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DEBRECEN

INVESTIGATIONS ON THE DECAY SCHEME OF I^{131} IN THE LOW ENERGY REGIONS OF GAMMA-RAYS

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The region below 364 keV energy of gamma-radiation deriving from the decay of I^{131} was examined by scintillation techniques with ordinary as well as with sum-coincidence method. A new cascade of 156—210 keV /of an intensity of ~ 1 % in relation to the cross-over transition/ from a level of 364 keV into the ground state was found. Furthermore, the existence of the 177 keV line was confirmed by our studies.

1. Introduction

I^{131} is one of the best known artifical radioactive isotopes. The clarifying procedure of its decay scheme is dealt with by *Siegbahn*'s handbook of nuclear spectroscopy in the chapter of illustrative examples [1]. At the same time, the Nuclear Data Sheets summarising all the data on the individual isotopes contains also a gamma-ray line with a mark of interrogation /208 keV/, and it does not represent the 540 keV level of Xe^{131} [2] from which the 177 keV gamma-ray line found also by two authors [3-4] is supposed to start out. *Seaborg* and collaborators also omit this level is their recent Table of Isotopes [5], while the same level is plotted by *Dželepov* and *Peker* with dotted line in their book of the decay-scheme of radioactive nuclei [6]. /The decay-scheme reported by them can be seen in Fig. 1./ All these indicate still existing lesser unclarified items in the decay-scheme of I^{131}.

The ordinary and sum-coincidence [7] spectra of the gamma-radiations deriving from the decay of I^{131} in the energy region below 364 keV were examined by the authors using scintillation techniques. The applied NaI/Tl/ crystals were of ~ $1\frac{1}{2}$ in x $1\frac{1}{2}$ in size and the multipliers were of RCA 6342 type. The resolution of the analyzing crystal was ~ 7,5 % at the 661 keV γ-ray line of Cs^{137}. The resolving time of the coincidence circuit: τ was ~ 8×10^{-8} sec.

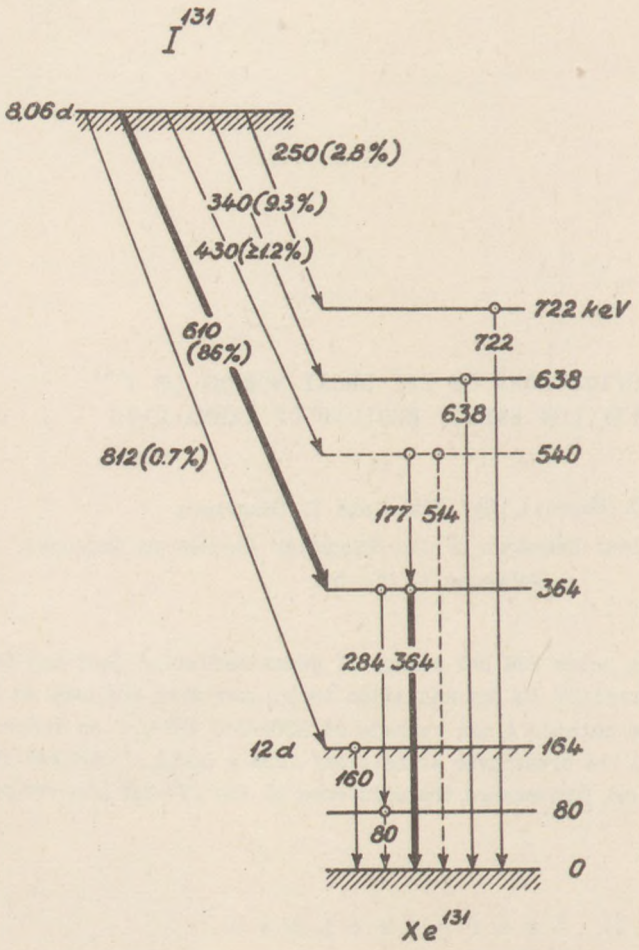

Fig. 1. Decay scheme of I^{131} from the book of *Dzelepov* and *Peker* [6].

2. Results and Discussions

Setting the sum-channel at 364 keV peak, the sum-coincidence spectrum visible in Fig. 2 was obtained. As it is well-known, when this sum-coincidence method [7] is used, only the peak-pairs pertaining to gamma lines in cascade appear in the spectrum, and at these peaks, the areas below the peaks are equal within the limit of error. As it can be seen in Fig. 2 in addition to the 80 and 284 keV lines, there is another cascade of 156-210 keV with an intensity of about five times less than that of the former lines. These new-peaks cannot derive from Compton-effect, partly because an anti-Compton shield had been placed between the crystals, partly because such peaks can only appear in the case of the existence of a gamma-line or lines actually being in cascade. This was checked up in the case of both this and another isotope. The spectrum observable in Fig. 2 was obtained also in the case of a source prepared from a shipment of I^{131} arriving at a

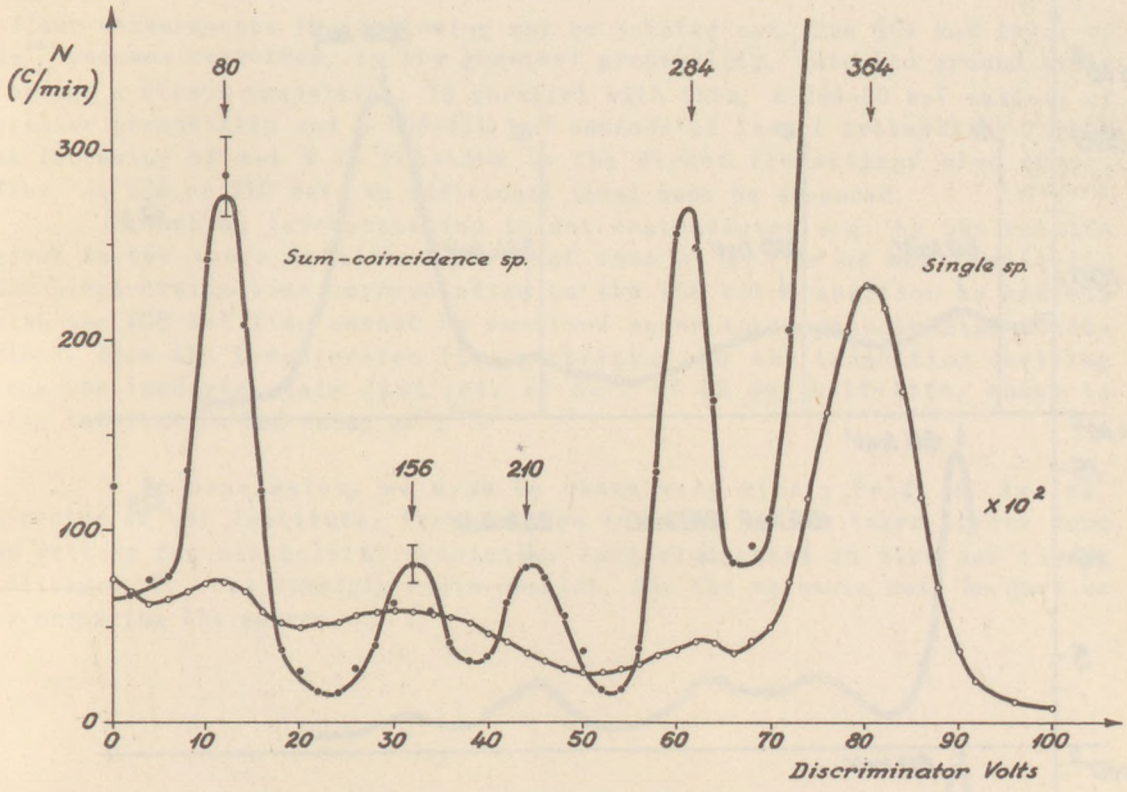

Fig. 2. Sum-coincidence spectrum in the region below 364 keV energy of gamma-radiation deriving from the decay of I^{131}. Sum-channel at the 364 keV peak.

later date, while in the case of identical sources, the ratios of the peaks were unchanged in the function of the time. Thus, contamination is out of question. It is otherwise sufficiently excluded also by the sum-coincidence method itself.

The existence of the 156-210 keV gamma-lines in cascade is also proved by the results of ordinary coincidence measurements, which were made in the former energy region of the gamma-radiations of Xe^{131}. These results are show in Figures 3b, 3c and 3d. In the first case, the selecting discriminator was integrally set in such a way that the analizing spectrometer should detect all the gamma-lines being in coincidence. It is observable that in this case, too, the two peaks appeared in the sum - coincidence spectrum are present. The same is true in the case when the selecting channel lets in only the gamma-radiation above 150 keV /Fig. 3c/. If, however, in the selecting channel, the gamma-lines above 280 keV are detected, the two peaks in the coincidence spectrum will disappear /Fig. 3d/ denoting that the two lines in question coincide with each other only, but are not in a cascade with a gamma-radiation of higher energy. In this latter case, however at 176 keV an additional peak appears, which may be identified with the 177 keV line reported in [3-4]. Thus, its presence of the decay of I^{131} is confirmed by our measurements.

The peak appearing in our experiment at 210 keV must be made to correspond to γ-line found at 208 keV by *Cook* and collaborators [8] and designated by a mark of interrogation in the Nuclear Data Sheets [2]. Up to now, this line could not be inserted into the decay-scheme. On the ground

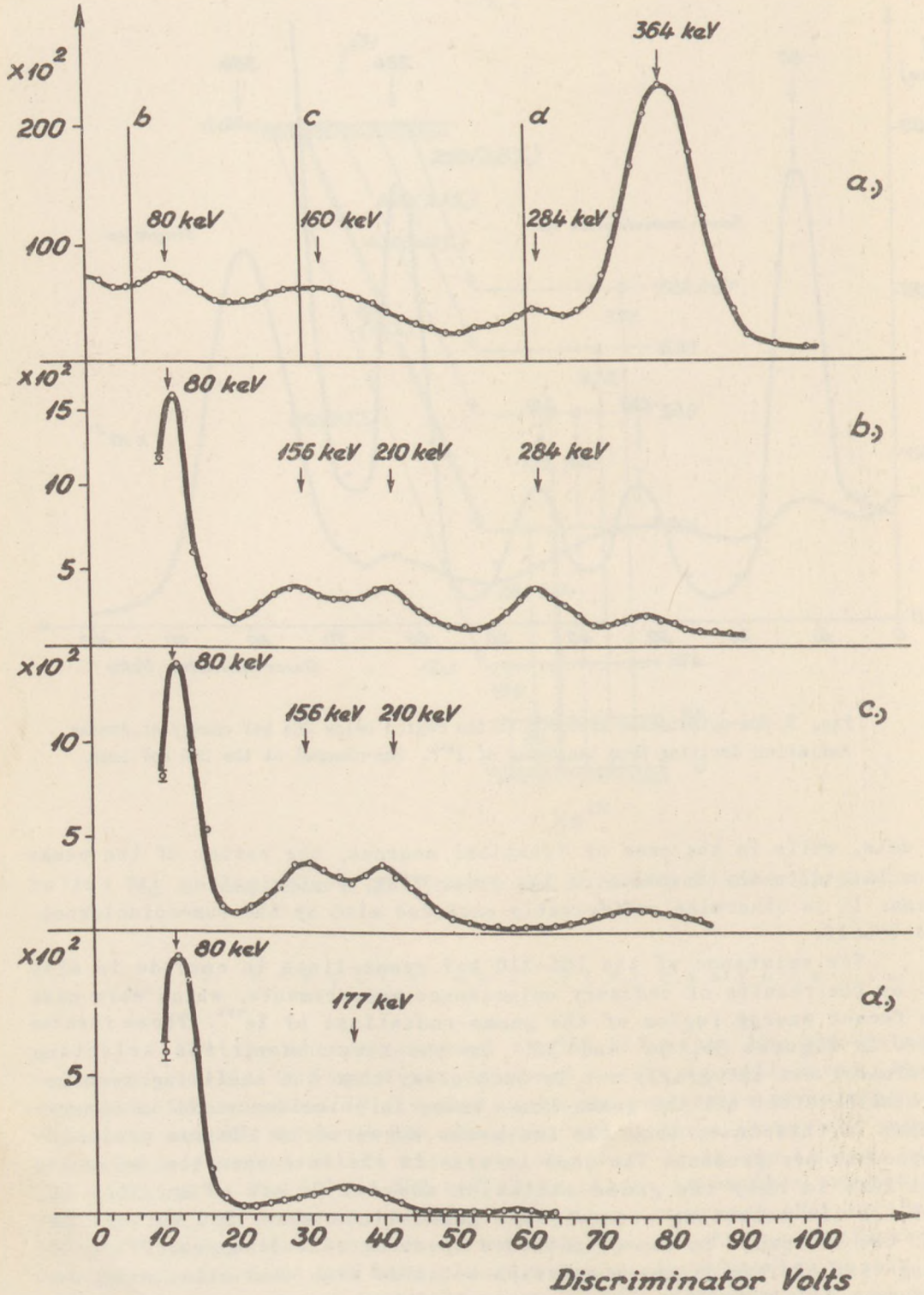

Fig. 3. The single spectrum and ordinary coincidence spectra in the region below 364 keV energy of gamma-radiation deriving from the decay of I^{131}. a/ Single spectrum. b, c, d/ Ordinary coincidence spectra. Selecting discriminator is integrally set accordingly at b, c, d points marked in Fig. 3a.

of our measurements the following may be pointed out. The 364 keV level of Xe^{131} becomes deexcited, ty the greatest probability, into the ground state through a direct transition. In parallel with this, a 284-80 keV cascade of greater probability and a 156-210 keV cascade of lesser probability / with an intensity of a~1 % in relation to the direct transition/ also occur. Thus, at 156 or 210 keV, an additional level must be supposed.

Such an interpretation is not contradicted e.g. by the results given in the above mentioned paper of *Cook* et al. To be more explicit, the L-conversion line corresponding to the 156 keV transition in cascade with the 208 keV line cannot be resolved under their experimental conditions, from the L-conversion line pertaining to the transition deriving from the isomeric state /163 keV/ of Xe^{131} of 12 day half-life, which is also involved in the decay of I^{131}.

In conclusion, we wish to thank very kindly Prof. *A. Szalay*, director of our Institute, for the keen interest he has taken in our work, as well as for his helpful criticizm. Acknowledgement is also due to our colleague, Dr. *Cs. Ujhelyi*, radio-chemist, for the valuable help he gave us by preparing the source.

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INVESTIGATIONS OF THE DECAY-SCHEME OF Fe^{59}

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We have examined the gamma-ray spectrum and gamma-gamma coincidence spectrum of Fe^{59} by means of scintillation spectrometers. The two lines of high energy have been found to be 1,08 and 1,27 MeV respectively. Between these lines no genuine coincidence could be detected.

It was the analysis of beta-spectrum and beta-gamma coincidence spectra which yielded the beta groups of 275±5 and 455±5 keV end-point energies. The intensity of these was 44,6 and 55,4 % respectively, and their corresponding log *ft* values were 5,3 and 6,1. The relative intensity of the high energy beta transition directly into the ground state was found not to attain 0,5 %.

1. Introduction

As early as in 1942, *M. Deutsch* and coworkers [1], on investigating the decay of Fe^{59}, found that the beta-ray of the above isotope consisted of two groups, the end-point energy values of which were 257 and 460 keV. The same authors, while investigating the spectrum of secondary electrons obtained from the lead radiator, identified also two gamma-ray transitions /1,1 and 1,3 MeV/. The latter gamma-lines were later measured also by several other authors, some of them using the above-mentioned method some investigating the internal conversion electrons [2-5]. One of these authors /3/ examined again the beta-spectrum too, but he did not find the group of 257 keV end-point energy.

