TRANSMISSION OF LIGHT CHARGED PARTICLES THROUGH SUPER-COLLIMATORS

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Abstract

The total transmission of light charged particles through supercollimators at different air pressure has been measured. Reduction in a number of light charged particles transmitted in case of increase of the air pressure has been demonstrated. It is due mainly to electron scattering at small angles by the atomic nuclei of the air and the following absorption by the walls of the collimators. The influence of energy of the light charged particles - beta-particles (^{147}Pm *and* $^{90}Sr(Y)$*) on scattering was demonstrated and the absorption coefficients were determined.*

1. INTRODUCTION

The interaction of light charged particles plays an important role in the study of their characteristics and the phenomena going along with it. Their transmission through collimators is an important aspect in the research work and its applications. In this aspect the transmission of light charged particles through tubules with narrow diameter, ensuring a higher degree of collimation of the ray of particles in comparison with collimators without third dimension, is of great importance. Some experiments have been carried out in this respect. Some of them concern transmission of gamma-particles through such kind of collimators, others – transmission of charged particles.

R.V. Paund and W. T. Vetterling have used glass tubes with inner diameter 9mm and length of 120 cm for channelling of 14,4 keV gamma irradiation of ^{57}Co as a result of reflection and resonant recoil-free absorption [1]. A collimating device has been used for the detection of radioactive contamination caused by the accident at NPP in Chernobyl in 1986 with collimating angles 15^0 and 20^0 and a scintillating detector [2,3]. Transmission, absorption and scattering of collimated beta-rays from absorbers with collimating angles of the collimators 5^0 and $2{,}5^0$ is investigated in [4].

When the ratio between the diameter d and the length of the tube L is much less than 1 $(d/L \langle\langle 1)$, the collimators are called supercollimators [5]. The small luminosity of a supercollimator can be compensated to certain extent if a large number of tubes is used. A quite interesting phenomenon – transmission of particles under very low pressure has been observed during the investigation of supercollimators with beta-rays.

Beta-rays of $^{90}Sr(Y)$ source reduce considerably their intensity after transmission through supercollimators for air thickness of $\approx 4\ mg/cm^2$, while electrons with maximum energy of ^{90}Y have maximum free range $1{,}1 \cdot 10^3\ mg/cm^2$, and for ^{90}Sr – approximately $1{,}2 \cdot 10^2\ mg/cm^2$. ^{147}Pm beta-rays cannot pass through supercollimators at all and their maximum free path is $50\ mg/cm^2$.

The main purpose of this work is to investigate transmission of beta rays through collimators at different air pressure. The exponential dependence of transmitted β-*particles of* ^{147}Pm and $^{90}Sr(Y)$ in the supercollimators on pressure has been experimentally proven. An explanation of the observed phenomenon has been suggested, in which the specific geometry of the experimental setting plays the most important role.

2. EXPERIMENTAL

The experiment for measurement of total transmission of β-particles through supercollimators is shown in Fig.1.

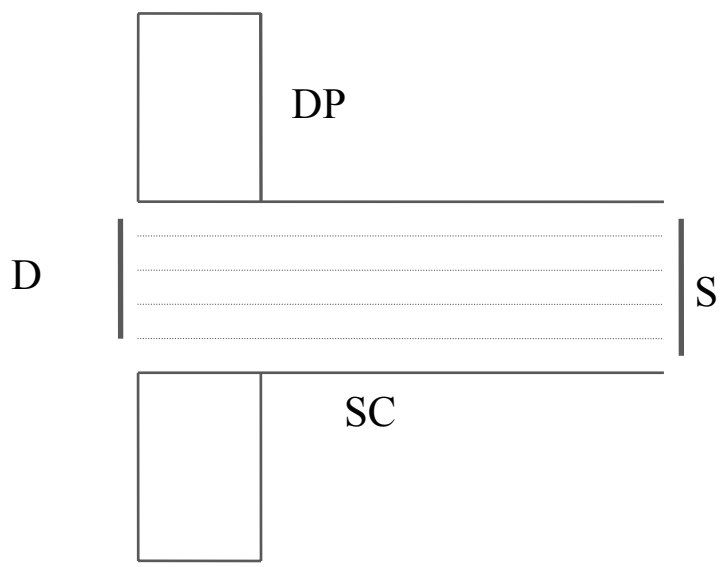


Fig.1. Experiment for measurement of the transmission of β-particles from $^{90}Sr(Y)$ and ^{147}Pm through supercollimators versus the air pressure. D – detector, SC – supercollimators, DP – diaphragm, S – source.

