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MEASUREMENT OF THE CROSS SECTION FOR THE ISOMERIC ACTIVATION OF ^{115}In BY γ-RAYS FROM ^{24}Na SOURCE*

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The activation cross section of ^{115}In for a 150 Ci ^{24}Na source emitting 1.38 and 2.75 MeV gamma photons has been determined. The value found on the basis of the induced ^{115m}In activity proved to be 13.5×10^{-32} cm^2, being about threefold of 4.9×10^{-32} cm^2, the value determined with the aid of ^{60}Co photons.

This deviation gives evidence of the existence of higher, 1.42, 2.13 and 2.63 MeV activation levels in addition to the first 1.078 MeV, which have already been measured when using accelerators for excitation.

The isomeric activity resulting from the ^{115}In(γ, γ') ^{115m}In reaction has already been measured and studied by several authors. For its activation not only the bremsstrahlung from particle accelerators [1] but also some of the γ-emitting radioisotopes were used. The activation cross section per gamma quantum, as evaluated for the 1.17 and 1.33 MeV γ-rays from ^{60}Co [2—4] was found to lie in the range $(1.3—8.3)\times10^{-32}$ cm^2, varying with the experimental conditions. For activation with γ-rays from the 54 min half-life ^{116m}In produced by indium—gallium reactor-loop, ABRAMS et al. [5] obtained a ^{115}In activation cross section of $(1.5\pm0.3)\times10^{-31}$ cm^2. The reaction cross section is obviously dependent on the energy of the primary γ-rays of the radiation source used. The relation between the energy of the activation level and that of the primary gamma quantum is always $E_a \leqq E_\gamma$, since a metastable state in any nucleus cannot be produced except by decay from a higher excited level. The isomeric activation cross-section also varies with the experimental conditions under which the Compton scattering resulting in the γ-quantum with an energy equal to that of the activation level is being produced. In addition, it depends on the number of higher levels which can be excited in the nucleus.

To extend the number of radiation sources available for the practical applications of the nuclear photo effect, like activity measurement and activation analysis [6—7], for which the effective activation cross section must be known, it seemed of interest to measure the ^{115}In activation cross section for the 1.38 and 2.75 MeV γ-rays from ^{24}Na.

* Dedicated to Prof. P. GOMBÁS on his 60th birthday.

Experimental

a) *Preparation of ^{24}Na source*

Sodium carbonate of c. p. grade, compressed to 19 mm × 44 mm cylindrical form of 19.108 g was irradiated for 71 hours in a thermal neutron flux of $4.33 \cdot 10^{13}$ n cm^{-2} sec^{-1} of the WWRS—2M reactor. One hour after termination of the irradiation the ^{24}Na activity was found to be 145 Ci. The activity measurement taken 25 hours after irradiation with the use of the Philips-type ionization chamber of the National Bureau of Measurements calibrated to $\pm 3\%$ showed 45^{+2}_{-4} Ci, in good agreement with the value predicted from the reactor flux with correction for decay time.

b) *Isomeric activation by ^{24}Na source*

Natural indium targets, each 3 g and Ø 10 mm by 6 mm in size, were used for the activation of ^{115m}In. The ^{24}Na source was placed in a paper cup

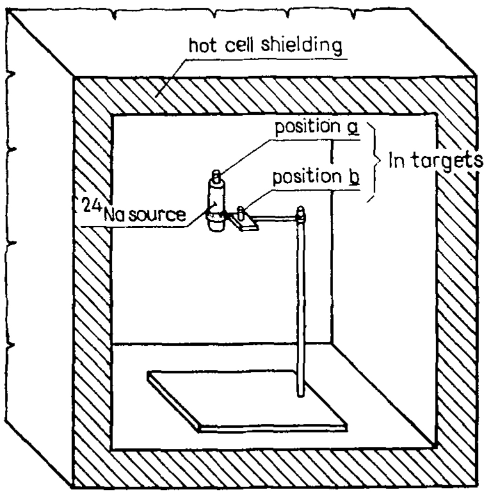

Fig. 1. The position of the indium targets during the gamma-irradiation by ^{24}Na source

located 400 mm from the bottom and at a somewhat greater distance from the top and the side-walls of the hot cell. Four indium targets were mounted around and two above the source in the arrangement shown in Fig. 1. Because of the 15h half-life of the ^{24}Na activity, the irradiation time was chosen to be, generally, 3 hours.

