Corrected Values of Tungsten *K*-Series X-Ray Wavelengths with the 2-Meter Curved Crystal Diffraction Spectrometer*

PHILIP SNELGROVE, JASSIM EL-HUSSAINI, AND JESSE W. M. DUMOND
California Institute of Technology, Pasadena, California
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Certain minor mechanical errors occasioned by small flexures in some components of our 2-meter curved crystal γ-ray spectrometer were discovered recently through comparison of wavelength measurements in different orders of reflection. These errors and the means adopted for their correction have been described in published papers and a program of redeterminations of nuclear γ and x-ray wavelengths is underway. In this program, a by-product of the study of the radioisotope Ta^{182} has led to measurements of the tungsten K-series x-ray lines, since tungsten is the daughter product of β decay of Ta^{182}. In this way we have obtained the following results: W-$K\alpha_2$=213.387±0.010; W-$K\alpha_1$=208.575±0.008; W-$K\beta_3$=184.785±0.027; W-$K\beta_1$ =183.997±0.019 all expressed in x.u. (Siegbahn). The agreement with other measurements, particularly those given in E. Ingelstam's dissertation (1937), is now well within the estimated standard deviation of our measurements, and to avoid further confusion (because our earlier values disagreed slightly from Ingelstam's) we wish to announce that our earlier results [published in Phys. Rev. **75**, 505 (1949)] are herewith superseded by these present ones.

IN 1949 a paper[1] was published entitled "A Precision Study of the Tungsten *K*-Spectrum Using the 2-Meter Focusing Curved Crystal Spectrometer." The primary purpose of this study was to calibrate the wavelength scale of the 2-meter curved crystal (diffraction) γ-ray spectrometer in terms of a well-established x-ray wavelength. With this in view a careful determination was first made of the wavelength ratio of the Mo-$K\alpha_1$ and W-$K\alpha_1$ lines using reflections from the (310) planes of two flat quartz lamina in a precision two-crystal spectrometer described in an earlier paper.[2] The Mo-$K\alpha_1$ line was chosen as a reference standard since its value on the Siegbahn scale (in x-units) is so well established.[3] The wavelengths of seven lines in the tungsten K spectrum α_2, α_1, β_3, β_1, β_2^{II}, β_2^{I}, δ, and the critical absorption edge, were then measured with the 2-meter curved crystal spectrometer on its nominal wavelength screw scale corrected for all the instrumental systematic errors which we were at that time aware of. The instrument design is such that ideally the wavelength screw readings should be strictly proportional to the sine of the Bragg angle and hence to the wavelength. On this assumption of a strictly linear wavelength scale, it was believed that all that was necessary was to establish a constant multiplying factor between nominal wavelengths after correction for screw errors and other small known instrumental errors on the one hand and true wavelengths in x-units (or angstrom units) on the other hand by a comparison of the nominal wavelength scale reading for the W-$K\alpha_1$ line with the true value established by the above-mentioned 2-crystal spectrometer determination.

Subsequent to publication of this 1949 paper,[1] however, we have discovered certain small departures from linearity in the relation between the nominal instrument scale of wavelengths and true wavelengths which we have found to be caused by slight mechanical flexures in certain components of the instrument.[4] As a result all the W-K-series wavelengths published in the 1949 paper, except of course the $K\alpha_1$ calibration line itself, are slightly in error. Relative to our quoted probable errors in that paper, these systematic departures are not very serious, and since our principal attention has been focused on gamma rays rather than on x-rays we have not until now attempted to correct these published values. We are indebted, however, to Erik Ingelstam of the Royal Institute of Technology, Stockholm, for (1) pointing out to us certain small discrepancies between these 1949 published wavelengths of ours and those he had obtained[5] by photographic methods, also with a curved crystal spectrometer, and (2) for suggesting that since the disagreement existed and physicists were using two discrepent sets of x-ray wavelength values indiscriminately, we should remeasure these K-series x-ray lines making use of the

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[1] Watson, West, Lind, and DuMond, Phys. Rev. **75**, 505 (1949).

[2] Jesse W. M. DuMond, Rev. Sci. Instr. **8**, 112 (1937).

[3] The ratio of wavelengths on the nominal Siegbahn x-unit scale to wavelengths as measured in milliangstroms is known by the work of four different workers (Bearden, Bäcklin, Söderman, and Tyrén) with x-ray diffraction at grazing incidence on ruled gratings previously calibrated with optical wavelengths. The relative uncertainty in our knowledge of this ratio is insignificant for the accuracy available with the 2-meter curved crystal γ-ray spectrometer over most of its scale.

