

THE K - SHELL FLUORESCENCE YIELD OF SELENIUM AND THE
ABSORPTION COEFFICIENT IN THE ENERGY REGION AROUND THE
K - EDGE

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Abstract: The K-shell fluorescence yield of selenium was investigated by use of a special wall-less proportional counter with methane filling to which small amount of dimethyl selenide was added as fluorescence radiator. In separate experiment absorption coefficient of selenium was measured in the energy region around the K absorption edge. The resulting value for the K-shell fluorescence yield of selenium amounts to $\omega_K = 0.605 \pm 0.005$. The values obtained for the photoelectric absorption coefficient at the K-edge are $(\tau/\rho)_K = (170 \pm 1) \text{ cm}^2/\text{g}$ and $(\tau/\rho)_{K'} = (22.3 \pm 0.2) \text{ cm}^2/\text{g}$ respectively and consequently the K-jump is $S_K = 7.61 \pm 0.06$.

1. Introduction

Experimental values of the K-shell fluorescence yield of selenium date from the early period of experimental investigations of the K-shell fluorescence yields as evident from the Table 1. As the measuring techniques have greatly improved since or newly developed, more reliable results seemed to be attainable. Thus a redetermination of the K-shell fluorescence yield of selenium was needed particularly as values higher than the published data could be expected on the base of the recent results for the K-shell fluorescence yield of the neighbouring elements germanium, arsenic and krypton^{7,8,9}).

As it was ascertained in preliminary experiments that small amount of dimethyl selenide $\text{Se}(\text{CH}_3)_2$ added to methane as filling gas is tolerable to the counter, proportional counter method with gaseous source was applied. Fluorescent and Auger transitions following the photoexcitation of selenium can be discriminated with methane filling as the counter detecting electrons is almost transparent to the fluorescence X-rays.

2. Experimental procedure

Gas of the counter was irradiated by a narrow beam of monochromatic radiation which passed radially through the counter through thin polyester foil windows. Molybdenum $K\alpha$ radiation with the photon energy of 17.4 keV was used. The beam proceeded from a molybdenum target irradiated by X-rays through a filter of niobium oxide with about 10 mg of niobium per cm^2 . A special wall-less multiwire counter was employed in order to avoid detection of characteristic X-rays coming from the material of the counter and to reduce the background due to the scattering effects from the wall. The cathode of the main counter has 56 mm in diameter and consists of 96 nylon threads 0.2 mm thick and covered by a conducting layer. The surrounding ring between the cathode and the wall is 14 mm wide and is turned into a separate counter by 20 tungsten wires 0.1 mm thick placed evenly on the middle circle of the ring.

Table 1

Author	Reference (year)	ω_K	Technique
Martin	1 (1927)	0.68	Increase of the ionization current in the cell due to the emission of the Auger electrons at the high energy side of the K-edge
Compton	2 (1929)	0.55	The intensity of the fluorescent radiation
Berkey	3 (1934)	0.55	„
Lay	4 (1934)	0.585	„
Arends	5 (1935)	0.550	„
Stephenson	6 (1937)	0.575	„

Dimethyl selenide $\text{Se}(\text{CH}_3)_2$ was prepared by boiling selenium and methyl iodide in presence of rongalit and sodium hydroxide¹⁰⁾. Pure compound was obtained by vacuum distillation and was introduced into the counter by evaporation at about 240 K to the pressure of 5 torr which was tolerated by the counter without appreciable deterioration of resolution. After that the counter was filled to 1 atm with methane. The counter was connected electrically in the usual way as shown in Fig. 2 so that it operated as low energy spectrometer.

The spectrum of pulses from the main counter which did not coincide with pulses from the ring counter is shown in Fig. 1. For recording the background spectrum the counter was filled with methane without selenium admixture. In the resulting spectrum two separate peaks appear, photopeak at the energy of the exciting radiation W_0 and escape peak at the energy of $W_0 - W_{K\alpha\beta}$. The number of counts in the photopeak determines the number of absorption events in selenium leading to the emission of Auger electrons due to the filling of vacancy in the K - or other shells. As the counter does not operate ideally as assumed, correction has to be made for the absorption of the selenium K X-rays in the gas of the counter and for the escape of electrons across the boundary between the main counter and the ring. Similarly the escape peak reveals the number of absorption events leading to radiative transitions after the corresponding correction is applied.

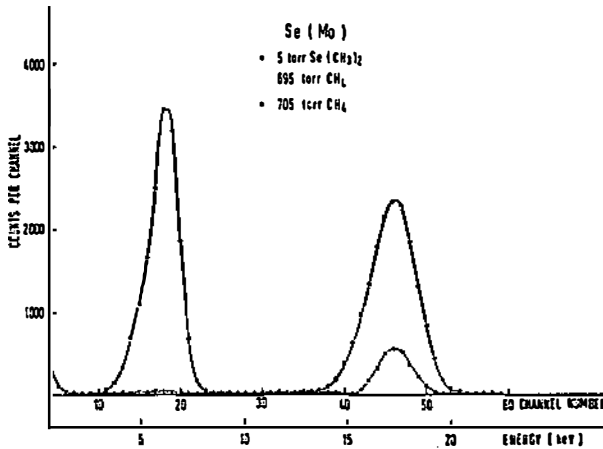


Fig. 1. Pulse spectrum obtained when the counter was filled with methane and dimethyl selenide admixture; background spectrum.