Subsequently, *Metzger* [6-7], using a source of high specific activity, investigated in detail the decay of the isotope in question. He studied the beta-ray spectrum, the internal conversion electron spectrum and the photoelectron spectrum produced from gold foil by gamma-rays; furthermore, he carried out measurements for gamma-gamma coincidence and angular correlation by using scintillation counters. As a result of these measurements he corroborated the existence of the beta-group of lower end-point energy. He even proved the 0,3 per cent occurence of a group of 1560 keV end-point energy. His further finding was the certitude of a gamma-line of 191 keV.

Considering that neither *Metzger* in any of his reports, nor other authors in any of their publications on Fe^{59}, have given account of beta-gamma coincidence measurements, we thought it desirable to contribute to the clarification and the corroboration of the decay scheme by such measurements. At the same time, we wish to report somewhat more in detail on our scintillation spectrometer studies of the gamma spectrum of Fe^{59}, as well as on gamma-gamma coincidence spectrometric measurements, as these have only been briefly reported hitherto [6].

2. Experimental.

2.1. SOURCE

The preparation of Fe^{59} was obtained in the form of $FeCl_3$ from Harwell. Its specific activity was 4,22 c/g Fe. The source both for beta and gamma spectroscopic studies were prepared by drop method with a backing of $\approx$ 1 mg/cm^2 mylar foil.

For the gamma-gamma spectrometric investigations the mylar foil was placed in the middle of a suitable shaped lead disc. The lead disc served the purpose of eliminating /unfortunately not quite successfully/ false coincidences arising from Compton scattering. When preparing the source for beta-spectrometric purposes in order to prevent charging of the backing, the plexi source holder skeleton, the foil, and the source spot itself were coated with vacuum evaporation of aluminium. To prevent dispersion of the radioactive substance, the source was covered with a Zapon foil of $\approx$ 10 μg/cm^2. The thickness of the source was 0,1 mg/cm^2 in order of magnitude.

The purity of the radioactive shipment was checked by half-life measurement.

2.2. GAMMA-RAY SPECTROMETER AND GAMMA-GAMMA COINCIDENCE SPECTROMETER

For studying the gamma-spectrum, a conventional scintillation spectrometer with NaI/Tl/ crystal was used [8]. The multiplier was of RCA5819 type. The diameter of the cylinder-shaped crystal was 37 mm with a height of 29 mm. The line width at half height was 10 % in the case of gamma-rays of Cs^{137}.

For the coincidence measurements, two such spectrometers were used. The source was placed between the two crystals supported by the lead disc reffered to in 2,1.

The coincidence unit was of *Hayashi*'s gate-circuit design [9-10] with a resolving time of 1,2x10^{-7} sec.

2.3. BETA-RAY SPECTROMETER AND BETA-GAMMA COINCIDENCE SPECTROMETER

The study of the beta-spectrum was made by a magnetic spectrometer of toroid-sector type [11-12]. The same was used for measuring beta-gamma coincidences, but combined with a NaI/Tl/ crystal gamma-spectrometer [13]. During the measurements, the beta-spectrometer was set so that it had a transmission of $\approx$ 3,0 % and a resolution of $\approx$ 5,5 %.

For the beta-gamma coincidence measurements also, the coincidence unit referred to in 2,2 was used.

Results and Conclusion

3.1. MEASUREMENTS FOR THE GAMMA-RAY SPECTRUM

The presence of the two high energy lines /1,1 and 1,3 MeV/ was clearly shown by the scintillation spectrum, but the line of 0,2 MeV was not demonstrable because of the position of the back-scattering peak.

Fig. 1 illustrates the scintillation gammaspectrum of Fe^{59} which was taken in such a way that a lead collimator of 90 mm length had been placed betweenthe source and the crystal. The diameter of collimator channel was 5 mm. The two high energy lines of Fe^{59} were found to be 1,08 and 1,27 MeV respectively.

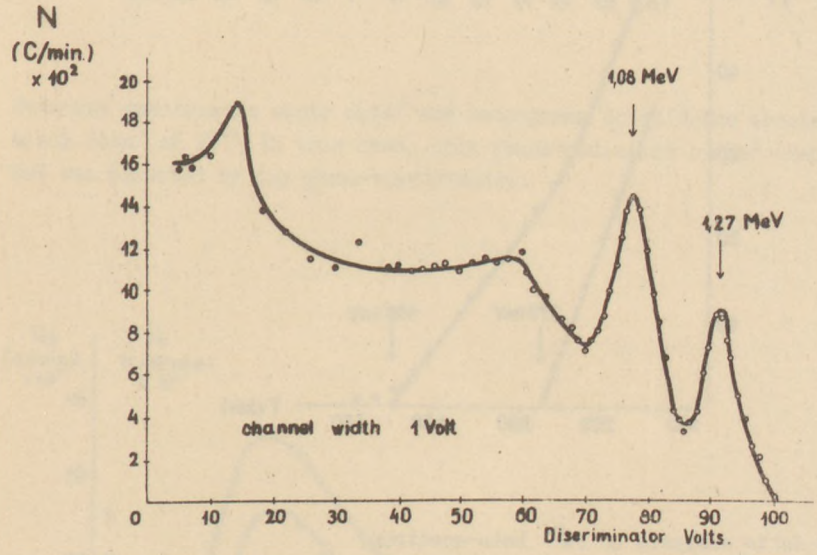

Fig. 1. Scintillation spectrum of Fe^{59} gamma-rays taken by using a lead collimator of 90 mm length and 5 mm channel diameter. /Channel width 1 volt./

The gamma-gamma coincidence measurements definitely revealed that there was no coincidence between the lines of 1.1 and 1.3 MeV. In this range the number of coincidences surpassed nowhere the number of chance coincidences.

3.2. BETA-RAY SPECTRUM AND BETA-GAMMA COINCIDENCES

Even from the graphic illustration without any particular evaluation of the data of the beta-spectrum it became evident that we were confronted with a complex spectrum. On the basis of the *Fermi-Kurie* analysis /see Fig.2/ two beta-groups may be distinguished: those of 455±5 and 275 ± 5 keV end-point energies. Their relative intensities were found to be 55.4 % and 44.6 % respectively. As to the high energy betagroup, whose end-point energy and relative intensity had been found by *Metzger* to be 1560 keV and 0,3 % respectively, we could only establish by our measurements that the relative intensity should be below 0,5 %.

The FK diagram is straight in the cases of both groups mentioned above. This fact refers to allowed transition, though the log *ft* value of the higher energy group is 6.1, which is just about the highest limit of the *ft* value-range usually involving the comparative half-life of allowed transition in case of nuclei with odd mass numbers [14]. For the group of lower end-point energy, log *ft* is 5,3. In computing these *ft* values we applied 45,4 days representing the mean of the values for the half-life of Fe^{59} reported in *Strominger, Hollander* and *Seaborg's*, table of isotopes [15].

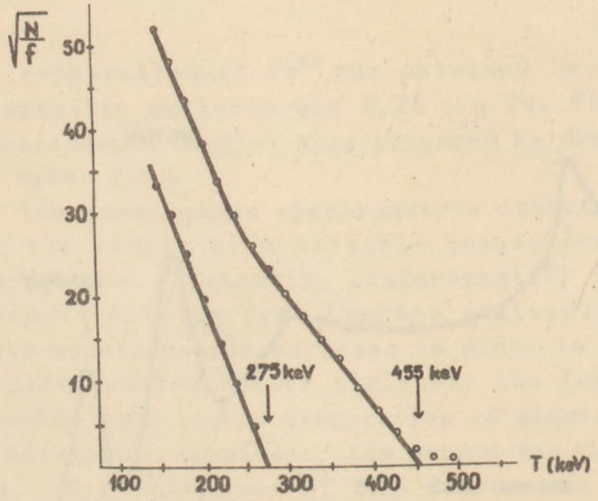

Fig. 2. *Fermi-Kurie* analysis of Fe^{59} beta-spectrum.

The beta-gamma coincidence measurements were made at two different settings of the gamma-spectrometer. By means of one of these settings we selected the beta-rays in coincidence with gamma-rays of higher energy /1,27 MeV/ while by means of the other one we studied the coincidence of beta-rays with all the gamma-rays. The gamma-spectrometer was used in both cases at an integral setting.

Figs. 3 and 4 give good illustrations of the results in beta-gamma coincidence measurements. In Fig. 3 the points of the coincidence spectrum were obtained by a measurement of 12x10 min and in Fig. 4 by a measurement of 3x10 min. Fig. 3 shows that the gamma-ray of 1,27 MeV is in coincidence only with the beta-group of lower end-point energy. If, however we establish beta-gamma coincidences with all the gamma-rays, the shape of this coincidence spectrum and that of the beta-ray spectrum will completely agree /Fig. 4/.

These results definitely show, partly that only the beta particles of the beta-group of lower end-point energy coincide with the gamma line of higher energy; partly that a predominant number of beta-rays is in coincidence with gamma-rays.

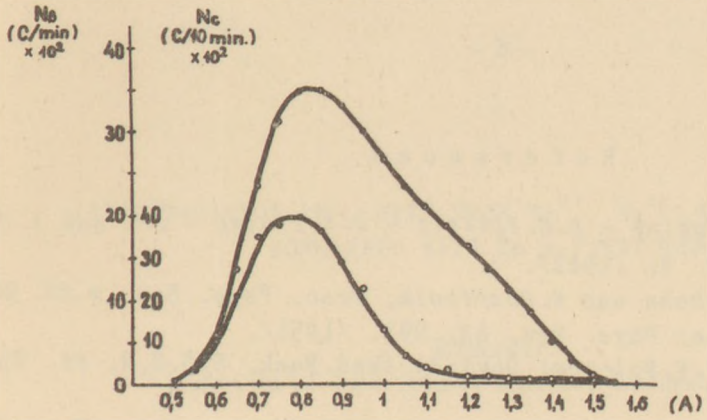

Fig. 3. Beta-ray spectrum /o empty dots/ and beta-gamma coincidence spectrum /• black dots/ of Fe^{59}. In this case, only gamma-radiation higher than 1,25 MeV was detected by the gamma-spectrometer.

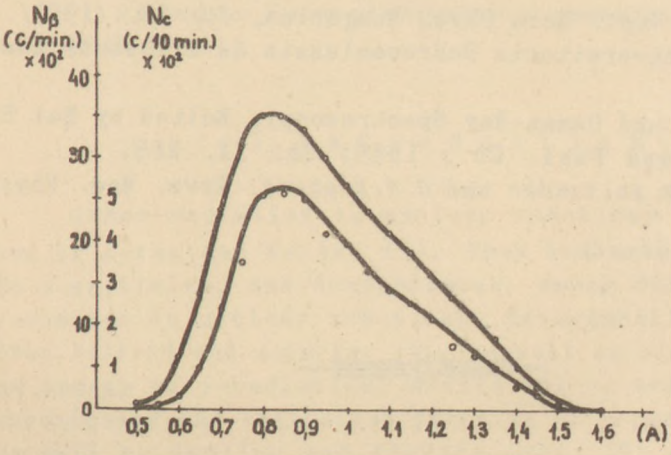

Fig. 4. Beta-ray spectrum /o empty dots/ of Fe^{59} and its beta-gamma coincidence spectrum /• black dots/ at the detection of all gamma lines in the gamma-spectrometer.

The values obtained for the end-point energies of the two beta-groups by the FK analysis of beta-gamma coincidence spectra are in very good agreement with the values obtained by the analysis of beta-ray spectrum.

In this way, our investigations confirm the decay scheme set up by *Metzger*.

Acknowledgement is due to the director of this Institute, Prof. *A. Szalay* for his valuable help and the special interest he has taken in our work. Furthermore, the careful preparation of the source by our radiochemist colleague, *Dr. Cs. Ujhelyi* is greatly appreciated.

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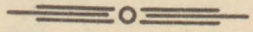

ATOMKI 27/1960 - 400 példány.

INVESTIGATION OF γ-RAYS FROM Mg^{24}, Mg^{25}, Mg^{26} Isotopes BOMBARDED WITH Po-α-PARTICLES

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Electromagnetically seperated Mg^{24}, Mg^{25}, Mg^{26} isotopes were bombarded with Po-α particles. In the case of Mg^{25} and Mg^{26} the excitation function of γ-radiation from the nuclear processes was taken on a thin target. In the case of the Mg^{25} target, resonance was found at α-energies of 3,58; 4,33; 4,47; 4,61; 4,80; 4,99 and 5,09 MeV; in the case of Mg^{26} target, at α-energies of 4,56 and 5,01 MeV; from which data seven highly excited states of the Si^{29} compound nucleus and two the Si^{30} nucleus were determined. The origin of γ-radiation was defined by the observed spectra of γ-rays.

A method for a micro-electro-chemical separation of Mg has been elaborated by the author.

1. Introduction.

Gamma-radiation in nuclear reactions was, for the first time observed by *Bothe* and *Becker* [1]. They bombarded several light elements with Po-α-particles, and demonstrated, among others in Mg, the presence of γ-radiation in nuclear reactions. Subsequently *Webster* [2] and *Savel* [3], then *Pollard* and *Alburger* [4], as well as *Alburger* [5] determined the quantum-energy of γ-radiation; *Slätis* [6] as well as *Szalay* and *Csongor* [7] investigated the excitation function of γ-radiation. *Breen* and *Hertz* [8], as well as *Nemilov* and *Piszarevszkij* [9] defined the spectrum of this γ-radiation.

All the above measurements were carried out on natural Mg targets. In nature, Mg is a mixture of 3 stable isotopes: Mg^{24} (78,6 %), Mg^{25} (10,11 %) and Mg^{26} (11,29 %). In the case of bombardment with α-particles, there is a possibility both for proton- and neutron-emissions, as well as for elastic and inelastic scattering, which - regarding the three isotopes - mean 9 such reactions that may be accompanied by γ-radiation. Likewise β-decay of Al^{28} and Al^{29} radioactive nuclei remaining after the proton-emission may be associated with γ-radiation and so, in principle, γ-radiation may, when natural Mg is bombarded with α-particles, arise in the wake of 11 different reactions.

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* The research work was carried out at the Institute of Nuclear Research, Debrecen, by the courtes of the Institute.

Previous measurements reveal that (1), the excitation function has not been defined with sufficient punctuality to allow for any conclusion to be drawn regarding the excited states of the compound nucleus; (2) the data on the quantum-energy and spectral compositon of γ-radiation are contradictory; (3) the origin of γ-radiation is not cleared up, which is mainly due to the previous investigations having been made with a Mg target of natural isotope-mixture.

With a view to clearing up the existing problems, (a) the excitation functions of γ-radiation, (b) the spectra of γ-rays - in order to have their origin determined - were individually taken on electromagnetically seperated MgO isotopes.

2. Experimental Apparatus and Target Preparation.

For the observation of γ-particles, a NaJ(Tl) crystal scintillation counter, and spectrometer was used. The block-scheme of the apparatus is shown in Fig.1. The NaJ(Tl) crystal 30 mm high and 40 mm in diameter was fitted to an RCA 5819-type photo-multiplier. After pre-amplification, the output signal was further amplified by a wide-band amplifier, and then the signals selected by the analyzer were counted by a decadic scaler. The spectrum was taken by a single-channel differential discriminator of 2% relative channel-width.