c) *Measurement of isomeric activity*

The irradiated samples were measured by Siemens single channel analyzer coupled to a 2 in. $\times 1\frac{3}{4}$ in. NaI (Tl) well-type scintillation counter. The energy and half-life of the measured radiation were found to be $E = 335$ keV and

$T_{1/2} = 4.5$ h, i.e. the characteristic data for ^{115m}In. The resolution of the detector, as checked with the 661 keV line of ^{137}Cs—^{137m}Ba was 13.7%. For the 323 keV line of ^{51}Cr used for the calibration of the efficiency and geometric factor of the well-type NaI (Tl) crystal and the self-absorption of the sample, the counting efficiency in the channel width used was measured as 28%. The activity measurements lasted from 5 to 10 minutes. The background in the channel corresponding to the 335 keV photopeak of ^{115m}In with a channel width of 14 V (174 keV) was found to be 32 cpm.

Discussion

The activation cross section per primary gamma quantum of the radiation source can be evaluated from the measured isomeric activity by making use of the expression

$$\sigma_m = \frac{I(\alpha+1)}{\Omega\Sigma} \cdot \frac{A}{N.a.m.} \cdot \frac{1}{f.S}, \tag{1}$$

where the first factor on the right hand side gives the isomeric activity as determined by the counting rate I in cps, the internal conversion coefficient is α and the counting efficiency is $\Omega\Sigma$. The second factor gives the number of target nuclei as determined by the atomic weight A, the Avogadro number N, the weight m and the isotopic abundance a of the target. The third factor stands for the primary γ-flux f and the saturation factor $S = 1-\exp.(-0.693t \cdot T^{-1})$ with t being the irradiation time and T the half-life of the isomeric nucleus. The activation cross section evaluated for the primary γ-quanta of ^{24}Na with the use of this formula, gives $1.35 \pm 0.27 \times 10^{-31}$ cm^2 as compared with that of $4.9 \cdot 10^{-32}$ cm^2 obtained in an earlier measurement [8] for ^{60}Co of the same size as the ^{24}Na source and with similar indium targets. The difference of the two values can be explained by the fact that the 1.17 and 1.33 MeV γ-lines of ^{60}Co can excite, through Compton scattering, only the first activation level in indium at 1.078 MeV [9], while the 2.75 MeV lines of ^{24}Na are capable of also exciting the higher levels of 1.42, 2.13 and 2.63 MeV, the existence of which have already been shown in experiments with bremsstrahlung (Fig. 2).

The effective activation cross section under the given experimental conditions can be predicted [10—11] if one uses the formula

$$\sigma = \sum_i \Delta\Phi_{ei}\, \sigma_{ai} \left\{ \frac{n_{01}\, e^{\mu_1 d\, 2}\, e^{\mu_2 \varrho}}{\mu_1\, e^{\mu_{1i} d\, 2}\, e^{\mu_{2i} \varrho}} (1 - e^{-\mu_1 d\, 2}) + \right.$$
$$\left. + \frac{n_{02}}{\mu_{2i} - \mu_2} \left[1 - e^{(\mu_2 - \mu_{2i})\varrho}\right] + \frac{n_{04}}{\mu_4} \left(1 - \frac{1}{\mu_4 l} + \frac{e^{-\mu_4 l}}{\mu_4 l}\right) \right\}, \tag{2}$$

where $\Delta\Phi_{ei}$ the differential cross-section for electron scattering to the i-th activation level i.e. to the range of energies corresponding to the level width.

