Mv NRL Van de Graaff accelerator. The reactions were studied in a sliding seal reaction chamber[7] using a CsI crystal to detect the reaction products. The sliding seal chamber allowed the angle of the CsI crystal counter to be varied continuously from 0° to 130°. In addition, a fixed monitor counter at 163° to the axis of the beam allowed a single point to be obtained at this angle. For angles below 20° the collector cup was removed and the beam was stopped on a 200-microinch nickel foil which was inserted behind the target. This foil was sufficiently thin to allow most of the reaction products to pass through it. The current to this foil was measured; however, the beam was actually monitored by the 163° monitor counter during this period, since no means of repelling secondary electrons was provided.

Over a large region of angles the ground state deuteron groups produced about the same size pulses in the CsI crystal counter as the p_1, p_2, or p_3 proton groups. Figure 1 shows the pulse-height spectra obtained at 110° for a bombarding energy of 4.5 Mev with a 100-channel pulse-height analyzer. Because of the different energy losses in Al of protons and deuterons, it was in general possible to separate the ground-state deuteron group from the proton groups by adding Al absorbers (see Fig. 1). On the other hand, regardless of the Al absorber

[7] F. I. Loukes, Rev. Sci. Instr. **28**, 468 (1957).