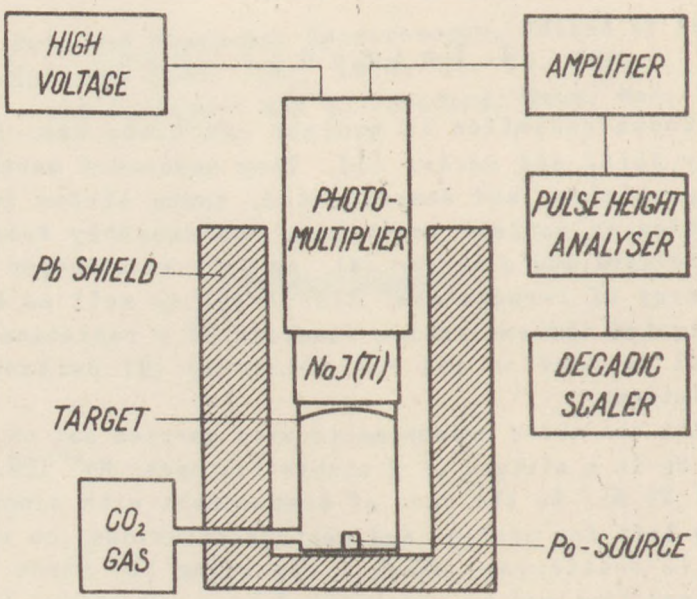

Fig. 1. Block-scheme of the apparatus.

The electromagnetically seperated isotopes in the form of MgO were procured from Harwell [10]. Because of the small quantity of substance (5 mg), no attempts were made to prepare the target by the usual method of vacuumevaporation [11], [12], [13], which is by no means an easy task in the case of MgO [14].

For the preparation of the thin target, a micro-electro-chemical method was finally elaborated by the author [15]. MgO was transformed to $MgCl_2$ by adding HCl. After drying, $MgCl_2$ was solved in pyridin and carried into an electrolyzing container. For a cathode, a spherical segment of rust proof steal was used /backing of the target/; for an anode Pt bent in ring-shape was used. The two electrodes were seperated by a porous glass partition /Schott G2 filter/ and the Cl_2 arising upon the anode was disposed of by circulating argon gas. The electrolysis occured at 0,2 mA / cm^2 current-density.

The thickness of the prepared target was 0,18 mg/cm^2 that is 1,2 mm air-equivalent.

For α-source, Po-preparation of 40 mC was used which had been volatilized onto a Pt-Ir disc 3 mm in diameter, according to *A. Szalay*'s method [16].

3. Survey of the Excitation Functions and Excited States of Si^{29}, Si^{30} Nuclei.

The Po-α-source was placed at the center of the curvature of the spherical segment shaped MgO target (Fig.1.). The thin target and the use of a small solid angle assured the energy-homogeneity of α-particles.

The energy of α-particles was kept down to the level required by the pressure of CO_2 stopping gas, and the yield of α-particles was measured at the respective α-energies by an integral-discriminator. The adjustment of discriminator-voltage made the elimination of the 0,8 MeV γ-radiation of Po possible. Consequently, in the course of measurements, all the γ-quanta belonging to the respective α-energies and possessing more than 1 MeV energy were counted. The excitation functions obtained while Mg^{25} and Mg^{26} isotopes were bombarded are shown in Figures 2. and 3. In the case of Mg^{24} isotope, it was not possible to take the excitation function because of the small yield of γ-radiation. Both excitation functions revealed marked resonances, from which the highly excited states of Si^{29} and Si^{30} compound nuclei could be determined. The data are included in Table I.

In the two investigated excitation functions the cross-section also was estimated and

$$\sigma_{Mg^{25}+\alpha} \approx 120 \text{ mbarn} \pm 40\ \%, \text{ and}$$

$$\sigma_{Mg^{26}+\alpha} \approx 50 \text{ mbarn} \pm 40\ \%$$

values were obtained at maximal α-energy, which is in good agreement with $\bar{\sigma}$ value theoretically computed by *Shapiro* [18].

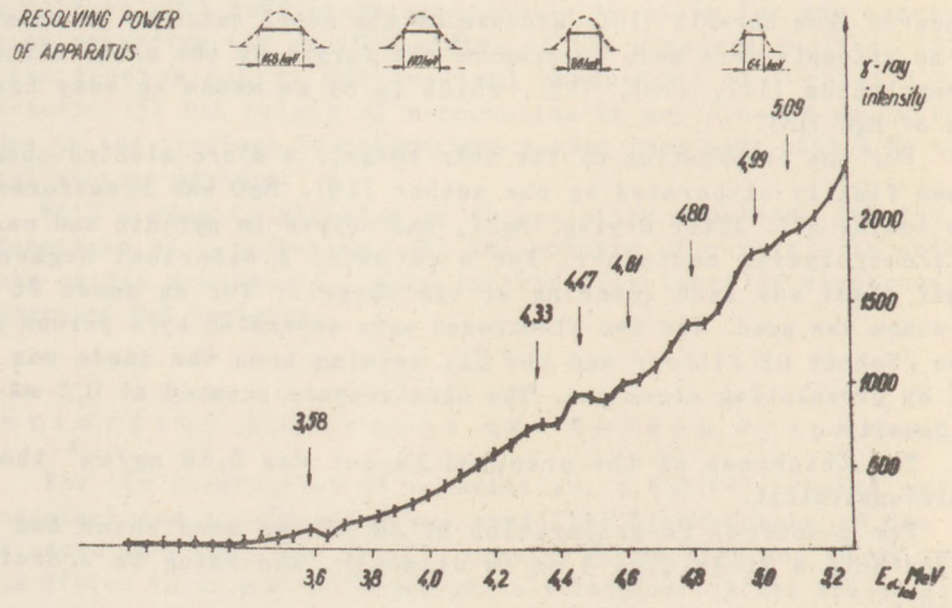

Fig. 2. Excitation function of γ-radiation accompanying nuclear transformations produced by Po-α-particles upon a thin Mg^{25} target (0,18 mg MgO/cm^2). (Abscissa: energy of bombarding α-particles; intensity of γ-radiation in arbitrary units.)

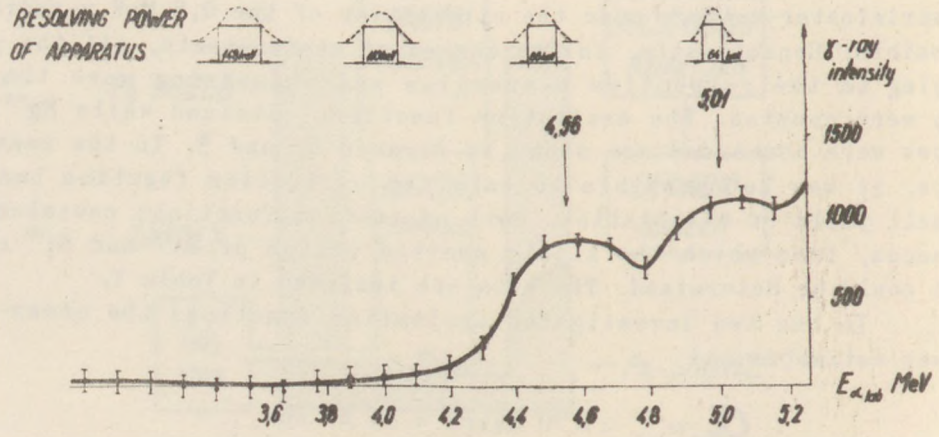

Fig. 3. Excitation function of γ-radiation accompanying nuclear transformations produced by Po-α-particles upon a thin Mg^{26} target (0,18 mg MgO/cm^2). Coordinates: same as in Fig. 2.

Table I.

The excited states of Si^{29} and Si^{30} nuclei observed in these investigations. (On the basis of accumulated data [17], the binding energy of the α-particle in the compound nucleus was calculated E_b = = 11,141 MeV for the Si^{29} nucleus, and E_b = 10,633 MeV for Si^{30}).

Compound nucleus	Bombarding energy $E_{\alpha\ lab}$ MeV	Excited state E_c MeV
Si^{29}	3,58 ± 0,070	14,227 ± 0,060
	4,33 ± 0,048	14,872 ± 0,041
	4,47 ± 0,042	14,994 ± 0,036
	4,61 ± 0,041	15,115 ± 0,035
	4,80 ± 0,036	15,278 ± 0,031
	4,99 ± 0,032	15,442 ± 0,028
	5,09 ± 0,030	15,529 ± 0,026
Si^{30}	4,56 ± 0,046	14,585 ± 0,040
	5,01 ± 0,032	14,975 ± 0,028

On comparing the shape of excitation functions, it is remarkable that while the resonances observed in the case of Si^{30} nucleus were only two in number but broad ($\Gamma_1 \approx 350$ KeV, $\Gamma_2 \approx 300$ KeV), the Si^{29} nucleus had seven narrow resonances, even narrower than the resolving power of the apparatus.

On the basis of the shell-model, a qualitative explanation may be had for the difference of excitation functions. In the case of the Mg^{24} target, the small yield of γ-radiation is noticeable (see spectra). The binding energy of the last neutron is very high in the Si^{28} compound nucleus owing to the fact that the Si^{28} nucleus is semimagic and owing to the state of Z (even) = N (even), wherefore neutron emission, when a Po-source is used is out of question for reasons of energetics. The analysis of the spectrum of γ-rays shows that inelastic scattering is not a process of great probability either. According to measurements of *Kaufmann* and collaborators [19], the elastic scattering of α-particles is the most probable process in this energy-range. Thus it stands to reason that the yield of γ-radiation should be small in the case of Mg^{24} target, because this appears as a concomitant only to proton-emission process of small probability.

In the case of Si^{29} nucleus, the single neutron outside the closed $d_{5/2}$ shell becomes easily excited.

Similar to the Si^{30} nucleus, several other nuclei possessing an excess pair of neutrons (Ne^{22}, Be^{10}, O^{18}) have two highly excited levels of great width.

4. The Spectra of γ-Rays and Origin of γ-Radiation.

Figures 4., 5. and 6. show the energy-spectra of γ-particles arising from bombardment of Mg^{24}, Mg^{25} and Mg^{26} targets with Po-α-particles in the range of 1-4,5 MeV energy. The spectra reveal that γ-radiation is much more complex and consists of many more components than it was reported by previous authors [8], [9].

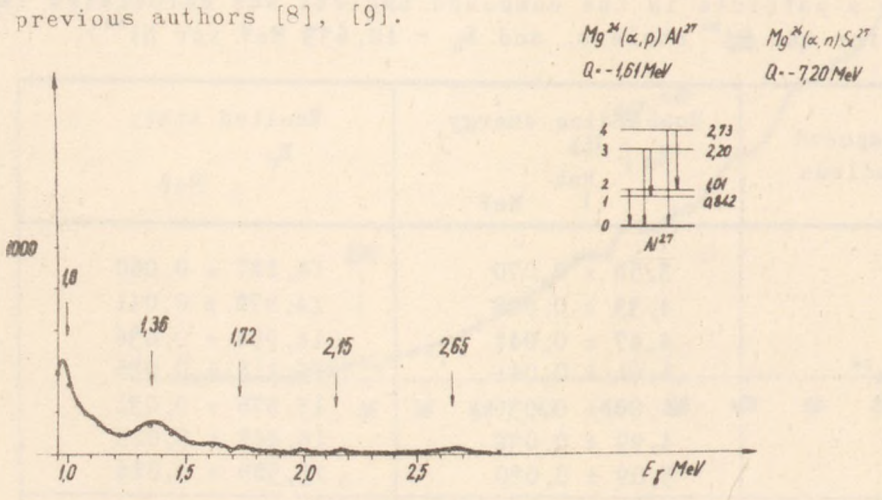

Fig. 4. The spectrum of the γ-radiation (part above 1 MeV) accompanying nuclear transformations produced by Po-α-particles on a Mg^{24} target.
(Abscissa: γ-energy in MeV; Ordinate: intensity of γ-radiation). Observed transitions and energy level scheme of residual nucleus.

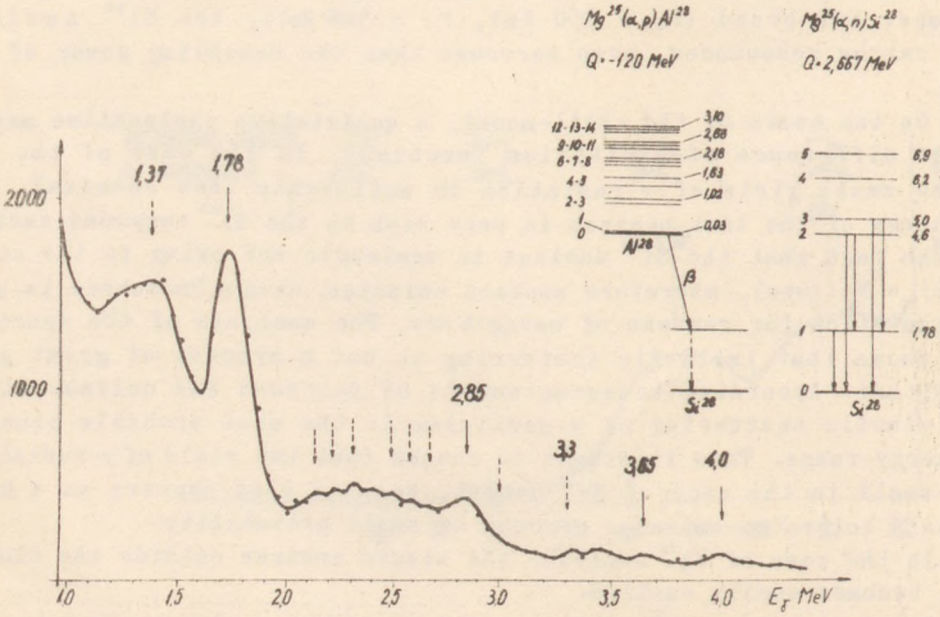

Fig. 5. The spectrum of the γ-radiation (part above 1 MeV) accompanying nuclear transformations produced by Po-α-particles on a Mg^{25} target.
Coordinates same as in Fig. 4.
Observed transitions and energy level schemes of residual nuclei.

The origin of γ-radiation may be regarded as cleared up if the observed γ-energies can be ascribed to some nuclear reaction, in other words, the observed γ-ray energies can be assigned to the energy level-scheme of nuclear reaction.

For this purpose, the energies detected in the spectra were compared with all the possible transitions [20] of the heretofore known excited states of residual nuclei in the possible nuclear reactions.

The detected γ-energies and the conclusions regarding their origin are included in Table II.

Table II.

Results from γ-ray spectra

Target	Observed γ-energy MeV	Origin of radiation	
		residual nucleus	transition between excited states of the residual nucleus
Mg^{24}	1,0	Al^{27}	2 → 0
	1,36		3 → 1
	1,72		4 → 2
	2,15		3 → 0
	2,65		4 → 0
Mg^{25}	1,78	Si^{28}	1 → 0
	2,85		2 → 1
	3,3		3 → 1
	3,65		2 → 0
	4,0		3 → 0
	1,37	Al^{28}	4 → 0
	2,13		6 → 0
	2,21		7 → 0
	2,30		8 → 0
	2,49		9 → 0
	2,58		10 → 0
	2,67		11 → 0
	3,0		12 → 0
Mg^{26}	1,25	Si^{29}	1 → 0
	1,45		3 → 0
	1,75		4 → 1
	2,0		2 → 0
	2,45		3 → 0
	3,0		4 → 0

The transitions corresponding to the observed γ-energies are marked with arrows in the energy level-scheme of Fig. 4., 5. and 6.

