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X-Ray Resonance Absorption Lines in the Argon *K* Spectrum

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Recorded with a two-crystal vacuum spectrometer, the absorption curve for argon gas near the K absorption edge, 3866 x.u., is analyzed in terms of the main edge and the $1S\rightarrow nP$ $(n>3)$ series of resonance absorption lines. The main edge is determined uniquely as follows: the wave-length position is taken as at the series limit; the width is obtained from the measured width of the most intense absorption line; and the shape is given by the theoretical arctangent curve. The wave-length positions of all the resonance absorption lines are taken from the optical terms of potassium, and, with the width and shape of each line known, the various members of the series $1S\rightarrow nP$ are determined uniquely. The relative intensities of these lines are 100 : 34 : 18 : 8.5, etc. This analysis illustrates the type and completeness of the analysis we should like to make for solid absorbers, but, unfortunately, the definition and meaning of the main edge of a solid absorber are rather obscure.

THE existence of fine structure accompanying x-ray absorption edges has been known for some twenty years. The interpretation of this structure is that the electron may be removed to some one of the many outer energy levels. Each of these transitions has a characteristic probability and, of course, satisfies Bohr's frequency condition.

Most investigations of fine structure have been concerned with absorption edges of solid absorbers. Studies of the distribution of outer levels and the transition probabilities for a solid absorber are very complex. Considerable but somewhat limited progress has been made in these studies.[1] In the present note we shall interpret an absorption curve for the simplest type of absorber, a monatomic gas, and discuss the type of analysis that we should like to make for solid absorbers.

In a monatomic gaseous absorber the electron transition may be to any one of the unfilled atomic optical levels,[2] the transition obeying the usual selection rules,[3] or, with sufficient absorbed energy, the transfer may be to infinity. According to this interpretation, one expects fine structure on the long wave-length side of the main absorption edge for a monatomic gas and one expects the structure to consist of true resonance absorption lines of frequency separations and relative intensities predictable from spectral theory. Generally, the overlapping of absorption lines with themselves and with the main edge makes impossible an unambiguous recognition of the expected component structure. The experimental curve of the K absorption region for argon gas, however, is amenable to analysis. A study of the argon K edge was made in 1926 by Coster and van der Tuuk[4] with similar but less definitive conclusions than those of the present study.

With a two-crystal vacuum spectrometer[5] several absorption curves of the argon K region, wave-lengths near 3866 x.u., were recorded for each of several values of mass per unit area of the absorbing gas. For the precise study of each section of the curve between mass absorption coefficients μ_1 and μ_2, the optimal value of mass per unit area is

$$\rho x=\log_e (\mu_2/\mu_1)/(\mu_2-\mu_1),$$

where ρ is the density and x is the thickness for the maximum relative change in transmitted intensity. The average of these several curves is reproduced, the solid dots, in Fig. 1.

The first step in the analysis of the observed curve is a correction for the finite resolving power of the spectrometer. The calcite crystals used in the present work were perfect specimens

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[1] For example, see A. E. Lindh, *Handbuch der Experimental Physik* (1930), XXIV 2. Teil, Chapter X; R. de L. Kronig, Zeits. f. Physik **75**, 191 (1932); and Beeman and Friedman, Phys. Rev. **55**, 1115(A) (1939).

[2] W. Kossel, Zeits. f. Physik **1**, 119 (1920).

[3] M. Siegbahn, Zeits. f. Physik **67**, 567 (1931).

[4] D. Coster and J. H. van der Tuuk, Zeits. f. Physik **37**, 367 (1926).

[5] This spectrometer has been previously described: L. G. Parratt, Phys. Rev. **54**, 99 (1938).

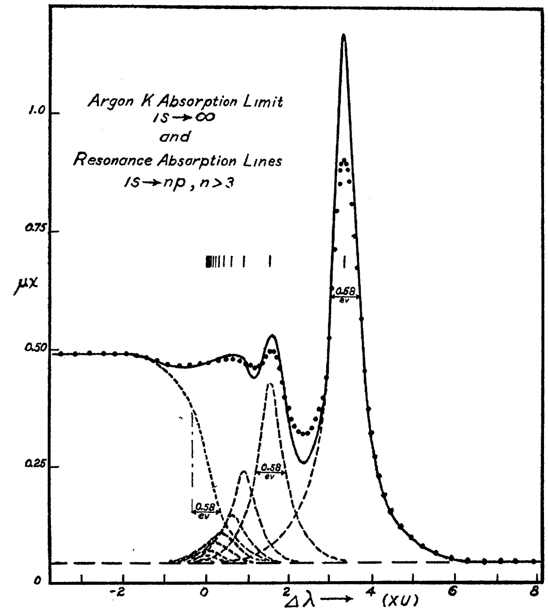

FIG. 1. Microscopic analysis of the absorption curve near the K edge for argon gas. The dots are observed values of absorption coefficients; the solid curve is corrected for finite resolving power; the broken curves represent the component structure: the main edge and resonance absorption lines.

of Class I,[6] and with such crystals the uncertainty in the correction is perhaps a minimum. We know that the observed width of the first sharp resonance absorption line is greater than the true width by the approximate amount[7] $2.9\times(0.34)^{1.7}=0.45$ x.u. This corrected width and the fact that the observed and corrected curves are not much different where the slope is constant or nearly constant serve as guides in our sketching of the corrected absorption curve, the solid line in Fig. 1. The most certain part of the somewhat arbitrarily corrected curve is the width of the most intense absorption line, 0.58 electron volt.