[4] For a discussion of these small effects, which were discovered by a comparison of the nominal values of wavelengths reflected in different orders of reflection, and the means developed for their correction, the reader is referred to the following papers: Muller, Hoyt, Klein, and DuMond, Phys. Rev. **88**, 775 (1952); J. W. M. DuMond, Phys. Today **5**, 13 (1952); and "The Spectroscopy of Nuclear Gamma-Rays by Direct Crystal Diffraction Methods," J. W. M. DuMond, Special Technical Report No. 28 to the Office of Naval Research and No. 8 to the Atomic Energy Commission, March 1954 (unpublished). Optical means in the form of a well-corrected 6-inch concave mirror and a microscope have since been installed for measuring the flexural errors each time precision measurements are made, and a program of remeasuring our earlier wavelengths to take account of these so-called "mirror corrections" is now in progress.

[5] Erik Ingelstam, Inaugural dissertation, Uppsala, 1937 (unpublished).

TABLE I. Tungsten K-series wavelengths in x.u.

	W-$K\alpha_2$	W-$K\alpha_1$	W-$K\beta_3$	W-$K\beta_1$
Present corrected results	213.387±0.010	208.575±0.008	184.785±0.027	183.997±0.019
Ingelstam (1937)	213.382	208.571	184.795	183.991

new optical means we have installed for correcting for the flexures in the instrument and publish a set of corrected values. This we have recently done for the case of the Ta-$K\beta_1$ and β_3 lines using as the source of x-rays a strip of neutron activated tantalum (Ta^{182}) which after β decay becomes W^{182} and emits, in addition to a rich spectrum of nuclear γ rays, copious K-series x-ray lines of tungsten. In addition to corrections for all systematic instrumental errors, correction has also been made, in the case of the W-$K\beta_3$ line, for the presence of two weak Ta-K lines, β_2^{I} and β_2^{II}, also emitted by such a source which appear superposed on the W-$K\beta_3$ line in such a way as to distort and shift the total profile and increase the peak height, relative to W-$K\beta_1$, quite noticeably. This correction could be made with considerable certainty because the (much stronger) Ta-$K\alpha_1$ and α_2, β_1, and β_3 lines are also observed in this spectrum so that the Ta-K β_2^{I} and β_2^{II} line profiles can be inferred as to intensity and position from measurements by others on the Ta-K spectrum with amply sufficient accuracy for the purpose of this relatively small correction. The accompanying Fig. 1 shows the observed and corrected profiles, from which it can be seen that after subtracting the Ta-K β_2^{I} and β_2^{II} lines the W-$K\beta_3$ line takes on its normal shape, width and peak height relative to W-$K\beta_1$.

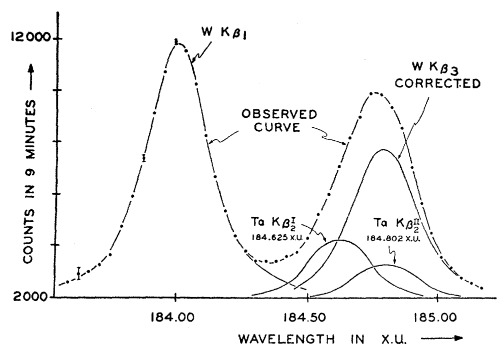

FIG. 1. Observed and corrected line profiles of W-K β_1 and β_3 x-ray lines emitted by a neutron activated source consisting of a strip of pure tantalum. The active Ta^{182} decays to W^{182} and emits copiously both nuclear gamma rays of tungsten and the x-ray lines of that element.

No correction is necessary, of course, for the standardizing wavelength, W-$K\alpha_1$, since its value depends only on the 2-crystal spectrometer measurements, but is independent of the calibration of the 2-meter curved crystal instrument. W-$K\alpha_2$ is so close to this that no significant instrumental correction is needed for this wavelength either. We show in Table I our present corrected results compared with the corresponding results of Ingelstam's (1937) work.

Our latest measurements with the "mirror" and other corrections[4] are seen to agree with Ingelstam's 1937 results well within our independently assigned probable errors. We have not troubled to measure the much weaker W-$K\beta_2^{II}$ and $K\beta_2^{I}$ lines,[6] but our agreement with Ingelstam for the closely adjacent W-$K\beta_1$ line is so satisfactory that it seems very safe to assume that our 2-meter instrument would have yielded values in good agreement with his for these two lines also.

[6] These are much attenuated because they fall on the high absorption side of the tantalum K edge.