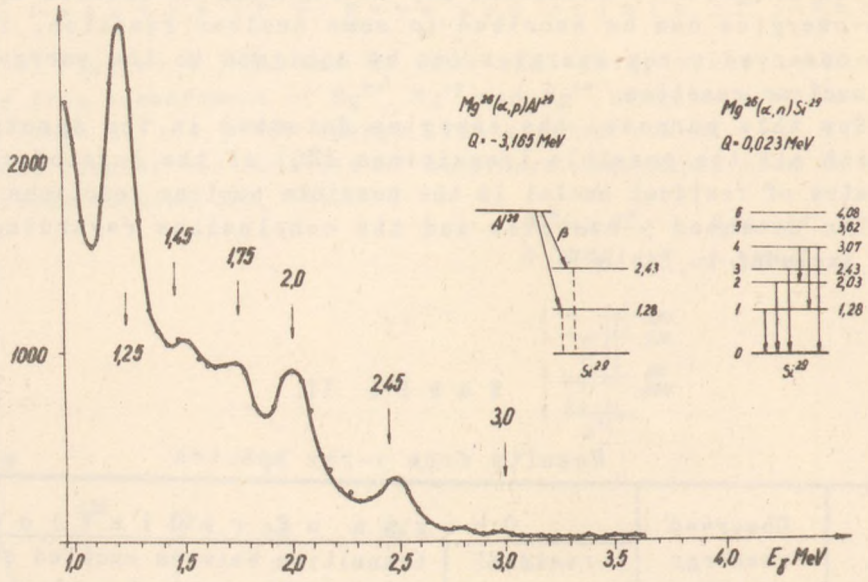

Fig. 6. The spectrum of the γ-radiation (part above 1 MeV) accompanying nuclear transformation produced by Po-α-particles on a Mg^{26} target. Coordinates : same as in Fig. 4.
Observed transitions and energy level schemes of residual nuclei.

In so far as the respective targets are concerned, the following conclusions my be drawn regarding the origin of γ-radiation:

a./ Considering that on bombarding the Mg^{24} target, the neutron-emission cannot even arise for reasons of energetics (Q = -7,2 MeV) when a Po α-source is used, and as the energy of 1,36 MeV characteristic of inelastic scattering does not appear with a pronounced intensity in the spectrum, it is obvious that the observed γ-radiation may be assigned to the excited states of the residual nucleus from the $Mg^{24}(\alpha,p)Al^{27}$ reaction. The observed energies can be very well fitted into the level-scheme.

b./ The spectrum obtained when Mg^{25} target is used derives from the superposition of two spectra; the peaks appearing with a low intensity may be assigned to the excited states of the residual nucleus of the $Mg^{25}(\alpha,p)Al^{28}$ reaction of lesser yield; the peaks of the spectrum appearing with higher intensity belong to the excited states of the residual nucleus in the $Mg^{25}(\alpha,n)Si^{28}$ reaction.

Considering that the high energy component of γ-radiation could only be observed when the Mg^{25} target is bombarded, and as this can - for reasons of energetics - be assigned only to reaction with neutron emission, the fact is supported by direct experimental evidence that the high energy component of γ-radiation observed by previous authors can exclusively be assigned to the $Mg^{25}(\alpha,n)Si^{28}$ reaction.

c./ The lines of spectrum taken with the Mg^{26} target belong to the excited states of the Si^{29} nucleus. Although beside the neutron-emission, the proton-emission also occurs with less probability, but on one hand, the excited state of the Al^{29} residual nucleus is not known; and on the other hand, the Al^{29}, too, by β-decay transforms to Si^{29} nucleus. These two γ-

lines concomitant with β-radiation then get superposed upon the γ-spectrum accompanying the neutron-emission.

Acknowledgements

The author is greatly indebted to Prof. *A. Szalay* for having prepared the Po-source and made it possible to carry out the necessary measurements at the Institute of Nuclear Research. Acknowledgement is due also to *Mr. Gy. Máthé* who designed and constructed the scintillation counter.

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ATOMKI 34/1960 - 300 példány.

THE ENERGY OF NEUTRONS FROM REACTION $Be^9/\alpha, n/C^{12}$

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The investigated nuclear reaction was produced by Po^{210} alpha-source. The energy of the neutron was measured by photoemulsion method in directions of 30°, 90°, 120°, 150° and 180°. In some of the cases, the Q-value, i.e. the relative intensity of neutron groups can be determined from the distribution of neutrons.

Of the great number of authors dealing with reaction $Be^9/\alpha, n/C^{12}$, several [1, 2, 3] investigated the energy-distribution of neutrons. Reports on the energy-spectra of various Be/α, n/-sources also may, in some respect be mentioned, though the conditions of such investigations are seldom favourable for studying nuclear reaction.

From the viewpoint of the energy production of red giant stars, it is important to study the transition of nucleus C^{12} from its excited state of 7,656 MeV into the ground state. In this relation, it is indispensable to know also the intensity-ratio of the neutrons belonging to the first and second excited states [4]. On this point, there are but few reports in literature [1, 2, 5], and the results are not concordant. Therefore it seems worth while to study the energy-distribution of neutrons from reaction $Be^9/\alpha, n/C^{12}$ in a direction not yet investigated and to possibly obtain further data on the ratio of neutron intensity.

Experimental conditions

For an alpha-source in producing reaction, Po^{210} was used which had been prepared according to the method elaborated by *Szalay* [6]. The intensity of the Po^{210} preparation volatilized onto a Pt-Ir disc 3 mm in diameter was 53,34 mC by the absolute counting of alpha-particles at the beginning of the experiments. The high grade of purity and energy-

homogeneity of the alpha-source was checked by measuring the energy-distribution of the emitted alpha-particles with an electromagnetic alpha-spectrometer [7].

The Be-target was prepared by vacuum evaporation. Its layer-thickness established by mass measurement was 0,06 mg cm^{-2}, and its holder was a carefully burnished and electrolytically polished copper disk 3 mm in diameter.

The distance between the Po and the parallel target-surface was 5 ± 0,01 mm. The holders of the alpha-source and the target were made from copper. Likewise the glass vacuum container holding the radiation-source was lined with copper plate, and it contained a vacuum of Hgmm 10^{-2}, during irradiation.

The Agfa K2 nuclear plates of 200 μ layer-thickness were placed at 30 mm distance from the Be-target in a lightproof case cylindric in shape and made of iron so that they were folded two by two with the emulsion upon their inside faces. Some of the plates were exposed first at 0° around the neutron-source and simultaneously at 30° stages, but measurements were only made on plates irradiated in directions of 30°, 90°, 120°, 150° and 180°. The time of exposure was generally 3 weeks. During irradiation, the source together with the case of plates was suspended by a wire. The minimal distance of other objects in the room was 110 cm.

The nuclear emulsions were proceeded by temperature-development with amidol [8]. In order to reduce the shrinkage factor, an aqueous solution of 10 % glycerin was applied.

For measuring the tracks of recoil protons, C.Zeiss /Jena/ LgOG and Leitz Ortholux II microscopes were used with Leitz 100x, 53x, Ks immersion-objectives applied in each case. Projected ranges of the proton recoils were measured by a calibrated eyepiece micrometer i.e. by the fine-focus motion of microscope, and the azimuth-angle was determined with a goniometer-attachment made at this Institute [9]. The tracklengths were calculated by nomograms [10].

For the range-energy relation of Agfa K2 nuclear emulsions, *Bebel's* values were used [11], as they seemed to be suitable according to our measurements [12].

Data and results of measurement

If the straight line connecting the centers of the discs holding the Po and the Be-target is taken in 0° direction in the laboratory-system, the energy-distribution of neutrons is studied, in relation to this direction in 30°, 90°, 120°, 150° and 180° directions. Table I shows the emulsion volume of the examined plates placed in these directions, and it shows the number of measured recoil protons.- The same Table includes the number of neutrons obtained after the usual corrections, i.e. for the variation at the energy of the neutron-proton scattering cross section [13] and for the escape of protons from the emulsion [14]. The background was established by checking a not irradiated emulsion of corres-

ponding volume belonging to the same batch. In both cases, only proton-tracks traveling in a cone having a half angle less than 15° to the direction of neutrons were taken into consideration.

T a b l e I

Direction	Scanned emulsion volume in mm^3	Number of recoil proton-tracks	Number of neutrons
30°	375	379	636
90°	602	378	588
120°	597	390	550
150°	527	412	525
180°	766	558	738

In order to determine the neutron-energy, the length of proton-tracks was reduced for all the paths to the direction of 0°, on the ground of measured data.

The distributions of neutron-energy, after all the necessary corrections have been made, can be seen in Fig. 1. The number of neutrons at 0,2 MeV intervals were always represented in arbitrary units, so that the height of the highest peaks had an identical ordinate value in all distributions. In the energy-spectra, this peak appears everywhere at the neutron-energy value belonging to the transition into the first energy level of C^{12}. The maxima from neutrons belonging to transitions into the ground level and 7,656 MeV level are considerably lower, and do not always emerge from the background of recoil protons. In the Figure showing the distribution of neutron-energy, the values of measurement for energy-resolution, but mainly the values defined by the conditions of irradiation, are equally represented at neutron-energies belonging to the transitions into energy-levels of the residual nucleus C^{12}. This half-breadth value was calculated as usual [15] on the basis of error function. The resolving power of our measurements is - first of all - defined by the geometry of the source and of irradiation. The maximal value of straggling induced by factors other than geometric ones is 0,7 MeV. The max. and min. energy-values calculated by accounting for the occurrence of factors that may most infavourably influence straggling are designated by small vertical lines, of which those marking the minimal values are dotted.

By means of energy values derived from the distribution of neutron-energy, the respective Q-values for nuclear reaction and energy level were computed. Taking the mass-value from the *Dželepov-Peker* Table [16] and calculating E_α as equal to 5,3 MeV, the values in Table II were obtained.

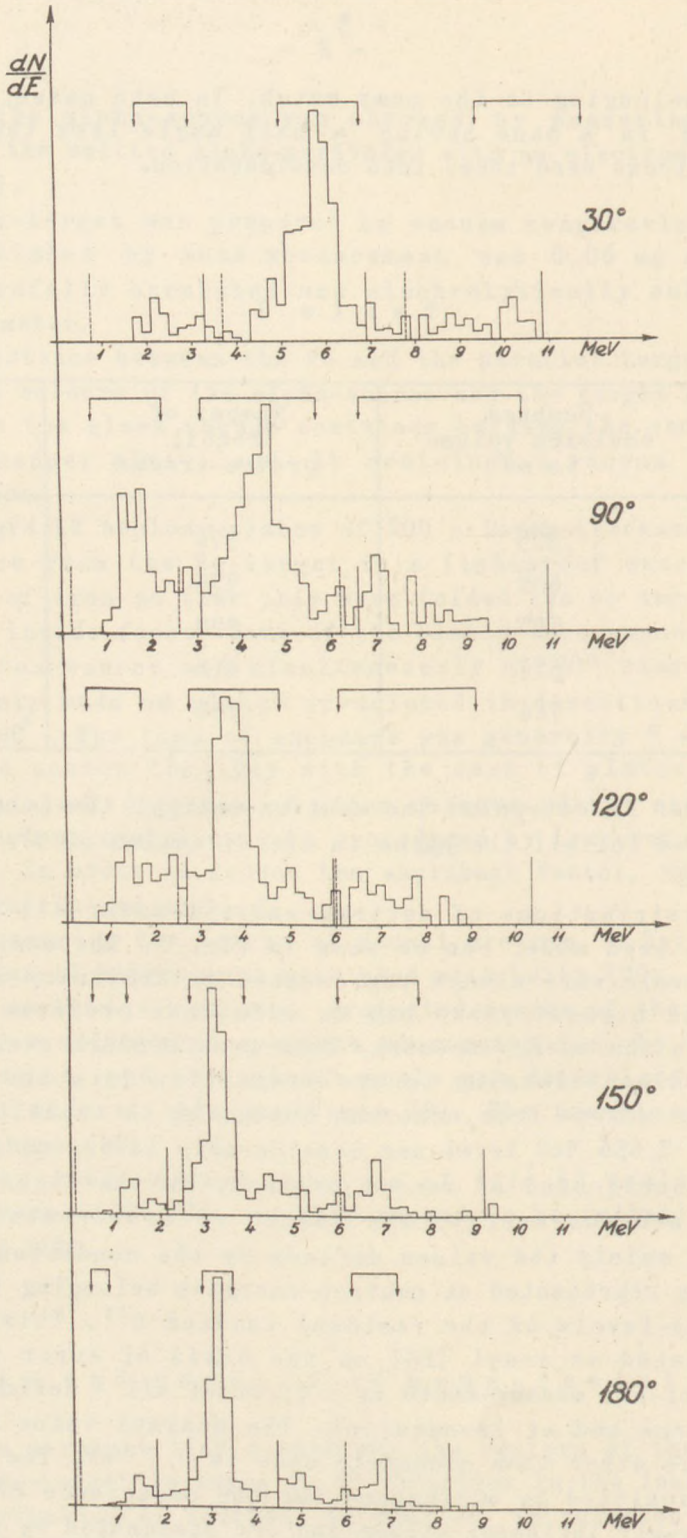

Fig. 1. Energy-spectrum of neutrons from reaction $Be^{9}/\alpha,n/C^{12}$ in various directions in the laboratory-system.

The upper signs bounded by arrows designate the half-breadth values for the transitions into the respective levels of the residual nucleus to be expected under our experimental conditions. The small vertical lines upon the energy-axis denote the maximal and minimal energy values to be expected in the most unfavourable cases /the minimum is marked by a dotted line/.

Table II

Direction of observation	Q - value		
	at ground level:	at 4,433 MeV level:	at 7,656 MeV level:
30°	-	1,198	-
90°	-	1,292	-1,798
120°	-	1,220	-
150°	5,580	1,321	-
180°	5,727	1,316	-

From the results of our measurement, the position of the maximum for transition into the 4,433 MeV level can be deduced most securely by the half-breadth of energy-interval, i.e. by an error of ± 0,1 MeV. Accordingly, the Q-values for the different directions show quite good agreement. Their weighted average according to the number of neutrons in the maximum: $Q = 1,280^{MeV} \pm 4,6$ %, which shows good agreement with previous values [17] The agreement of Q-values for the other two levels shown in Table II with the data in literature is also acceptable.

From the ratio of areas below the maxima in histograms, the determination of the ratio of neutron intensities for the transition into different levels has been attempted in some cases. The obtained ratios are included in Table III.

Table III

Direction of observation	Ratio of intensities in the case of neutrons belonging to the	
	ground and first levels	first and second levels
30°	1 : 5,6±1	9,5±2,6 : 1
150°	1 : 5,1±2	12 ±6 : 1
180°	1 : 5,1±3,4	10 ±6 : 1

The ratios of neutron-intensities for the first and second excitation levels are generally higher than the 8:1 ratio determined by *Guier*, and collaborators in forward direction. Similarly high ratios have recently been observed also by *Ajzenberg-Selove* and *Stelson* [5]. The great error of these values is evident from the afore-said experimental conditions.

Data on the intensity ratio of neutrons for the ground and first excitation levels, in the case of various bombarding alpha-energies, have so far been reported only in directions of 0° and 180°. The values here published are considerably higher than either of the two previous values [1, 2]. The tracks belonging to the transition into ground level appeared in a rather small number, but owing to the experimental conditions, within quite a broad energy interval. Even so, the errors here also are great. At any rate, the values reported in this paper seem to be realistic as against the previous 1:2 ratio because in the case of thicker emulsions applied in the present experiments, the correction necessary on account of the escape of proton-tracks from the emulsion is considerably less.

I wish to thank Professor *A. Szalay* for having prepared the Po-source as well as for his great help by taking interest in the subject. The valuable discussions of my colleagues: Mrs. *E. Koltay-Gyarmaty* and *G. Meszéna* are also greatly appreciated. Acknowledgement is due to all that took part in preparing the emulsions and measuring the tracks for their conscientious and thorough work.

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INVESTIGATION OF THE ALBEDO OF THERMAL NEUTRONS

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The albedo value for paraffin was determined on the basis of the definition of "experimental albedo" introduced by *Amaldi* and *Fermi*. The value thus obtained was $\beta = 0{,}855 \pm 0{,}003$. The value calculated for the given experimental arrangement by the diffusion-theory was $\beta = 0{,}785 \pm 0{,}012$. The reasons for deviation of the two values and possibilities for their comparison were investigated. A method was elaborated to experimentally determine the albedo defined by the diffusion-theory. The experimental control of the method is in progress.