Supercollimators are a system of tightly arranged glass tubes with diameter $\phi 0{,}5\ mm$, length of $30\ mm$, around 350 in number inserted into a plastic shield. The diameter of shield is $15\ mm$. The collimation angle of supercollimators is $0{,}95^0$, but

for the purpose of the experiments collimators with much greater collimation angle have been used. Some experiments without supercollimators under different air pressure have been performed preserving the distance between the detector and $^{90}Sr(Y)$ source ($\approx 3\ cm$). A plastic diaphragm, with diameter $15\ mm$, $1\ cm$ thick, has been placed in front of the detector in order to eliminate the background. The distance between source-supercollimators and detector-supercollimators is about $1\ mm$.

The beta sources are not spectroscopic: $^{90}Sr(Y)$ with diameter $\phi 8\ mm$, $2{,}5 \cdot 10^5\ Bq$ (type BIS-2, for industrial applications, Russia) and ^{147}Pm, with diameter $\phi 5\ mm$, $3 \cdot 10^7\ Bq$ (type BIP-7, also for industrial applications, Russia). The detector for $^{90}Sr(Y)$ is a Si-Li planar detector with thickness $d = 3\ mm$ of the active layer, area $S = 20\ mm^2$, energy resolution for the electron conversion line of ^{137}Cs of $0{,}625\ Mev$ - $\delta E = 12 \ldots 20\ keV$, $T \approx 20^0 C$ and reverse voltage $U = 80 \ldots 100\ V/mm$. The detector for ^{147}Pm is a planar detector with thickness $d = 1\ mm$ and area $S = 50\ mm^2$, energy resolution for $0{,}625\ Mev$ - $\delta E = 12 \ldots 20\ keV$, $T \approx 20^0 C$ and reverse voltage $U = 80 \ldots 100\ V/mm$.

3. TRANSMISSION OF $^{90}Sr(Y)$ BETA-PARTICLES THROUGH SUPERCOLLIMATORS

The spectrum of that particular $^{90}Sr(Y)$ source has been investigated and the results have been reported in [5], from where it becomes clear that the source is thick enough, so that the spectrum of $^{90}Sr(Y)$, to be almost totally absorbed. This is the reason why mainly ^{90}Y β-particles reach the detector. The measurements were performed for 10 values of the air pressure with minimum air pressure $0{,}2\ torr = 0{,}026\ kPa$. The spectra of the sources for air pressure $0{,}026\ kPa$ and $95{,}32\ kPa$ and equal periods for data collection are shown on Fig.2. β-particles are better absorbed under low energies, especially under high air pressure. The difference between the two spectra of the β-particles reveals that the conditions of the experiment, i.e. the using of tubes-collimators and the variable air pressures, influence them considerably.

Spectra for different air pressure without supercollimators and for the same distance between the detector and the source have been recorded. No cconsiderable difference between the spectra at different air pressure was observed. The increase in number of the detected particles for the highest pressure and the lowest pressure is 2%. Therefore the difference in number of the detected particles for different air pressure is attributed to the specific geometry of the experiment i.e. to the supercollimators. The deviation of the β-particles at low angles in the air because of the scattering leads to their absorption in the walls of the supercollimators and to reduction in the number of the transmitted particles.

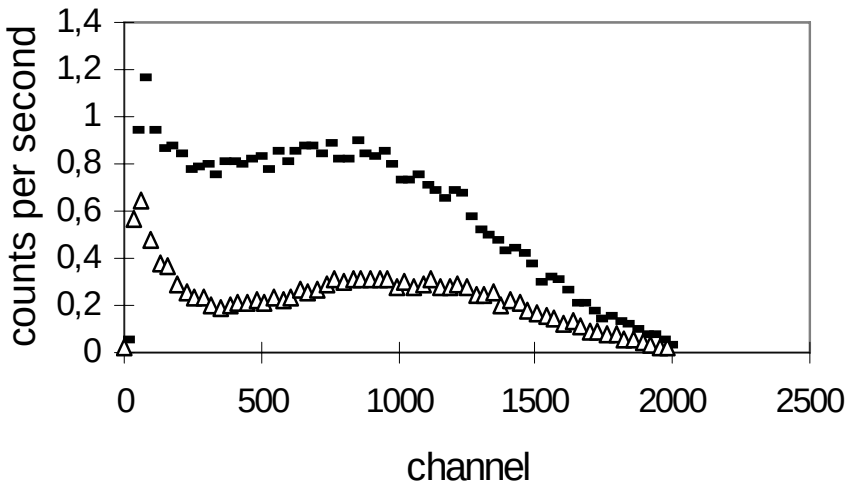


Fig.2. Spectrums of ^{90}Sr(Y) under air pressures 0,026kPa - , and 95,32kpa - Δ..