The electronic configuration of argon, $1s^22s^22p^63s^23p^6$, is altered in the absorption act by the removal of one of the $1s^2$ electrons to infinity or, with less absorbed energy, to an outer optical P level (if we neglect possible jj coupling between this electron and the inner electron hole). P levels are the only final levels allowed by the selection rules. (The distinction between the $P_{1/2}$ and $P_{3/2}$ levels is not significant because of their negligible separation.) So far as the outer levels are concerned the argon atom with a missing inner electron behaves approximately as a potassium atom. From the optical terms of potassium,[8] the various P level separations are: $4P\rightarrow 5P=1.44$ ev; $5P\rightarrow 6P=0.53$ ev; $6P\rightarrow 7P=0.25$ ev; etc., with the series limit at 2.71 ev from the $4P$ level. If we identify the first resonance line in the absorption curve with the transition $1S\rightarrow 4P$, the first transition allowed by the selection rules, we may represent the wave-length positions of the other absorption lines of the series $1S\rightarrow nP$ ($n>3$) and of the series limit by the short vertical lines in the center of Fig. 1.

Before we attempt the resolution into component lines we must determine the background or the main absorption edge. By definition for a monatomic gaseous absorber, the center of the main K edge coincides in wave-length with the $1S\rightarrow nP$ series limit. The width of the main edge is equal to the width of the $1S\rightarrow 4P$ line, 0.58 ev, minus the width of the $4P$ state, according to an interpretation[9] of the theory of Weisskopf and Wigner.[10] Since the width of the $4P$ state is negligible compared with the $1S$ width we conclude that the width of the main edge is 0.58 ev. Furthermore, the theoretical shape of the main edge is given by an arctangent curve.[9] Then, with the position, width and shape known, the main edge is readily drawn as in Fig. 1. This analysis places the main edge at a wave-length position somewhat less, 3.5 to 4 x.u. in the present case, than its usually accepted measured value. In this connection we note that most measured wave-lengths of absorption edges are obtained with instruments of resolving power insufficient to reveal the absorption lines or to allow their proper interpretation.

Having thus determined the background, we proceed with the resolution into component resonance lines. By the same arguments as above, all these lines have the same shape and the same width, 0.58 ev. The component lines would be determined uniquely if their wave-length positions were known. The separations between the

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[6] L. G. Parratt, Rev. Sci. Inst. **6**, 387 (1935).

[7] From Eq. (7) of reference 6.

[8] R. F. Bacher and S. Goudsmit, *Atomic Energy States* (McGraw-Hill, 1932), p. 245.

[9] Richtmyer, Barnes and Ramberg, Phys. Rev. **46**, 834 (1934).

[10] V. Weisskopf and E. Wigner, Zeits. f. Physik **63**, 54 (1930).

three most intense lines whose resolution is more or less obvious agree within experimental error with the predictions from the potassium term values: we conclude that our interpretation is correct and that the wave-length positions of all the lines are known. The components are readily sketched in the figure with the obvious additional criterion that the sum of the component ordinates at a given wave-length must equal the observed intensity. It is gratifying that all of the observed intensity is accounted for satisfactorily by component lines whose relative intensities decrease gradually to zero. The relative intensities of these lines are 100 : 34 : 18 : 8.5, etc.

It is of interest to note that the corrected width of an absorption line gives directly the width of the initial state if the final state width is negligible. Many solid absorbers have prominent and easily measurable absorption lines (sometimes called "white lines" in photographic studies) and, when applicable, this direct method of determining the width of a K or an L state may be very convenient.

In the absorption curve of a solid absorber we expect to find on the short wave-length side of the main edge resonance absorption lines more or less perturbed by overlapping wave functions from neighboring atoms. We also expect to find resonance absorption bands due to transitions to the allowed Brillouin energy bands.[11] The resolution of these resonance lines and bands into the component structure, which would yield very significant information about the solid, demands first a determination of the contour of the main edge. It is evident from the analysis of the argon curve and from the additional complications of the solid structure that the meaning of the main edge for a solid absorber is rather obscure.

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[11] A typical absorption curve for a solid absorber, the L_{III} region for silver, is reproduced in Fig. 5 of reference 5.

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Nuclear Energy Levels in B^{10} [1]

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Five thousand stereoscopic pictures of electron tracks in a cloud chamber yielded six hundred sixty-five Compton electrons from a thin mica foil and seventy-six ± electron pairs formed in the gas in the chamber. These data indicate thirty-one lines in the γ-ray spectrum of B^{10}. Nine energy levels account for the observed lines in a satisfactory manner, and are not in disagreement with the neutron spectrum from the same reaction. An attempt to correlate the observed energy levels with those predicted by theory leads to the following suggested classification: $^3S_1$ as the ground state (relative energy zero); $^3D_{123}$ at 0.26, 0.50 and 0.61 Mev; ^1S at 1.44 Mev; ^1D at 1.93 Mev; ^3D at 2.92 Mev; ^1D at 3.64 Mev; and ^3F at 4.73 Mev.

A PREVIOUS[3] examination of the γ-rays from B^{10} showed the presence of six γ-ray lines which could be correlated with the neutron data of Bonner and Brubaker.[4] However, the probable error in the lines reported was of the order of 0.1 Mev and the resolution of the method poor, so that it was impossible to say if more than six γ-ray lines were present. For that reason the experiment has been repeated under conditions which give better resolution and higher accuracy of the measurement of γ-ray energies.

There are two convenient ways of measuring γ-ray energies: the Compton recoil electron method and the ± electron pair production

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[1] A preliminary report of part of these data was given at the Washington meeting of the American Physical Society, Phys. Rev. **55**, 1129(A) (1939).

[2] Fellow at the Westinghouse Research Laboratory since September 1938.

[3] P. G. Kruger and G. K. Green, Phys. Rev. **52**, 773 (1937).

[4] T. W. Bonner and W. M. Brubaker, Phys. Rev. **50**, 308 (1936).