1. Introduction

The concept of albedo as a reflection coefficient on the interface of two scattering media with similar or different diffusion properties has been introduced by *Amaldi* and *Fermi* [1]. It was *Placzek* [2] who gave an excellent summing up of the application of the albedo-concept in elementary diffusion theory.

Fermi [3] had pointed out that albedo is not any universal characteristic of the medium, but depends on the circumstances /geometric sizes and shape of the media in question, source-distribution in the media, angular distribution of neutrons falling on the interface/ under which the reflection occurs. The method of measurement originated by *Amaldi* and *Fermi* [1] for experimentally determining the albedo substantiates certain special circumstances. The method is as follows:

Let us assume an infinite scattering medium filling up the half-space in which the distribution of the thermal neutron sources is homogeneous in the whole volume. Let us assume furthermore an infinitely thin /that is, the probability that a thermal neutron passing through the detector is captured should be negligibly slight/ flat-plate-shaped detector sensitive to thermal neutrons. The first time let us place the detector upon the free surface of the scattering medium and measure the activity.

Let the activity measured in this way be $A_{th}(o)$. /The free surface is also well represented by an infinite flat-plate-shaped Cd-absorbent placed at a great distance from the real free surface, inside the scattering medium./ The second time let us place the detector at a great distance from the free surface, inside the scattering medium; let the measured activity be $A_{th}(\infty)$. If β means the probability of reflection /albedo/, then the $\eta = A_{th}(\infty)/A_{th}(o)$ ratio and its relation:

$$\eta = \frac{2}{1-\beta}. \qquad (1)$$

Thus β albedo can be deduced experimentally from η-measurement.

If the detector is not infinitely thin, that is, it captures a considerable proportion of thermal neutrons passing through it /let ζ designate the probability of capture/, then the relation of η and β will be:

$$\eta = \frac{2}{1-\beta(1-\zeta)}. \qquad (2)$$

In practice, homogeneous thermal source-distribution is a requirement very hard to realize. By means of averaging the measurement of activity on two sides of a Cd-absorbent representing the free surface, the inhomogeneous source-distribution can be homogenized. Activity induced by epithermal neutrons may be taken into consideration through forming Cd-difference [1].

The albedo concept introduced above is not yet completely defined as the ratio of reflected neutrons depends also on the angular distribution of incident neutrons. *Amaldi* and *Fermi* [1], [3] attempted to overcome this difficulty by defining the albedo with equation (1) which is true in the case of an infinitely thin detector. To β defined by equation (1), they gave the nomenclature: "experimental albedo".

The experimental albedo depends on the N number of free paths a thermal neutron can travel on the average before becoming captured by protons present in paraffin. *Fermi* [3] determined the relation of this two values:

$$\beta = 1-2/\sqrt{N}. \qquad (3)$$

In paraffin, *Amaldi* and *Fermi* measured $\eta = 9,7$ with silver detector. Accounting for neutron capture in the detector, they obtained $\beta = 0,82$ value for the albedo of paraffin.

Fermi [3] has called attention to the fact that for the very reason of arbitrariness involved in the definiton of experimental albedo itself, no direct comparison can be made between measured albedo values and those calculated according to the diffusion theory. We have set ourselves the task of determining the difference between the two values and our further aim is to find out in what way their comparsion may be possible.

2. Detector and detecting conditions

Our experimental arrangement shown in Fig. 1 is substantially the same as *Amaldi* and *Fermi*'s [1]. In order to precisely keep the time of activation the source was pneumatically shifted. The flying time of the source through 1,5 m distance was 0,1 - 0,2 sec. A Harwell Po + Be neutron source of 10 Curie strength was used. Its geometry: cylinder 15 mm in height and 18 mm in diameter.

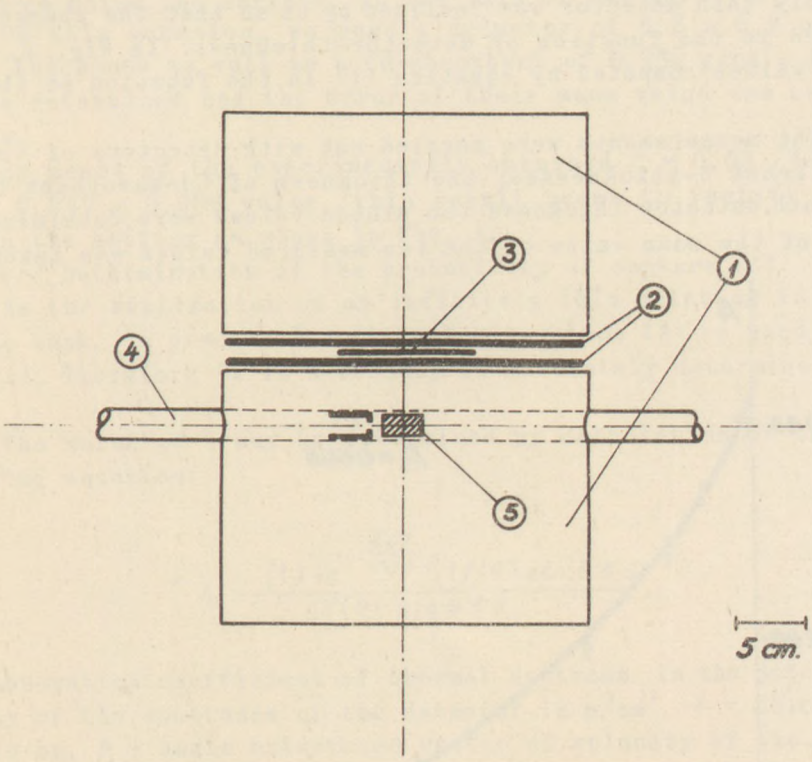


Fig. 1. Experimental set-up. 1 = paraffin blocks, 2 = Cd-adsorbents, 3 = detector, 4 = tube for moving the source, 5 = neutron source.

Square-shaped silver foils were used for a detector. The lengths of time of activations and measurements, that is, the lengths of time between the end of activation and the beginning of measurement were different; the general point in selecting these was that the activity of the foils of different thickness should be approximately alike and the maximal number of impulses should remain by about two orders of magnitude below the resolving power of the counting system.

For the purpose of increasing the resolving power and determining the activity in foils of large extension, we connected in parallel three CTC-6 type counter tubes 15 cm long, 2 cm in diameter /sensitive volume/ and charged with halogen. The indications were registered by a BK-3 type impulse-counter.

In view of the fact that we only needed measurements for relative activity, we simply had to take care that, within the measurement of an ap-

parent η-value, the detector should always get in the same position in relation to the source and the counter tubes respectively.

3. Results of measurement

a./ Measurement of the albedo.

Equation (1) defining the experimental albedo requires the use of an infinitely thin detector. The measurement of the experimental albedo with an infinitely thin detector was realized by us so that the change of η-ratio was measured in the function of detector-thickness. In Fig. 2, we plotted the albedo values computed by equation (1) in the function of the detector-thickness.

The measurements were carried out with detectors of 8×8 cm^2 area and of different δ-thicknesses; the thickness of Cd-absorbent being 0,936 g/cm^2. At each detector thickness ten albedo values were determined, and the mean error of the mean value of the ten measured values was taken for error.

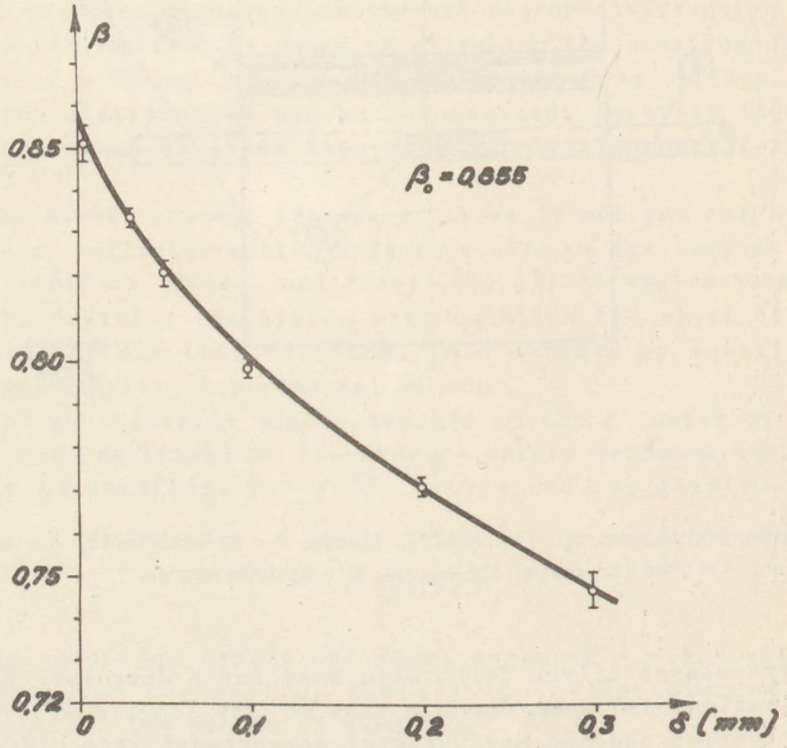


Fig. 2. Dependence of the albedo on detector-thickness. Abscissa = detector thickness; ordinate = albedo.

It is apparent from Fig. 2, that the albedo value relating to the infinitely thin detector can easily be obtained by extrapolating the curve drawn through the points of measurement to $\delta = 0$. The $\beta_0 = 0,855 \pm 0,003$ value obtained in this way shows a considerable discrepancy - even more striking than in *Amaldi* and *Fermi*'s measurements - from $\beta = 0,785 \pm 0,012$

value calculated on the basis of the diffusion theory for our actual measuring conditions /finite scattering medium in all directions and point source/.

Because of neutron leakage, the experimental albedo must necessarily depend also on the size of the setting. In order to get, in this regard a quantitative value and to check up on the reliability of our experimental results obtained thus far, we measured the albedo also in a setting with different geometric dimensions; namely with two cylinders 12 cm in diameter and 9,5 cm in height. The neutron source was placed in the lower cylinder, 3 cm below the surface, in the axis of the cylinder.

On this occasion, we used a detector of 6,2 x 6,2 cm^2 area and 0,05 g/cm^2 thickness as well as a Cd-absorbent of 0,936 g/cm^2. Three albedo values were determined and the error of their mean value was calculated as said before.

By means of the experimentally obtained ζ = 0,04 /3/b. point!/, we got β = 0,827 ± 0,008 value, this result seems to justify the results measured in the setting as shown in Fig. 1.

b./ Determination of the probability of capture (ζ).

As the realization of an infinitely thin detector is generally a troublesome task, in practical work rather equation (2) is used instead of equation (1). Therefore it is necessary to accurately determine the inplied ζ.

The value of ζ may be determined by calculation on the ground of the following equation:

$$\zeta = \frac{\int (1-e^{-\frac{K\rho\delta}{\cos\theta}}) f(\theta) \sin\theta \, d\theta}{\int f(\theta) \sin\theta \, d\theta},$$

where K = absorption coefficient of thermal neutrons in the detector in cm^2/g, ρ = density of the substance of the detector in g/cm^3, δ = thickness of the detector in cm, θ = angle between the vector of velocity of the neutron and the normal of detector-surface; and $f(\theta)$ = angular distribution of neutrons.

Inside of a scattering medium, the neutrons display on isotropic distribution of $f(\theta) = c.\cos\theta$, where c is a proportional factor; in this case we get the following explicit formula for ζ:

$$\zeta_1 = 1 - e^{-K\rho\delta}(1 - K\rho\delta) + K^2\rho^2\delta^2 \, Ei(-K\rho\delta), \qquad (4)$$

where $Ei(-K\rho\delta)$ is the known integral-exponential function [4].

In the case of a thin detector ($K\rho\delta \ll 1$):

$$\zeta_1 = 2K\rho\delta. \qquad (4a)$$

It is well-known both from theoretical [3], [5] and experimental [6] literature that the number of neutrons leaving the surface of a scattering medium in the unit solid angle is proportional to $(\cos\theta + \sqrt{3}\cos^2\theta)$. In this way, at $A_{th}(\infty)$ - measurements, an isotropic distribution, whereas at $A_{th}(o)$-measurement, the afore-mentioned, so-called surface distribution will come

about. Therefore it is necessary on the assumption of this distribution also to compute the probability of capture (ζ_2), which, after the introduction of a = $K\rho\delta$ abbreviation will explicitly be:

$$\zeta_2 = 1-\left\{e^{-a}\left[1-\frac{a(3+\sqrt{3}-\sqrt{3}a)}{3+2\sqrt{3}}\right]+\frac{\sqrt{3}}{3+2\sqrt{3}}a^2(a-1)Ei(-a)\right\}. \qquad (5)$$

In the case of a thin detector:

$$\zeta_2 = \sqrt{3}a = \sqrt{3}K\rho\delta. \qquad (5a)$$

For the actual calculation of ζ_1 and ζ_2 the latest K = 0,335 cm^2/g value relating to naturel silver was used [7].

In order to decide which one of ζ_1 and ζ_2 values obtained by the calculation will approach more closely the real value of ζ /that is the value for the measurement of albedo, and not that of $A_{th}(\infty)$ or $A_{th}(o)$/, the experimental determination of ζ seemed to be useful.

ζ was experimentally determined from the curve shown in Fig. 2. From β_0-value obtained by extrapolation for the infinitely thin detector as well as from experimental value (β_x) measured in the case of a detector of any desired thickness ($\delta = x$), the ζ_x relating to a detector of any desired thickness can easily be computed according to the equation:

$$\beta = \frac{\beta_x}{1-\zeta_x}.$$

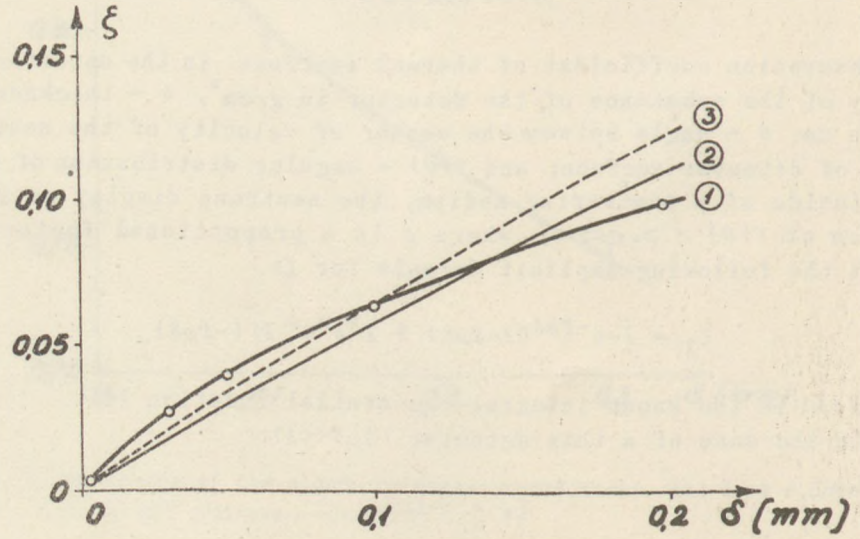


Fig. 3. Dependence of the different ζ-s on the detector-thickness. Abscissa = detector-thickness; ordinate = probability of capture. 1 = experimental curve, 2 = curve calculated by surface distribution, 3 = curve calculated by isotropic distribution.

For comparison, ζ_1 and ζ_2 as well as the average ζ obtained experimentally are plotted in the function of detector thickness /Fig. 3/. It can be seen in Fig. 3 that in the case of thin detectors, ζ_1 computed by isotropic distribution shows better agreement with the average ζ obtained experimentaly; while in the case of thicker detector, ζ_2 calculated by surface distribution does, The divergence of experimental and computed ζ values can be interpreted if we consider that in calculating the albedo not exclusively isotropic or surface distribution is involved, but some combination of the two.