With conditions present in the counter correction for the photopeak amounts to 1.5% while correction for the escape peak to 2%. Thus the corrected number of counts in the photopeak is $N_{ph} = 17100 \pm 100$ while in the escape peak $N_e = 19100 \pm 100$. The K-shell fluorescence yield is obtained from the formula

$$\omega_K = \frac{w_K + w_{L,M}}{w_K} \cdot \frac{N_e}{N_e + N_{ph}}, \quad (1)$$

where w_K and $w_{L,M}$ are the probabilities for the photoeffect in the K-shell or in the L and other shells.

The ratio $(w_K + w_{L,M})/w_K$ is needed at the energy of the primary X-rays of molybdenum. From a table of K-jump values given by Blokhin¹¹⁾ and Kirchner¹²⁾ the value of the ratio at the K-edge of selenium can be estimated as 1.15 which might be about 1% higher than the value at the required energy. This uncertainty is limiting the accuracy of the proportional counter method with gaseous source. Thus the probability ratio was determined in a separate experiment. In the low energy region the ratio of probabilities is equal to the ratio of corresponding photoelectric absorption coefficients τ_{tot}/τ_K which can be determined experimentally as $\tau_{tot}/(\tau_{tot} - \tau_{L,M})$.

3. Investigation of the absorption coefficient

The experimental arrangement for the investigation of the absorption coefficient of selenium is shown in Fig. 2. A 20 cm long aluminium tube with thin plastic windows at both ends, used as absorption chamber, was placed between the target and proportional counter window so that the filtered beam of monochromatic X-rays coming from the irradiated target passed the absorption chamber and entered the counter. Various elements around the selenium in periodic table were used as targets in order to have absorption measurements performed at sufficient number of photon energies around the K-edge of selenium.

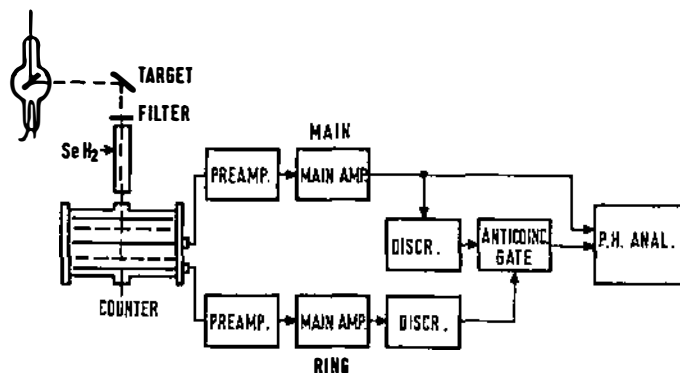


Fig. 2 Experimental arrangement for measurement of the X-ray absorption coefficient in selenium.

Selenium hydride was used at various pressures in the absorption chamber. It was prepared from aluminium selenide and water by the usual procedure. Gas was purified by repeated vacuum distillation at 193 K in order to hold back higher selenium hydrides present and was introduced then into the absorption chamber. The proportional counter was filled with the normal argon methane mixture and was employed as detecting element of the low energy spectrometer. Intensity of the transmitted X-rays was determined by the number of counts in the photopeak

in a certain time interval. Measurements were repeated at different pressures of selenium hydride, which defined the amount of selenium. The total mass absorption coefficient μ/ρ was determined from the slope of the best fit line through the measured points in the semilogarithmic diagram of the intensity versus pressure. Scattering cross sections τ/ρ were calculated from the tabulated values for coherent and incoherent scattering functions^(13,14). So the photoelectric mass absorption coefficients τ/ρ were determined for various energies of the incident X-rays on both sides of the K-edge of selenium as given in Table 2. The logarithms of the coefficients plotted against the logarithms of relative wavelengths lying on straight lines shown in Fig. 3 can be described by equations

$$\tau/\rho = (\tau/\rho)_K (\lambda/\lambda_K)^{2.77+0.2} \text{ for } \lambda < \lambda_K \quad (2)$$

and

$$\tau/\rho = (\tau/\rho)_{K'} (\lambda/\lambda_K)^{2.91+0.02} \text{ for } \lambda > \lambda_K, \quad (3)$$