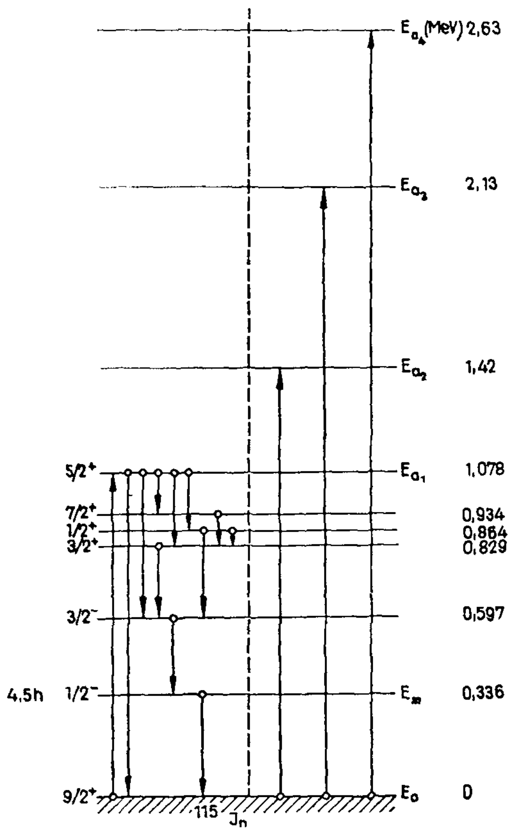

Fig. 2. The excited level scheme of ^{115}In

$\Delta\Phi_{ei}$ can be evaluated from the Klein—Nishina formula. σ_{ai} is the cross-section for resonance absorption at the i-th level. The terms in the brackets stand for the source, the absorber and the target, as determined by the electron densities n_{01}, n_{02} and n_{04}, the absorption coefficients μ_1, μ_2 and μ_4 and the thicknesses d, ϱ, l, respectively.

The cross section for excitation to the first, 1.078 MeV level in indium with subsequent decay to the metastable state was evaluated from Eq. (2), as $\sigma = 5.15 \times 10^{-32}$ cm^2 by taking the resonance level width to be $4 \cdot 10^{-3}$ eV, as estimated by GUTH [12], which gives $\sigma_a = 10^{-22}$ cm^2 for the absorption cross section.

Comparison of the value predicted for the first excited level at 1.078 MeV with the measured cross section of 13.5×10^{-32} cm^2 shows clearly that there must be an appreciable contribution to the activation from the second and possibly higher excited levels of indium. The individual contributions, however, cannot be evaluated without a knowledge of the absorption cross section and level width data involved.

REFERENCES

1. B. Pontecorvo and A. Lazard, Compt. Rend., **208**, 99, 1939.
2. G. Harbottle, Nucleonics, **12**, (4), 65, 1954.
3. N. Ikeda and K. Yoshihara, Radioisotopes, **7**, 11, 1958.
4. A. Veres, Int. J. Appl. Rad. and Isotopes, **14**, 123, 1963.
5. И. А. Абрамс, Л Л. Пелекис, Известия АН Латв СССР, Сер. Физ. и Техн. 1968. 1. 19.
6. A. Veres, I. Pavlicsek and M. Ozsgyáni, Standardization of Radionuclides, IAEA, Vienna 1967 p. 453.
7. A. Veres, Proc. of the Analytical Chemical Conference, Budapest, 1966 p. 360.
8. A. Veres and I. Pavlicsek, Int. J. Appl. Rad. and Isotopes, **17**, 69, 1966.
9. Э. А. Запаров, Б. С. Мазитов, Прогр. и Тез. XVIII. ежегодн. совещ. по ядерной спектроскопии и структуре ядря. Рига, 1968, 57.
10. K. Yoshihara, Isotopes and Radiation, **3**, 464, 1960.
11. A. Veres, Magyar Fizikai Folyóirat, **14**, 143, 1966.
12. E. Guth, Phys. Rev., **59**, 325, 1941.

ИЗМЕРЕНИЕ ЭФФЕКТИВНОГО СЕЧЕНИЯ АКТИВАЦИИ ЯДЕРНОГО ИЗОМЕРА ^{115}In γ-ЛУЧАМИ ^{24}Na

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Резюме

Определяется эффективное сечение активации изомера ^{115}In, относящееся к гамма-лучам энергии 1,38 и 2,75 Мэв радиоактивного источника ^{24}Na при активности 145 кюри. Из измерения активности изомера ^{115m}In данное значение получилось равным 13 5 $\times 10^{-32}$ см^2, что примерно в три раза больше значения полученного гамма-лучами ^{60}Co (4.9×10^{-32} см^2). Степень расхождения подтверждает, что наряду с первым активационным уровнем при 1,078 Мэв существуют и высшие уровни с энергией 1,42; 2,13, 2,63 Мэв, уже наблюденные ускорителями.