4. Summary

The discrepancy mentioned in 3/a. between the experimentally measured and theoretically calculated albedo-values is the outcome of factors independent from one another. One reason for the discrepancy is evidently that while the theory defines the albedo as a ratio of the number of reflected neutrons to that of incident neutrons, the definition of experimental albedo is based on the measurement of activity produced by a thin detector; now this activity is not simply the measurement of the number of neutrons intersecting the detector, but it depends on the angular distribution of the respective neutrons. The angular distribution of the incident and reflected neutrons being different, there is to be expected a discrepancy between the measured and computed albedo-values.

The disagreement may partly be eliminated by reducing the activities to numbers of neutrons that is by taking into consideration that

$$\frac{A_{th}(\infty)\sqrt{3}}{A_{th}(o)\,2} = \frac{N_{th}(\infty)}{N_{th}(o)},$$

where $N_{th}(\infty)$ and $N_{th}(o)$ designate, in the corresponding cases, the number of thermal neutrons intersecting the detector, - and the experimental albedo will be defined by the following relation:

$$\beta = 1 - \frac{2N_{th}(o)}{N_{th}(\infty)} = 1 - \frac{4A_{th}(o)}{\sqrt{3}A_{th}(\infty)}. \qquad (6)$$

Naturally in this case the relation of average N number of collisions made by a thermal neutron till its capture and β will be:

$$\beta = 1 - \frac{4}{\sqrt{3}}\frac{1}{\sqrt{N}}. \qquad (7)$$

The other reason is that in deducing equations (1) and (6) [1]

defining the experimental albedo, the dependence of β from the angle of incidence of the thermal neutrons was neglected. This negligence would cause no difficulty in comparison with theory if the angular distribution of incident thermal neutrons were unequivocally known. Because of the multiple reflection occurring when the experimental albedo is measured, the angular distribution of incident thermal neutrons is unknown, and thus the experimentally measured average albedo-value cannot be compared with any average albedo theoretically computed.

From what has been stated it is obvious that an experimental method involving merely a single reflection and at the same time making the angular distribution of incident neutrons definable, would eliminate difficulties. To this end, the following method seems suitable:

Let us assume an infinite scattering medium filling up the half-space with a thermal point source placed on its free surface. Let us further assume an infinitely thin detector of infinite extent, flat-plate-shaped and sensitive to thermal neutrons. The detector now should be placed between the source and scattering medium, and the activity measured. Let the measured activity be $A_{th}(\infty)$. Now removing the scattering medium; let $A_{th}(o)$ stand for the activity thus measured.

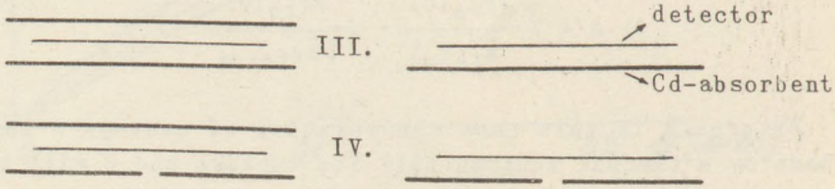
If β designates the probability of reflection /albedo/, and N represents the number of neutrons falling on the detector from the source, then $N\beta$ will be the number of reflected neutrons. Now activity $A_{th}(\infty)$ will be in ratio with $N/1+\beta/$ and $A_{th}(o)$ with N quantity. The relation of the experimentally measurable $\eta = A_{th}(\infty)/A_{th}(o)$ ratio and β will be:

$$\beta = \eta - 1. \tag{8}$$

Because of the single reflection involved in this method, the angular distribution of incident thermal neutrons can be given unequivocally, and so the method will make direct comparison with theory possible.

Because of the above, the experimental albedo is defined by equation (8); this equation presupposes: 1. the use of an infinitely thin detector, 2. indentical angular distribution of the incident and reflected neutrons.

The thermal point source and detection can be realized in practice by the following four arrangements /omitting, for the sake of simplicity, the lower scattering medium containing the neutron-source, and the reflecting upper one/:



The multiple reflection eventually arising at the gap in the cadmium can be decreased at will by the proper choice of the size of the gap.

At once it becomes evident that by deducting the activity measured in set-up I from the activity measured in set-up II we obtain just $A_{th}(o)$;

that is II-I = $A_{th}(o)$. Similarly: IV-III = $A_{th}(\infty)$.

It must be pointed out that in reality conditions 1. and 2. of the validity of equation (8) are not fulfilled. This fact needs also to be expressed numerically.

Let N designate the number of thermal neutrons incident on the detector, β the probability of reflection and ζ that of capture. As the angular distributions of incident and reflected neutrons cannot be regarded indentical, in the case of incident neutrons ζ_i and in the case of reflected ones ζ_r have to be accounted for. In this way, from N neutrons falling on the detector $N(1-\zeta_i)$ will pass on to the reflecting medium; at the same time the activity of the detector will be in ratio with $N\zeta_i$.

Out of the transitting $N(1-\zeta_i)$ number of neutrons $N(1-\zeta_i)\beta$ will return, in other words, the activity of the detector induced by these neutrons will be in ratio with $N(1-\zeta_i)\beta\ \zeta_r$. For this reason, $A_{th}(\infty)$ will be in ratio with $[N(1-\zeta_i)\beta\zeta_r + N\zeta_i]$ quantity.

The relation of η to β is now obviously:

$$\beta = \frac{(\eta-1)\ \frac{\zeta_i}{\zeta_r}}{1-\zeta_i}. \qquad (9)$$

Insofar as the angular distribution of incident and reflected neutrons is identical ($\zeta_i = \zeta_r = \zeta$) and the work is done with an infinitely thin detector ($\zeta \approx o$), equation (9) transforms into equation (8).

In practical work, equation (9) is naturally regarded as the defining equation of the experimental albedo.

To sum up in short the advantages of the method:

1. The average albedo-value measured by the *Amaldi-Fermi* method - as mentioned before - cannot be assigned to any given angular distribution of the incident neutrons, on account of the multiple reflection. At the same time, the average albedo-value measured by the suggested method belongs to a well defined /generally simply definable/ angular distribution of the incident neutrons.

2. It makes the experimental determination of the angular distribution of reflected neutrons possible. This may be done as follows: let us measure the change of η and plot the change of $\beta = \eta - 1$ in the function of detector thickness. By means of β_o value extrapolated to $\delta=o$, ζ_r is calculated and plotted in the function of detector thickness. Finally function $f(\theta)$ is to be found, by whose help ζ_r-s are computed which follow the line of the experimental curve.

3. It can be experimentally determined how the albedo-value depends on the angle of incidence of the neutrons, that is function $\beta(\theta)$, and how *Fermi*'s [3] relating theoretical formula can be tested.

4. It does not require identical substances for the reflecting scattering medium and that which contains the source.

Disadvantage of the method is that for practical purposes it requires a thermal neutron source. As a matter of fact the epithermal background of fast neutron sources in general use is too large as compared to the number of thermal neutrons, and this makes measuring inexact. For a

thermal source, in the first place, the thermal colum of such an atomic reactor seems suitable where in the $\frac{\text{thermal flux}}{\text{fast flux}}$ ratio even 10^3 - 10^4 value is attainable. The *Sb+Be* photo-neutron source may also te taken into account by virtue of its low average energy.

In the case of a medium of great diffusion length the detector of an infinite extent /that is the measurement of the activity of this detector/ may be realized, for instance, by measuring the change of activity with a small size detector by means of the distance from the source and then integrating to the desired surface.

Acknowledgement is due to *K.M.Dede* for valuable discussions.

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RANGE OF PROTONS IN THE AGFA K2 NUCLEAR EMULSION

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By measuring the range-energy of recoil protons produced in the nuclear emulsion by reactions $H^2/d,n/He^3$ and $H^3/d,n/He^4$, calibration points were obtained to determine the range-energy relation of the Agfa K2 emulsion. The measured ranges showed good agreement within errors with results in calculations for Agfa K2 emulsion containing 60 % relative humidity [1].

The photoemulsion method cannot be applied to determine the energy of particles without precise knowledge of their range-energy relation. Therefore it is not surprising that in literature so great a number of both calculated and measured data can be found on emulsions of different make and type.

The range-energy relation of Agfa K2 emulsions was investigated by *Lanius* [2] and *Bebel* [1]. Both authors carried out calculations for the protons, and obtained the calibration points by measuring and reducing the range of alpha-particles from the decay series of Th. Experimental data on protons were reported only by *Lanius* who measured the range of 0,58 MeV protons from reaction $N^{14}/n,p/C^{14}$. Both measurements were made in air of 60 % relative humidity, and the calculations were also made for emulsions of this kind. There is a substantial difference in the atomic composition reported by the two authors and accordingly also in the density of emulsions. According to *Bebel's* recent data, the latter is 3,38 g cm^{-3} as against the previous 3,84 g cm^{-3}. *Lanius* carried out the calculations as described by *Cüer* [3], while *Bebel* made them with the method developed by *Vigneron* [4] using - in addition to the composition of the emulsion - new data also for the average ionization potential value.

On the ground of the above, it can be expected and also understood that the discrepancy in the range of protons with identical energy is considerably greater between the referred two authors than the usual error in measurement. The data of measurement and calculated values - on the other hand - show good agreement with both authors. The reason for this, besides

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the use of emulsions with different stopping power - is to be found in the fact that the range of particles in the investigated region is shorter than 50 μ, and at lower energies, the straggling of ranges in emulsion is greater [5] than in air because of the small number of grains constituting the tracks.

T a b l e I.

Range of alpha-particles from decay series of Th measured in Agfa K2 emulsion

E MeV	Mean ranges in μ and relative mean errors		
	Lanius [2]	*Bebel* [1]	*Bujdosó-Medveczky* [6]
5,68	24,6 ± 4,2	25, 55 ± 4,1	25,5 ± 2,0
6,28	28,5 ± 4,0	29, 86 ± 3,5	29,5 ± 1,7
6,78	32,0 ± 3,1	33, 32 ± 3,2	33,0 ± 1,51
8,78	47,7 ± 1,3	49, 76 ± 1,8	49,0 ± 1,0

At measurements for alpha-particles from decay series of Th [6], we took into consideration only tracks falling in the plane of the emulsion. As it can be seen in Table I., values similar to those of *Bebel* were obtained, yet for the sake of accuracy in other investigations, the testing of the range of protons by means of longer tracks was needed. In this manner, it was possible to obtain calibration points at higher energies.

The proton tracks used at our measurements were produced by neutrons obtained from reaction /d,n/, with H^2 and H^3 targets respectively.

In relation to deuterons accelerated by 0,1 MeV, the irradiated plates were in the direction of an angle of 0° in the case of reaction D+D, and an angle of 90° in the case of reaction D+T. Accordingly, the energies of the obtained neutrons were 2,850 ± 0,001 and 14,06 ± 0,02 MeV respectively. The plates wrapped in aluminium foil and then in paper were placed at distances of 120 and 350 mm respectively from the target approximately 8 mm in diameter. At reaction D+D, plates of 100 μ layer-thickness were used, and the time of irradiation was 40 hours, whereas at D+T, the layer-thickness was 200 μ and the time of exposure 2 hours. The emulsions were proceeded by temperature-development with amidol [7]. The tracks from reaction D+D were measured under a magnification of approximately 1000X, while the measurements for the longer ones were taken under a magnification of approximately 420X. Transverse displacement of the tracks was measured by an eyepiece micrometer and the dip displacement by the finefocus motion of microscope. For the calculation of track-lengths nomograms [8] were used. Such tracks were considered only, where the angle between the direction of the track and the straight line connecting its initial point with the centre of the target was less than 10°. The results of measurement are shown in Figures 1. and 2. Both spectra are corrected for the variation with energy of the neutron-proton scattering cross section and for the escape of protons from the emulsion. The errors in-

dicated in figures are statistical errors only. Fig. 1 represents the range distribution of 2,85 MeV protons in 450 measured tracks. The mean range of the tracks is 70 ± 3 μ. The mean value calculated from the range distribution corrected of the measured 971 recoil protons of 14,06 MeV energy is 1075 ± 43 μ /Fig. 2/.

In Fig. 3, the results of our investigations are compared with range-energy relations reported by *Lanius* and *Bebel* respectively. As it can be seen, the results of our measurements fall systematically between the two range-energy curves. Taking the limits of error in measurement into consideration, the agreement in the mean ranges with *Bebel*'s figures is satisfactory, /even full in the case of extrapolated ranges/. The ranges are, by all means, greater than those reported by *Lanius*. In our opinion, the following facts are responsible for the slight systematic deviation from *Bebel*'s data: a./ our investigations were carried out in air containing strictly less than 60 % relative humidity, b./ the composition of emulsions is not completely identical in the different preparations [1].

Summing up our investigations, it can be stated that in Agfa K2 nuclear emulsions, it is the recently calculated values that correspond to the range-energy relation of protons. It is, however, desirable to carry out the calibration also at energies not yet investigated.

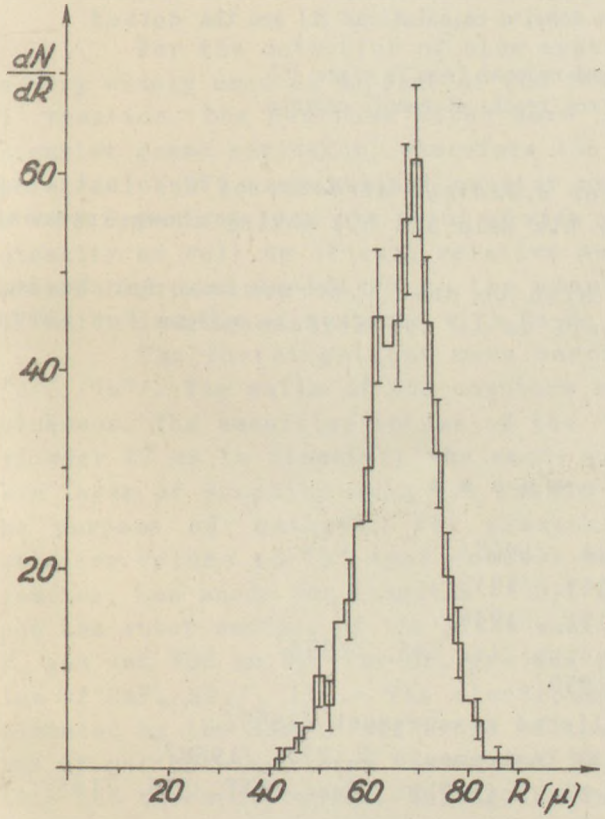

Fig. 1. Range distribution of 2,85 MeV protons.

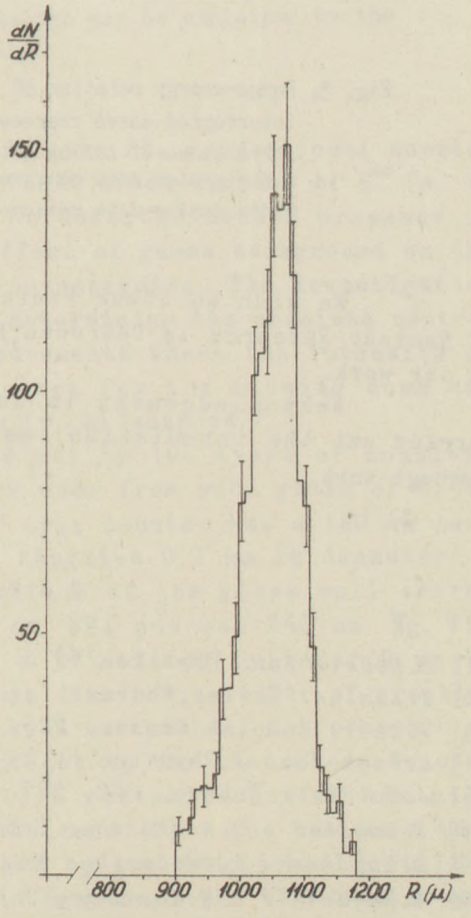

Fig. 2. Range distribution of 14,06 MeV protons.

