affect the magnetic properties very little compared to the large amounts of nickel and chromium in stainless steel. The iron particles in the present experiment have lattice constants that are reasonable for bulk γ iron and hence are probably negligibly strained.

Magnetic susceptibility measurements[10] on both samples indicate a gentle maximum at about 5°K. Extrapolation from the paramagnetic range for both samples to a zero value for $1/\chi$ gave Curie-Weiss constants of -8 to -13°K. The magnetic moment and Néel temperature given in the present investigation are thus regarded as quite close to the properties of pure γ iron. No explanation is offered at present for the tilted spins.

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K X-Ray Fluorescence Yield of Argon*

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Reported values of the *K* x-ray fluorescence yield of argon lie in two distinct groups, viz., low values (about 0.07) and high values (about 0.13). A new measurement herein reported gives 0.14 ± 0.014. This measurement was made from the "escape peak" in the pulse-height distribution of a flow proportional counter with monochromatic x rays. An Fe^{55} radio-isotope was used as the source of primary x rays. Corrections were made for the *L* and *M* ionizations in the argon gas, for the reabsorption of the *K* fluorescent x rays, and for background counts.

I. INTRODUCTION

THE method of measuring the *K* x-ray fluorescence yield of argon by analysis of the pulse-height distribution (PHD) of a proportional counter has been previously described,[1] and several such measurements[2–5] have been carried out in the last ten or so years. However, these measurements are not satisfactorily consistent—they vary from 0.06 to 0.13. With the exception of the values given by Heintze,[4] Locher,[6] and Parratt,[7] all of the published experimental *K* yields of argon, regardless of the experimental methods, lie in what may be called a group of low values,[8] clustering around 0.07. The exceptions cited are in a group of high values—around 0.13.

The theoretical values are likewise divided into two groups. In the theory of atomic fluorescence, developed by Wentzel,[9] the application of a simple wave function gave a value of 0.07 for the *K* fluorescence yield of argon.[1] Rubenstein,[10,11] using the Hartree wave function, obtained a value of 0.13. Dexter and Beeman,[12] using an experimental value[13] for the lifetime of the *K* hole in argon, obtained 0.123.[14] In the Dexter-Beeman calculations, Fock wave functions were used to evaluate the radiative transition probabilities. The latest calculation of the fluorescence yield by Callan[15] gave 0.125, in which the screened hydrogenic wave function was used.

In the experimental determination of the *K* yield by the proportional counter method, corrections must be made for the *L* and *M* ionization by the primary x rays,

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[14] The width of the argon *K* state reported by Parratt as 0.58 eV in 1939 (reference 13) was later restated by Parratt in 1959 as 0.5 ± 0.05 eV (reference 7). Had Dexter and Beeman (reference 12) used the later value they would have reported 0.14 for the argon *K* fluorescence yield.

[15] By private communication; see also E. J. Callan, Phys. Rev. **124**, 793 (1961).

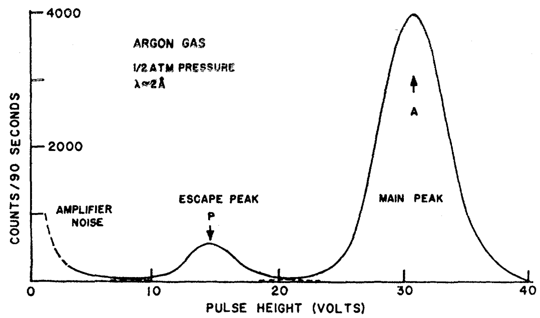

FIG. 1. A typical pulse-height-distribution curve.

TABLE I. Measurements in the K fluorescence yield of argon.

