Precise Measurement of the $X_K$ Emission Rate Following the Electron Capture-Decay of $^{54}$Mn — Fluorescence Yield $\omega_K$ of Cr

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This determination was made using the electron capture decay of $^{54}$Mn. Two methods were employed to measure the $K$ X-ray emission rate: by means of a pressurized $4\pi$ proportional counter with the gas at 1.5 MPa, and by means of a medium geometry-defined solid angle counter. The final result was $\omega_K = 0.2901 \pm 0.003$. Special care was taken in determining the corrections, some of which do not appear to have been allowed for so far. It is noteworthy that additional corrections, each about $+3\%$, had to be applied to the results obtained with each of the two methods. Thus there remains complete agreement between them, but at a higher value of $\omega_K$ than those appearing in recent publications.

1. Introduction

Results for $K$ fluorescence yield of chromium ($\omega_K$)$_{Cr}$ were reviewed by Bambynek [1] in 1967. Since then this constant has been remeasured several times [2-4], but the differences between all these results remain several times greater than the uncertainties assigned by the authors. The fact that $K$ fluorescence yield ($\omega_K$)$_{Cr}$ is still subject to significant uncertainties leads to many problems, when it is necessary to have accurate knowledge of the activity of radionuclides decaying by electron capture. The present work was undertaken as part of a program aiming to contribute to the improvement of this situation, and a redetermination of ($\omega_K$)$_{Cr}$ was selected as a first step to achieve this purpose. The constant ($\omega_K$)$_{Cr}$ is readily obtained by counting $K$ X-rays following the decay of $^{54}$Mn sources of known activity. The decay parameters of $^{54}$Mn are well known [5] and its activity can be measured with an accuracy of about 0.1% by $4\pi (X-\gamma)$ coincidence counting. Hence one expects to achieve consistent results without difficulty. The fact that there nevertheless exist wide differences between reported values of ($\omega_K$)$_{Cr}$ must be due to problems affecting the measurement of the $K$ X-ray emission rate $N_{X_K}$, since $\omega_K$ depends on $N_{X_K}$ as well as $N_0$, the absolute activity of the parent nuclide in accordance with:

$$P_1 \omega_K = N_{X_K}/N_0.$$  \hfill (1)

The magnitude of the variable $P_1$, the $K$ capture probability, is now well established. For the decay of $^{54}$Mn it is $P_1 = 0.896 \pm 0.003$ [5]. Like Bambynek [1] we used two procedures to measure $N_{X_K}$: $4\pi$ counting at a pressure high enough to absorb the $K$ X-rays in the counting gas, and medium geometry-defined solid angle counting. Great care was taken in determining all corrections and it will be seen that the present result for ($\omega_K$)$_{Cr}$ is some $3\%$ higher than most of those obtained previously.

2. Preparation of Sources

Two solutions of $^{54}$Mn of different origins were used. Inspection by $X$ (Si, Li), $\gamma$ (Ge, Li) and $\beta$ (Si with surface barrier) spectrometry failed to reveal any impurities with a threshold of 0.1% for $\gamma$ and $\beta$ analysis and 0.01% for $X$ analysis. The sources were prepared by evaporation in vacuum to reduce the self-absorption of photons $X_k$. Chemical analysis of the solutions used showed that the concentration of elements likely to be deposited during evaporation was about $3 \times 10^{-2}$ $\mu$g per source. Deposition was made on a 2.5 $\mu$m mylar foil, and a second similar foil was used to sandwich the active deposit. This thickness was selected for the following reasons:

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attenuation of $X_L$ photons and absorption of Auger electrons of the $K$ shell, minimum attenuation of $X_K$ photons, low spot thickness variation (less than 7%).

To check the attenuation correction, 3.5 μm and 6 μm mylar foils were also used. Assembly of these screens is an important problem for the $4\pi$ pressurized counter. A difference of 0.1 mm for a pressure of 0.5 MPa corresponds to a 3.5% attenuation of the $X_K$ radiation of Cr. Hence it is important for the assembly to be perfectly tight, so that no gas is trapped between the two foils. After a large number of tests, the process involving the dissolution of a few drops of PVC base cement in 50 ml of ethyl acetate was adopted. A calibrated burette was used to spread 100 mg of this solution on the film which does not support the source; the solvent evaporates rapidly, leaving a thin film of cement enabling perfect adhesion of the two mylar foils, using a heating press.

When the assembly is completed, a thin layer of aluminum ($\approx 1 \mu g cm^{-2}$) is deposited on each side using a metal sprayer. Only at this stage of preparation is it possible to determine the thickness of the mylar, because electrostatic forces distort weighing before metal deposition. Hence the weights of cement and aluminum deposited on the films must be derived from the results of the weighing. The cement weight is determined accurately using aluminum disks of known weight on which 100 mg of the ethyl acetate-cement solution have been deposited. After evaporation of the solvent at 80 °C, the disks are weighed. The weight of the cement deposited per film is then obtainable from the difference between the two series of weighings. For 100 mg of solution, this weight is $(0.250 \pm 0.001)$ mg. The weight of aluminum is indicated by the measurement instruments of the metal sprayer as $(0.05 \pm 0.004)$ mg. Once the diameter of the films $(3.6 \pm 0.01)$ cm is known, the thickness can be derived with an uncertainty of $\pm 1\%$.

In order to improve accuracy, the same sources are employed for activity measurements and $X_K$ intensity measurements, thus eliminating weighing errors.

### 3. Measurement of the Disintegration Rate $N_0$

The activity of the source was measured by $4\pi(X_K - \gamma)$ coincidence counting. The equipment is shown schematically in Figure 1.

The $\gamma$ detector is a $7.5 \times 7.5$ cm NaI (Tl) crystal. The $K$ X-ray detector is a $4\pi$ counter identical to that used for $X_K$ intensity ratio measurements [6]. The resolution of this instrument FWHM $X_K$ is only about 17% at 5.5 keV. High resolution is useful to minimize uncertainties when correcting for $\gamma$ background. The total systematic uncertainties were estimated as 0.05%, made up as follows: random coincidences 0.03%, inaccuracy of the timer 0.01%, dead time uncertainty 0.005%, correction for the $\gamma$ efficiency in the window 0.005%.

### 4. Measurement of Intensity Ratio $N_{X_K}$

Each of the two methods used involves a large number of parameters, some of which are specific to one instrument, while others are common to both measurements but with different orders of magnitude.

#### 4.1. Measurement with $4\pi$ High Pressure Counter

This measurement has been described by several authors, especially by Allen [7], Campion and Merri [8] and Legrand [6].

![Fig 1. Diagram of the experimental $X_K-\gamma$ coincidence system](image-url)