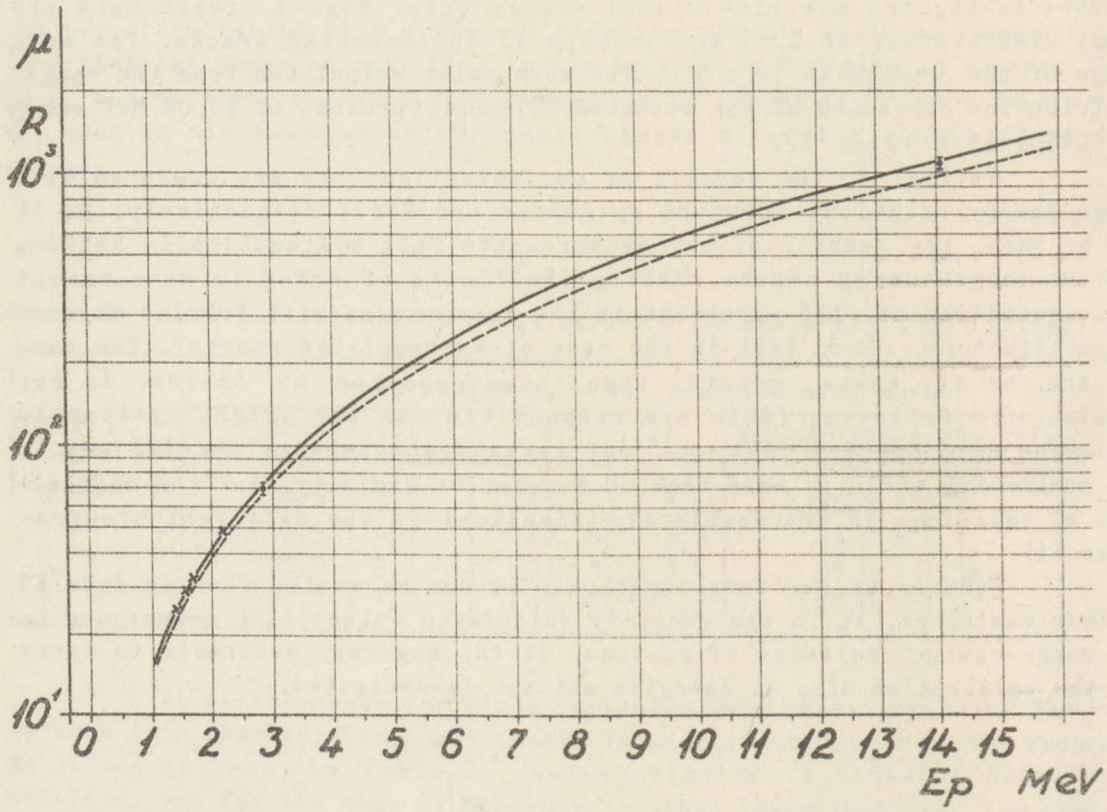

Fig. 3. Range-energy relation of Agfa K2 nuclear emulsions for protons. The uninterrupted curve represents *Bebel's* calculations [1] and the dotted curve those of *Lanius* [2].
x designates data measured and reduced from Th stars [6]
Ŧ designates data measured from tracks of recoil protons.

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Acknowledgement is due also to Mrs. *G. Bornemisza* for having carried out the irradiation, as well as to the microscopists for their thorough work.

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THE EFFECT OF GAMMA-BACKGROUND ON THE BF_3 PROPORTIONAL COUNTER

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The integral amplitude distribution the BF_3 proportional counter was found to be changing by the effect of a strong gamma background. In the function of electronic amplification, the distortion of amplitude distribution was investigated with counters of different cathodes. The distortion of amplitude distribution due to the effect of gamma radiation may be explained by the positive space charge developing around the anode.

For the detection of slow neutrons, the BF_3 proportional counter is very widely used on account of the favourable cross-section of B^{10} (n, α) Li^7 reaction. The neutrons often have to be detected in the presence of intensive gamma radiation, wherefore the effect of gamma background on the operation of BF_3 proportional counter was investigated. The investigation is very important from the point of view of determining the absolute neutron intensity as well as of such relative measurements where the intensity of gamma background varies /e.g. the measurement for the slowing down and diffusion lengths of neutrons with Ra-Be or (γ, n) sources./

The investigations were carried out by two types of counters /"a"/,/"b"/. The walls of the counters were made from soda glass of 0,5 mm thickness. The sensitive volume of the "a" type counter was a 160 mm long cylinder 17 mm in diameter; the anode was tungsten 0,1 mm in diameter; a thin layer of graphite upon the inside surface of the glass wall served the purpose of cathode; the pressure of BF_3 gas was 260 mm Hg. The sensitive volume of "b" type counter was a 30 mm long cylinder 9 mm in diameter; the anode was tungsten of 0,1 mm in diameter; a layer of graphite upon the outer surface of the glass wall served as cathode; the pressure of BF_3 gas was 200 mm Hg. The BF_3 gas was produced by the thermal decomposition of $CaF_2/BF_3/_2$ [1].- The electronegative contamination of the gas- estimated by the length and slope of the plateaux [2] - was not more than that of gas obtained from commercial BF_3 gas by two fractional distillations and thermodiffusion. During the investigations, the BF_3 counter was placed on the surface of a paraffin cylinder of 30 cm height and 25 cm in diameter, inside of which at 3 cm from the surface, there was a 3 curie Po-Be neutron source. Co^{60} isotope was made available for gamma source.

When placing a Co^{60} isotope of 4 mC close by an "a" type counter, the integral amplitude distribution was found to become distorted by the effect of the strong gamma background. Fig. 1 shows the integral amplitude distribution of the impulses deriving from the neutrons without gamma background /A/, and with gamma background /B/. The voltage of the counter was 50 V lower than the voltage corresponding to the electron-threshold /V_e/ and so the impulses produced by the electrons could not be detected. In case of high gamma intensity, the plateau of integral amplitude distribution disappears completely, in consequence of which the impulses produced by the neutrons and gamma rays cannot be seperated.

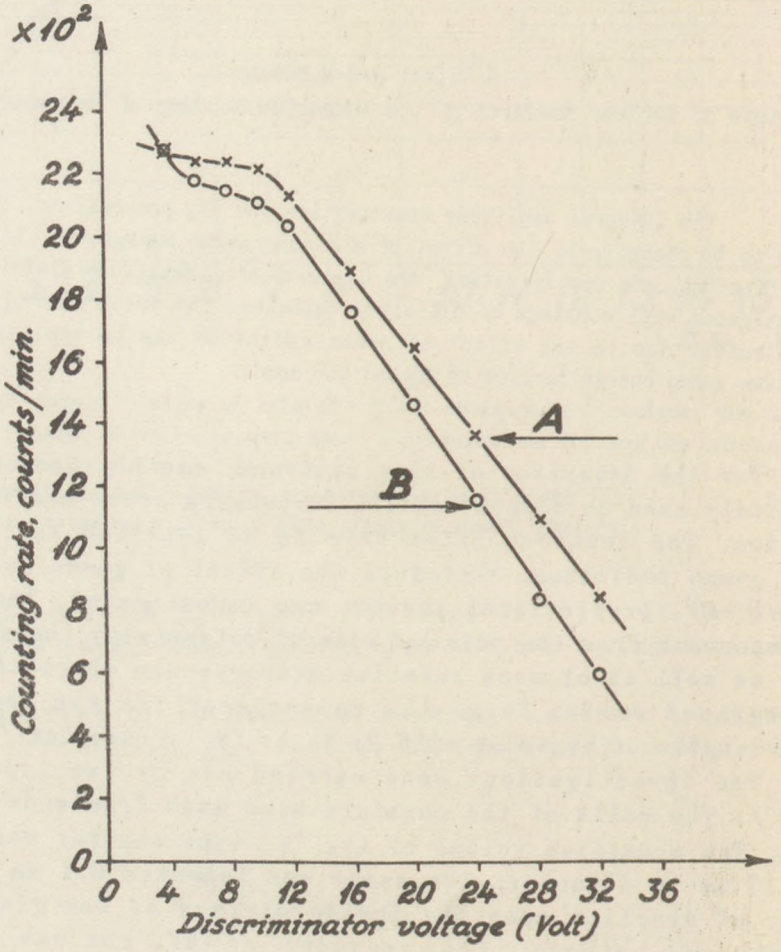

Fig. 1. Integral amplitude distribution of impulses derived from the neutrons: /A/ without gamma background, /B/ with gamma background.

Under the same conditions, the distortion of amplitude distribution was examined by using counters of different cathodes. Fig. 2 shows the $(n-n_\gamma)/n$ quantity in the function of the discriminator voltage /where

n and n_γ represent the number of impulses from the neutrons without or with gamma background/ when internal graphite /A/, internal brass /B/ and external graphite /C/ cathodes were used. As it can be seen in Fig. 2, the effect of gamma background is the smallest in the case of an internal graphite cathode.

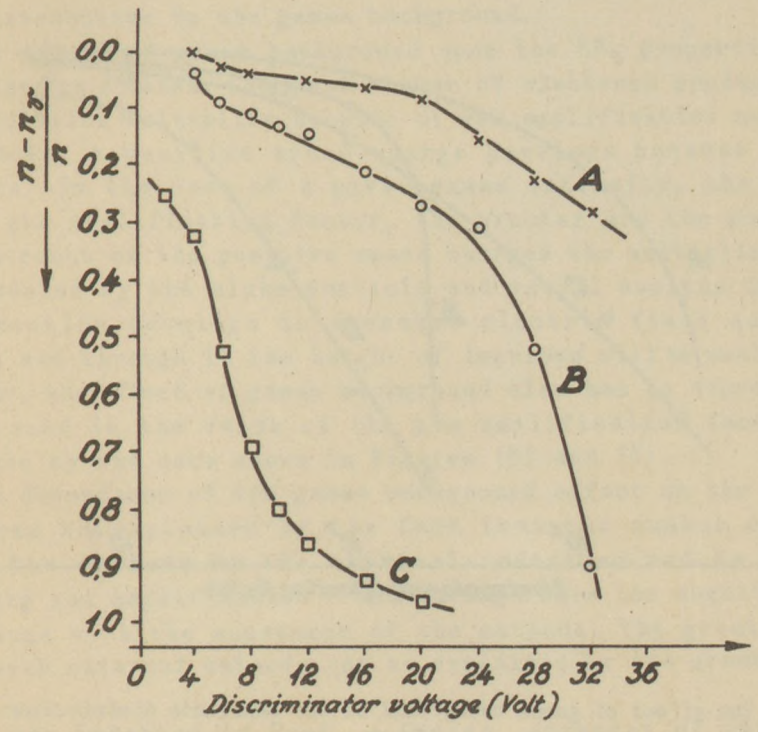

Fig. 2. The effect of gamma background on the operation of counters with different cathodes: /A/ internal graphite, /B/ internal brass and /C/ external graphite.

The distortion of amplitude distribution was investigated also in the function of electronic amplification. At V_e-50 V counter voltage in each single electronic amplification, the n and n_γ values were measured at 10 and 20 V discriminator voltage. In Fig. 3, the dependence from electronic amplification of $(n-n_\gamma)/n$ quantities obtained by a "b" type counter is shown when using two gamma sources of different intensities. At 10 /A, C/ and 20 /B, D/ V discriminator voltage, the A and B curves, were obtained by placing the Co^{60} isotope of 3 mC close by the counter, while C and D surves were produced by placing the Co^{60} isotope of 45 mC at a distance of 1 cm from the counter. As Fig. 3 shows, at low electronic amplification, that is, at high gas amplification, the effect of gamma background is quite significant and decreases to a considerable degree when electronic amplification is increased. For the sake of comparsion, in the case of an "a" type counter, too, the $(n-n_\gamma)/n$ quantities were determined as the function of electronic amplification at 10 /C/ and 20 /D/ V discriminator voltage so that the Co^{60} preparation of 45 mC was placed at a

distance of 1 cm from the counter /Fig. 4/. As it can be seen in Figures 3 and 4, the investigation was made possible by the resolving time of the electronic apparatus.

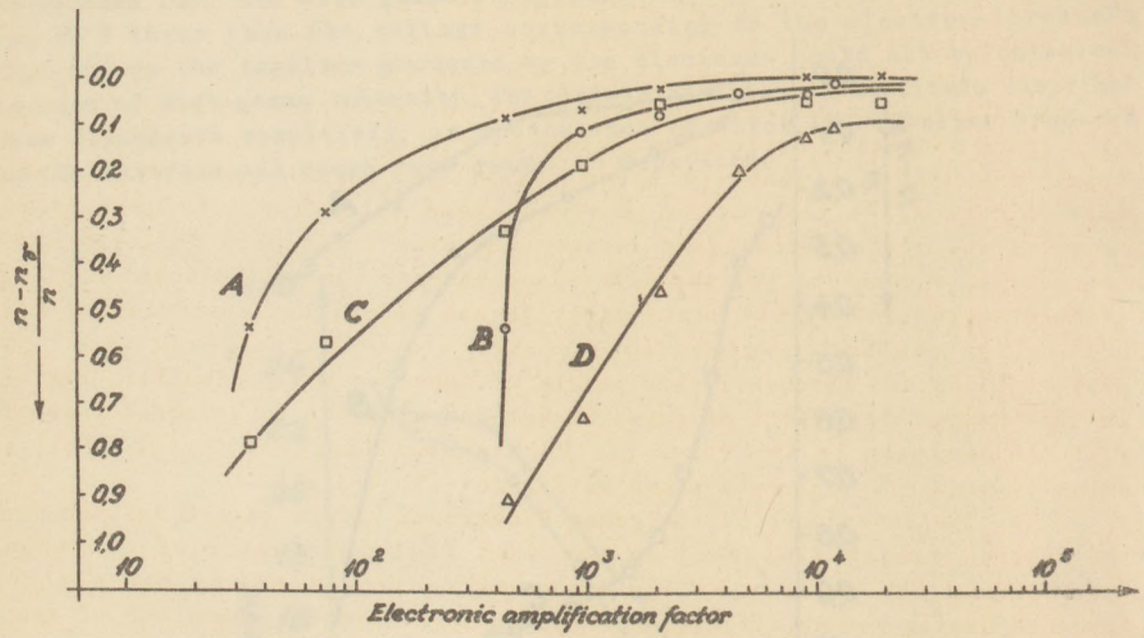

Fig. 3. The effect of gamma background on the amplitude distribution of a "b" type counter, in the case of different electronic amplifications.

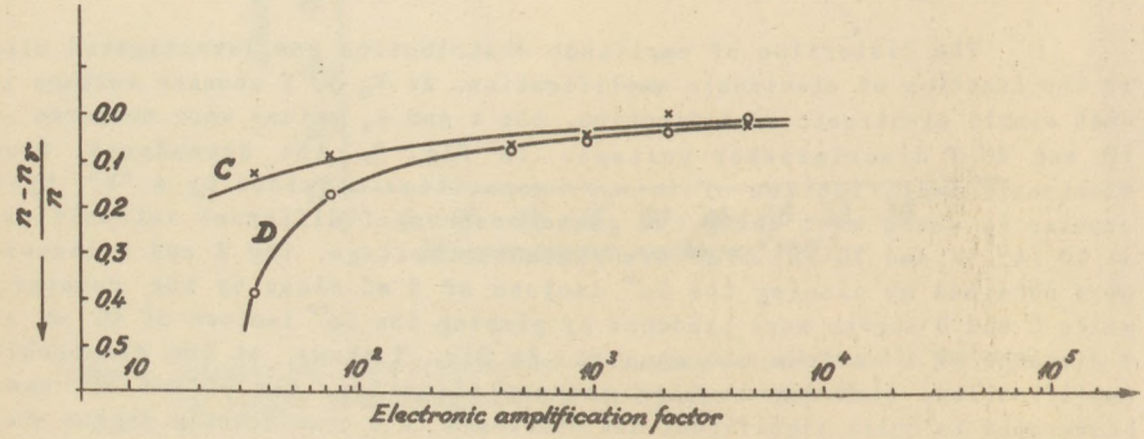

Fig. 4. The effect of gamma background on the amplitude distribution of an "a" type counter, in the case of different electronic amplifications.