	1 atm	1/2 atm	1/3 atm
$\omega_K{}^e=P/(A+P)$, uncorrected values	0.078 ± 0.006	0.101 ± 0.008	0.110 ± 0.011
$\omega_K{}^c=1.1\omega_K{}^e$, corrected for L,M ionization	0.086 ± 0.007	0.110 ± 0.009	0.121 ± 0.012
Intensity N_0 (counts/90 sec)			
at A peak	6000	4050	2400
at P peak	600	600	390
Relative statistical error, $\Delta\omega_K{}^e/\omega_K{}^e$	0.075	0.080	0.099

for the re-absorption of the K fluorescent x rays, for background radiation, and possibly for such secondary effects as the emission of electrons from the counter walls. For the first correction, one can use the absorption coefficient at either side of the K absorption edge to evaluate directly the relative probabilities that the ionization process leaves a vacancy in the K shell as compared with a vacancy in the L, M shells. Correction for the re-absorption of K fluorescent x rays was developed by Bertolini *et al.*[3]; the yield is given by the limit of the experimental value at zero counter pressure. Heintze[4] calculated theoretically this re-absorption correction, but it may be shown that his correction is essentially the same as the mathematically simpler procedure of Bertolini.

II. APPARATUS

The apparatus of the present experiment consists mainly of an Fe^{55} radioactive source of manganese x rays, a laboratory-made flow proportional counter, a regulated dc power supply, a linear amplifier with a built-in pulse-height discriminator, and a scaler unit.

General discussion of a proportional counter and of its operation can be found in the literature.[4] The specific counter in the present experiment was 5 in. in length and $1\frac{1}{4}$ in. in diam. It was constructed of nickel-plated brass with the axial wire of stainless steel having a uniform diameter of 0.002 in. Guard rings prevented leakage signals. To reduce noise to a minimum, the entire counter unit was placed in a metal shield box.

The counter signal was passed through a cathode follower to a linear amplifier. The counter voltage and amplifier gain were chosen to maintain a pulse height of less than 40 V. The amplifier output was fed through a differential pulse-height discriminator to the scaler unit. The window of the discriminator was kept constant at 1 V and the pulse-height distribution was scanned in steps of 0.5 V. A typical set of operating conditions were: (1) 1610 V on the counter, and (2) amplifier gain of about 8700 with 1/2 atm of argon in the counter. With these values, the main peak of the pulse-height distribution occurred at 31 V. Data were obtained for each setting of the discriminator window by accumulating pulses from the discriminator for a fixed time-interval of 30 sec.

Three runs were taken for each of three different counter pressures. These different runs, adjusted in the abscissa scale so that the main peak of each curve occurred at the same pulse-height voltage, were then added together to give a single curve of data for an effective time-interval of 90 sec. A representative plot of the number of counts vs pulse-size is shown in Fig. 1. The K fluorescence yield was determined from measurements of the relative areas under the peaks A and P by the method described below.

III. RESULTS, CORRECTIONS, AND ACCURACY

The experimental results for argon are shown in Table I for runs at the three different counter pressures, viz., at 1, $\frac{1}{2}$, and $\frac{1}{3}$ atmospheres. The uncorrected values of the K fluorescence yield $\omega_K{}^e$, i.e., the ratio of the numerically integrated areas $P/(P+A)$, are given in the first row, and the values $\omega_K{}^c$ corrected for the L and M ionization are given in the second row. In the next row are listed the total numbers of recorded counts at the A and P peaks, respectively. The relative statistical error is shown in the last row. The final value of the K yield is obtained from $\omega_K{}^c$ after making a final correction for re-absorption.

The use of an Fe^{55} radio-isotope (manganese K radiation) as the primary x-ray source reduced to unimportance the ejection of electrons from the walls of the nickel-plated counter; a manganese K x ray has an energy approximately 2.3 keV below the K absorption edge of nickel.

The background intensity, as measured when the primary source was thoroughly shielded, was found to be small in the present experiment but not negligible. It was at most 5 counts/30 sec in the pulse-height region of interest. Correction for this background has been made in the values of Table I.