Table 2

Characteristic line	Wavelength/Å	Total mass absorption coefficient $(\mu/\rho)/(\text{cm}^2/\text{g})$	Scattering coefficient $(\sigma/\rho)/(\text{cm}^2/\text{g})$	Photoelectric absorption coefficient $(\tau/\rho)/(\text{cm}^2/\text{g})$
Fe, <i>Kα</i>	1.937	161.2	2.72	158.5
Cu, <i>Kα</i>	1.542	86.6	2.25	84.3
Zn, <i>Kα</i>	1.436	72.7	2.12	70.6
As, <i>Kα</i>	1.177	38.9	1.75	37.1
Se, <i>Kα</i>	1.106	33.4	1.64	31.8
Br, <i>Kα</i>	1.041	28.1	1.54	26.6
Se, K-edge	0.9798			
Sr, <i>Kα</i>	0.877	126.9	1.27	125.6
Zr, <i>Kα</i>	0.787	93.2	1.13	92.1
Mo, <i>Kα</i>	0.711	70.5	1.00	69.5
Rh, <i>Kα</i>	0.615	48.3	0.85	47.4
Ag, <i>Kα</i>	0.561	36.8	0.76	36.0

where λ_K is the wavelength corresponding to the K-edge energy. Values of the photoelectric absorption coefficient at the K-edge obtained from the high and low energy part are

$$(\tau/\rho)_K = (170 \pm 1) \text{ cm}^2/\text{g}$$

and

$$(\tau/\rho)_{K'} = (22.3 \pm 0.2) \text{ cm}^2/\text{g}$$

respectively. Thus the value for the K-jump amounts to $S_K = 7.61 \pm 0.06$. The ratio $(w_K + w_{L,M})/w_K$ at the K-edge has the value of 1.151 ± 0.002 which agrees well with the value given by Blokhin¹¹⁾.

4. Discussion

The partial absorption coefficient $\tau_{L,M}$ for molybdenum K α radiation in selenium can be obtained by extrapolating the energy dependence of the coefficient below the K-edge, given by expression (3), to the energy of molybdenum radiation. This procedure gives the value of 7.96 for the ratio $\tau_{tot}/\tau_{L,M}$ and the value of 1.144 ± 0.005 for the ratio of probabilities $(w_K + w_{L,M})/w_K$. With the result of the measurement the K-shell fluorescence yield of selenium is obtained from formula (1) as $\omega_K = 0.604 \pm 0.005$.

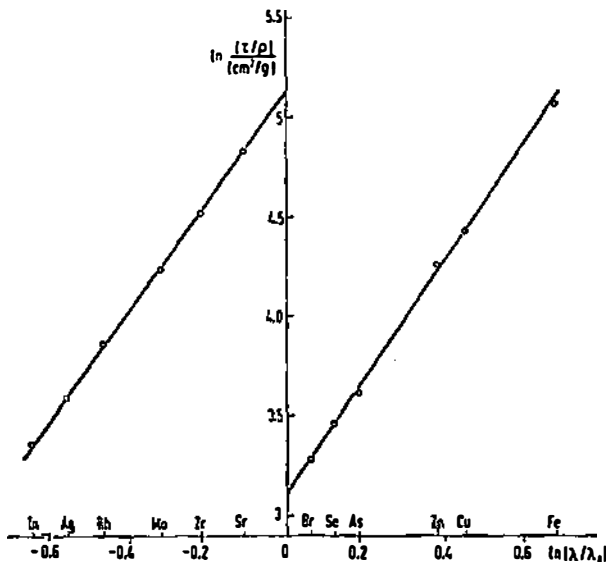


Fig. 3. Absorption coefficient of selenium in the energy region around the K-edge.

Measurements were repeated with zirconium K α X-rays as exciting radiation ($W_0 = 15.7$ keV) and silver K α X-rays ($W_0 = 22.1$ keV). The mean value of all three separate determinations is

$$\omega_K = 0.605 \pm 0.005.$$

The higher value for the K-shell fluorescence yield of selenium is in accordance with the values obtained for neighbouring elements and agrees with the results of recent calculations of Kostroun¹⁵⁾ ($\omega_K = 0.602$) and with the interpolated value of McGuire¹⁶⁾ ($\omega_K = 0.611$).

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FLUORESCENČNI PRIDELEK LUPINE K PRI SELENU IN EKSTINKCIJSKI KOEFICIENT SELENA V ENERGIJSKEM PODROČJU OKOLI ROBA K

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Vsebina

Fluorescenčni pridelek lupine K pri selenu je bil določen z brezstenskimi proporcionalnim števcem, ki je bil polnjen z metanom z dodatkom dimetil selenida. Posebej je bil izmerjen ekstinkcijski koeficient selena v energijskem področju okoli roba K. Za fluorescenčni pridelek je dobljena vrednost $\omega_K = 0.605 \pm 0.005$.

Za fotoelektrični absorpcijski koeficient so dobljene vrednosti $(\tau/\rho)_K = (170 \pm \pm 1) \text{ cm}^2/\text{g}$ in $(\tau/\rho)_{K'} = (22.3 \pm 0,2) \text{ cm}^2/\text{g}$ in tako za skok na robu K $S_K = = 7.61 \pm 0.06$.