The investigation reveals that the effect of gamma background upon the BF_3 counter is not negligible and depends on the cathode, the value of the gas amplification factor, the initial order of magnitude of ionization as well as on the intensity of gamma background. Presumably, these are responsible for the discrepancy of the results of measurements obtained [3], [4], [5] in a strong gamma background by a BF_3 proportional counter and by a method insensitive to the gamma background.

The effect of gamma background upon the BF_3 proportional counter may be explained as follows: the great number of electrons produced by intensive gamma radiation multiplies because of gas amplification near the anode. Around the anode, a positive space charge develops because of electron multiplication. In the case of a given gamma intensity, the greater the value of the gas amplification factor, the greater are the positive space charges. An account of the positive space charges the multiplication of the electrons produced by the alpha particle and recoil nucleus deriving from $B^{10}(n,\alpha)Li^7$ reaction develops in a weaker electric field and thus gas amplification and through it the height of impulses will be smaller. /Fig. 1/ In this manner, the effect of gamma background also has to decrease together with the decrease in the value of the gas amplification factor. This is actually proved by the data shown in Figures [3] and [4].

The dependence of the gamma background effect on the substance of the cathode can be explained by the fact that the number of electrons ejected from the cathode by the external radiation and by the photons produced during gas amplification - and through this the magnitude of space charges - change with the substance of the cathode. The greater effect on the counter with external cathode can be explained by its greater resolving time.

We are indebted to Prof. *A. Szalay*, director of this Institute for making these investigations possible. Thanks are due to *Mr. B. Schlenk* for having planned and constructed the necessary electronic apparatuses.

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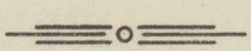

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INVESTIGATIONS ON HOW TO IMPROVE THE RESOLVING POWER SINGLE CRYSTALS SCINTILLATION GAMMA-SPECTROMETERS

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In the region of energy where scintillation-gamma-spectrometers are applied, the number of visible photons produced by gamma-rays is extremely small. Thus statistic fluctuation partly in the number of photons but mainly in that of photo-electrons from the photo-cathode of the electron-multiplier is great enough to limit the accuracy of energy measurements.

Methods will be described here whereby the number of applicable photo-electrons and, in consequence, the resolving power can be increased to the greatest possible extent. This has been achieved partly by the maximal utilization of the light arising in the crystal, partly by the optimal adjustment of the electron multiplier and that of contiguous electronics.

For obtaining information on the properties of the nucleus, the gamma-spectrometer is an indispensable means. In the course of time, several types of gamma-spectrometer have developed. When designing spectrometers, two main points are usually kept in mind by physicists, i.e. the optimal resolving power and the maximal counting efficiency. The simultaneous increase of these two properties usually excludes each other. Spectrometers of different type possessing great resolving power but low counting efficiency unfortunately cannot be used for determining the energy distribution of gamma-sources with low activity and a short half-life. Still less can they be used for coincidence measurements. The introduction of scintillation gamma-spectrometers with high counting efficiency was - despite their comparatively poor resolvint power - extramely important on account of the afore-mentioned points of view.

Let us make the scintillation gamma-spectrometer an object of our investigation to ascertain the parameters which decisively influence the resolving power of the apparatus. For this purpose let us make a sketch of the block-scheme of the spectrometer.

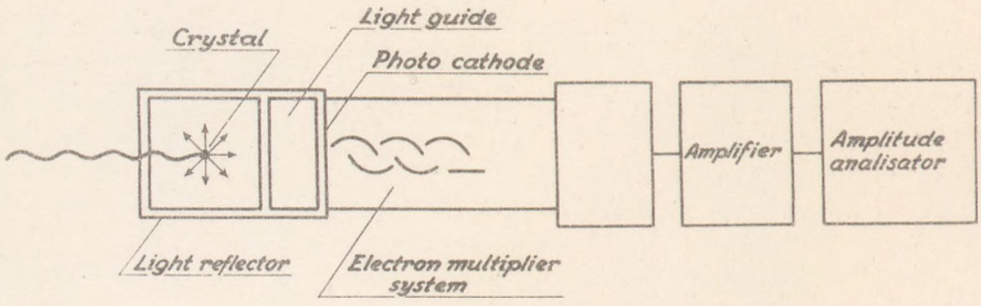

Fig. 1. Block-scheme of the gamma-spectrometer.

Supposing the entering gamma-radiation of energy E to have lost its whole energy through photo-effect, photon $E.\epsilon_1$ will arise in the scintillator, where ϵ_1 is the efficiency of gamma-quantum transforming into photons. All of the produced photons will not reach the photo-cathode as the light partly undergoes self-absorption within the substance of the crystal, partly it escapes from the crystal without being reflected by the surface of the crystal and partly it loses itself in the imperfect light connection between the crystal and photo-cathode. In this manner, photon $N_{ph} = E.\epsilon_1.\epsilon_2.\epsilon_3.\epsilon_4$ will reach the photo-cathodes, where ϵ_2, ϵ_3 and ϵ_4 are coefficients characteristic of transparence of crystal, of the reflection efficiency of its surface and of the light connection between the crystal and multiplier photo-cathode respectively.

From the photo-cathode, electrons are derived by the photons with δ_1 efficiency. After these electrons have been collected with δ_2 efficiency into the electron-multiplier system, they are multiplied by means of a secondary emission. Finally, the charge arriving at the anode is transformed into voltage-impulse and so measured with an amplitude-analizator. If all the coefficients are independent of primary energy /E/, the relation tetween gamma-energy and voltage-amplitude is linear. This expectation, however, is not always realized or rather only in certain ranges of energy.

The subsequent task is to ascertain the factors which decisively determine the resolving power.

The transformation of gamma-quantum into photons is a statistic process. It means that a gamma-quantum of a specific energy does not always produce the same number of photons, but their number fluctuates about a defined value. On account of the above-listed losses /ϵ_2, ϵ_3, ϵ_4/ the number of photons decreases, which again will increase relative fluctuation. The fact that electrons are derived from photo-cathodes only by a small percentage δ_1 of photons is responsible to a considerable extent also for the impairment of the resolving power. Further decrease is caused by the fact that not every photo-electron but only δ_2 times its number can be collected into the electron-multiplier system. The breadth of the line to be measured will be decided by the fluctuation in the number of arising electrons.

From what has been said follows that in the case of a given gamma-

energy, the greater the number of electrons arriving at the electron-multiplier, the better the resolving power of the spectrometer.

The aim is therefore to obtain from the crystal as great a light-signal as possible and to let the signals reach the photo-cathode with as little loss as possible. By the effect of light-signals, the photo-cathode should yield as many photo-electrons as possible, and these electrons should be focused into the electron-multiplier system with an optimal effect. In other words, the aim is to make quantities ϵ_1, ϵ_2, ϵ_3, ϵ_4, as well as δ_1 and δ_2 as great as possible, taking the signale into consideration.

Quantum-efficiency of the scintillator /ϵ_1/.

Up to the present the NaJ/Tl/ crystal has proved the most suitable for gamma-spectroscopic purposes. The reason for this is not only its great absorption capacity, but it is much rather the fact that this scintillator possesses the highest quantum-efficiency /ϵ_1/ which is enhanced by other advantageous properties.

The quantum-efficiency depends on the purity of the crystal and on the quantity of the Tl activator.

The aim is to prepare crystals containing an optimal quantiti of Tl and homoganeous to Tl.

Our experiences reveal that even crystals considered to be the best are very unlikely to have the same Tl-concentration in the full volume, as the concentration changes along the longitudinal axis. This supposition is based on the experience that the resolving power changes to a great extent if the reverse side of the same crystal is placed before the photo-cathode of the multiplier. If for the characterization of resolving power, relation p/v is taken, which designates the relation between the height of the 1,33 MeV peak of Co^{60} and the magnitude of the valley preceding the peak, the ratio will numerically change, e.g. from 2,7 to 4.

The transparence of the crystal /ϵ_2/

Crystal NaJ/Tl/ is transparent to a great extent regarding its own lustre. The increase of transparence is a matter of crystal-growrh. By increasing Tl-concentration, the transparence generally decrease, so that what has been gained in the yield of light by increasing Tl quantity, might be lost because of self-absorption. An opalescent crystal, however, happens to have a surprisingly good resolving power.

If the crystal is not homogeneous with regard to its transparence or Tl-concentration, this fact may result in non-linearity for the relation of energy-impulse magnitude. The reason is that gamma-rays of low energy get absorbed in the surface of the crystal, while those of higher energy do so inside the crystal too.

Finally, regarding transparence, it must be pointed out that in our experience, the resolving power is not influenced by a few mm split in the crastal.

Reflection efficiency of the surface of the crystal /ϵ_3/

If the surface of the crystal is surrounded with light-reflectors, the photons arising in the crystal can be utilized in a considerably greater number. According to what has been said in the introduction, this makes an improvement in the resolving power.

On the ground of experiences, reflecting metal surfaces do not yield satisfactory light.

In literature, many authors are reporting on this problem. Lately, the most popular views are those of *Borkowski* and *Clark* who tried a great many light-reflectors and found best the procedure to surround the surface of the crystal roughened by emery paper. No.120 with MgO or AlO powder as a diffuse-reflector. In this way, they found the resolving power to be much better than in any other case.

For same time the same procedure was followed by us. In Czechoslovakia as well as at the Institute of Medicophysics in Budapest, the diffuse-reflector was prepared so that the crystal which had become moist from the hygroscopic state of the air was desiccated in a dry stream of nitrogen. In this manner, one matt surface of white microcrystal NaJ/Tl/ was obtained.

We found crystale with such surfaces to give a far better resolving power. An improvement in the yield of light was achived so that a concentrated aqueous solution of pure NaJ was carried and dried over the polished surface of the crystal, instead of applying a aqueous solution prepared by moistening from the substance of the crystal. In this manner, there was no TlJ yellow precipitate insoluble in water to be found as an undesirable light-absorbent.

In the case of a given crystal, while e.g. a roughened surface and MgO were used, the p/v-ratio was 2, it improved to 4 by the application of the new method.

Light connection between the crystal and photo-cathode /ϵ_4/.

If the light arising in crystal NaJ/Tl/ is meant to be transferred to the photo-cathode with little loss, we have to make sure that the light does not get back into the crystal because of total reflection, Therefore it is advisable to chose the reflection-index of the connecting media in a way that they should be near values. Silicon oil marked DC200 of high viscosity between the crystal and the glass will do for this purpose.

From the viewpoint of resolving power, some authors think useful to apply a light-guide of a few mm. Its utility is manifested in that the full surface of the photo-cathode becomes evenly illuminated by its effect regardless of the site of the flash, and thus inequalities in the light-sensitivity of the photo-cathode will average. Our experiences reveal that photo-cathodes of the latest multipliers are uniform enough, consequently there is no need for a light-guide. On the contrary, it is definitely unfavourable on account of the ensuing losses.

Efficiency of the photo-cathode /δ_1/.

From the viewpoint of resolving power, photo-cathodes of high sensitivity are the most suitable. Therefore in the choice of the type of multiplier, sensitivity of the photo-cathode plays a decisive role from spectroscopic point of view. Care should be taken, of course, that distribution of colour-sensitivity should fit the emission-spectrum of NaJ/Tl/.

Collection of photo - electrons into the dynode - system /δ_2/

The good properties of photo-cathode can be turned to an advantage only of all the electrons issuing from the photo-cathode may be focused into the dynode-system. Consequently, the optimal focusing electrode-voltage has - one by one - to be found experimentally in multipliers with focusing electrodes, such as e.g. RCA 6342-A, M 12 FS, etc. In multipliers of a different type, it is also advisable to ascertain the optimal voltage between the first dynode of the photo-cathode. It is much less critical to set the voltage of the second and successive dynodes.

Other factors

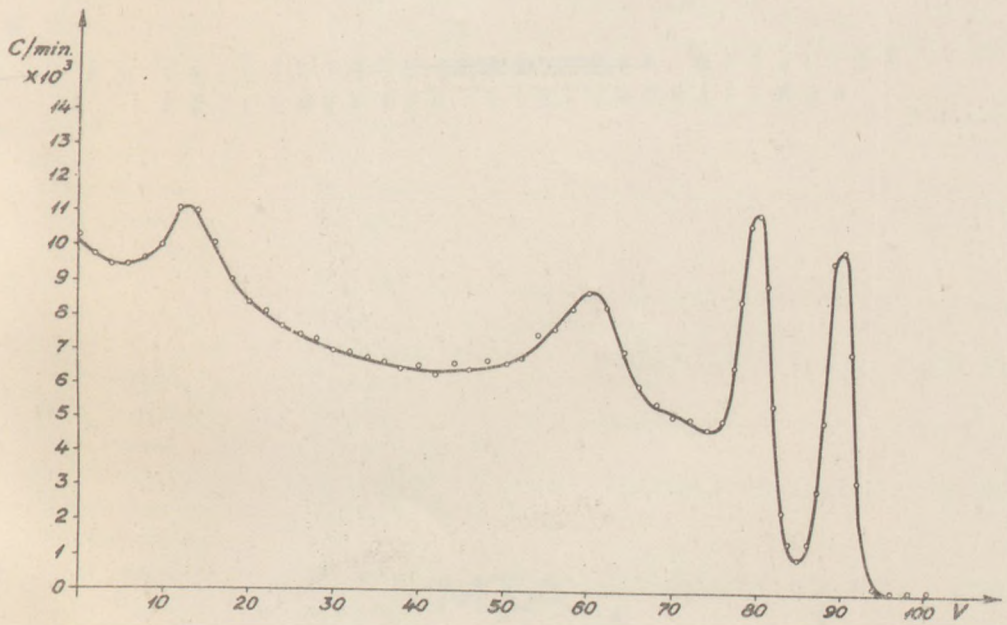

Fig. 2. Resolution of Co^{60} gamma rays using 1,5 x 1,5 inch sodium iodide crystal prepared with the described methods.

If too small an anode resistance /time constant of the integrating RC member /is chosen for the multiplier, it may effect the resolving power unfavourably. It is therefore advisable to take a few multiple of the time constant of the crystal. One-two μ sec for NaJ/Tl/. That is to say, it is important that the whole charge mounting the anode should contribute to the development of voltage-impulse.

The stability of electronic circuits, especially high voltage, as of discrimination level and channel width must also be emphasized.

Under the given conditions, p/v-relation in the case of Co^{60} is between 5 and 8, which corresponds to 7 - 6,5 % resolving power at the 0,661 MeV line of Cs^{137}.

We also have been able to achieve this value for nearly every tube or RCA 6342-A as well as for select M 12 FS tubes.- We were given the opportunity to make our choice of crystals from the products of the Institute of Medico-physics in Budapest.

It is obvious from what has been said that essential improvement in scintillation spectrometers can be expected only if we somehow manage to increase the number of electrons in the multiplier. Here, improvement can be expected only if indrusty suceeds in producing multipliers of higher sensitivity, or physicists invent a scintillator with better quantum-efficiency /ϵ_1/. A further increase of the other coefficients /ϵ_2, ϵ_3, ϵ_4 or δ_2/ cannot essentially increase resolving power, as their values approach the unit.

ATOMKI 33/1960 - 300 példány.

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