The statistical error as listed in the last row of the table was calculated as follows. It was assumed that the statistical standard deviation in N counts is given by $\sqrt{N}$ and that the PHD is approximated by a Gaussian distribution with a peak-height N_0 and half-width σ.

The approximate value of the area P or A is taken as the area, by integration, of this distribution function. A simple calculation shows that the relative standard deviation is $\pm(2/N_0)^{\frac{1}{2}}$. Such a calculation was made for both the escape peak and the main peak; the total error, as listed in Table I, is the sum of the relative errors for these two peaks. (*Note.* The assumption of Gaussian shape is made for the evaluation of the relative error only; this assumption is not made in the determination of the relative areas.)

Finally, the correction for the re-absorption of the K fluorescent x rays was made by considering the pressure-dependence of the re-absorption. If the probability that the fluorescent x rays escape from the counter is denoted by ϵ_K, then the experimental value ω_K^e can be interpreted as the product of the fully corrected yield ω_K and this escape probability. On the assumption that the escape probability ϵ_K is independent of the geometry of the counter and is dependent on only the counter pressure, it is possible to approximate ϵ_K as

$$\epsilon_K(p) \propto \exp(-Ap), \tag{1}$$

where p is the counter pressure and A is a constant. Then, the K fluorescence yield is

$$\omega_K = \lim_{p\to 0} \omega_K^e. \tag{2}$$

Combining Eqs. (1) and (2), and including the correction for the L and M ionization, the final K fluorescence yield is written in the relation

$$\ln\omega_K = \lim_{p\to 0} \ln\omega_K^c. \tag{3}$$

A plot of $\ln\omega_K^c$ against the counter pressure (Fig. 2) is a straight line whose intercept at zero pressure gives the fully-corrected and final value of the K yield.

This method of correction for the reabsorption of the K fluorescence x rays in the counter is essentially the same as that given by Heintze.[4] The constant A in Eq. (1) turns out to be 2.8×10^{-3} mm Hg^{-1} in the present experiment, in agreement with Heintze's value. The constant A is interpreted as a pressure absorption coefficient, viz., at the counter pressure $1/A$ the escape probability ϵ_K of the fluorescent x rays becomes e^{-1}. The agreement of A in the two different experiments argues that the re-absorption of the K fluorescence x rays in the counter is indeed independent of the geometry of the counter, at least in the pressure region of 0.1 to 1 atm.

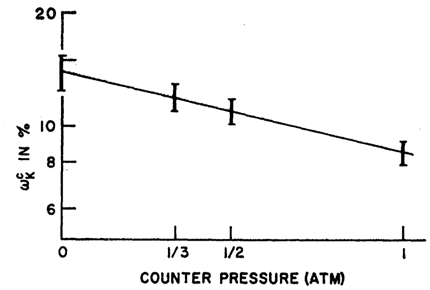

FIG. 2. Correction for re-absorption of fluorescent x rays.

The final value of the K yield is 0.14 ± 0.014. The statistical error, 0.014, could be improved by increasing either the counting time or the intensity of the primary x rays. Judging from the fact that the three experimental points lie very well on a straight line, the "effective" error is estimated to be considerably less than 0.014.

Returning to the discrepancies in the earlier published measurements with the proportional counter method, the authors believe that these discrepancies are probably due to the uncertainties in the determinations of the PHD curves. Unless a large number of counts is observed at the escape peak, the statistical error in the final result becomes uncomfortably large. Correction for the background intensity has also often been neglected.

IV. CONCLUSION

The value of the K fluorescence yield of argon in this experiment, 0.140 ± 0.014, is high relative to most earlier reports but its statistical precision is rather good and it is in agreement with the values by Heintz,[4] by Parratt,[7] by Rubenstein and Snyder,[10,11] and by Dexter and Beeman (corrected[14]).

It is believed that this experimental value for argon, for which the proportional counter method is so nicely applicable, may be used as a sort of anchor value in estimating with fairly good reliability the values for neighboring atomic numbers as was done in reference 7.

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