The rate of detection versus pressure is shown on Fig.3. The fitting expression is:

$$N = N_0 e^{-kp} \tag{1}$$

where k is a coefficient of absorption of the particles with dimension kPa^{-1}, N_0 is the number of the β-particles, entering the supercollimators, N is the number the β-particles, leaving the supercollimators. The value of k, defined from the data is $(0{,}00997 \pm 0{,}00021)\ kPa^{-1}$, taking into consideration that the absolute error is 2,1%. The coefficient of absorption of the particles in the collimators is $\mu = 0{,}2816\ \ cm^2/mg$ and $d_{1/2}$ layer is 2,46 mg/cm^2.

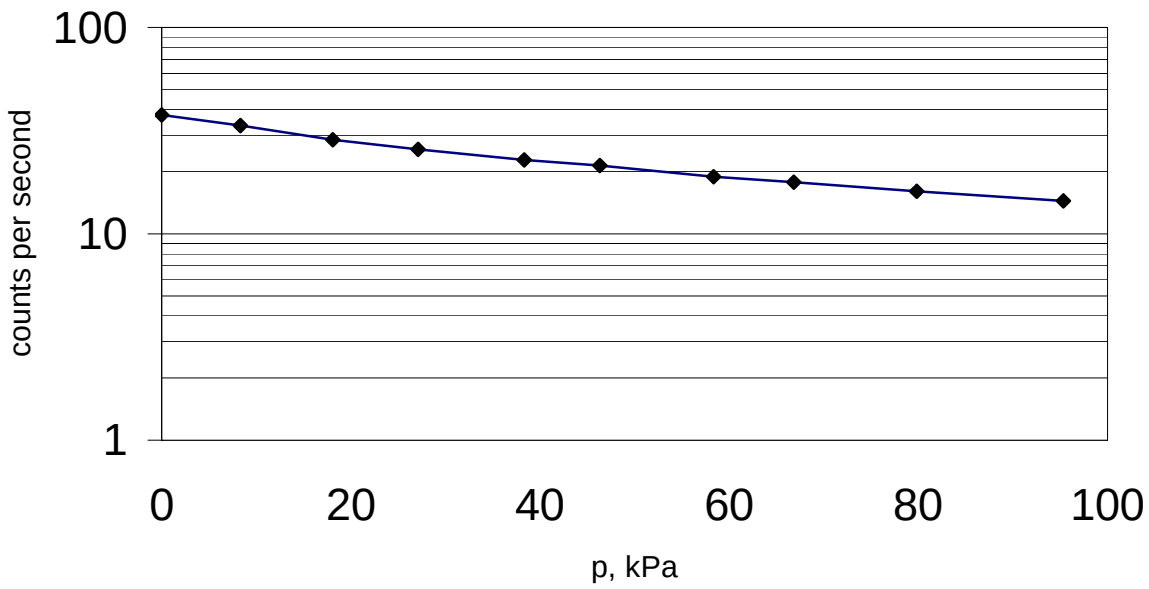


Fig.3. Dependence of the number of the impulses in logarithmic scale from the pressure in kPa for $^{90}Sr(Y)$.

The $d_{1/2}$ layer of ^{90}Y without collimators is 150 mg/cm^2 [6]. The difference is obviously due to the supercollimators. The scattering of the β-particles at low angles in the supercollimators from air cause the sharp increase of the absorption air pressure. The β-particles, scattered at low angles are absorbed from the walls of the supercollimators, because of the ratio $L/d \rangle\rangle 1$.

4. TRANSMISSION OF ^{147}Pm BETA-PARTICLES THROUGH SUPERCOLLIMATORS

On Fig.4 are shown two spectra of ^{147}Pm for pressures 0,026 kPa and 1,8 kPa and for equal collection periods. As for $^{90}Sr(Y)$, the difference between the two spectra is obvious. β-particles are better absorbed under low energies, especially under high pressure.

The rate of detection versus pressure for ^{147}Pm is shown on Fig.5.. The fitting expression is the same:

$$N = N_0 e^{-kp} \tag{2}$$

Here $k = 0{,}151$ kpa^{-1} and the mass absorption coefficient is $\mu = 4{,}271$ cm^2/mg, $d_{1/2} = 0{,}1623$ mg/cm^2. The $d_{1/2}$ layer of ^{90}Y without collimators is for ^{147}Pm

$d_{1/2} = 5{,}5 \quad mg/cm^2$ [6].

The measurements for ^{147}Pm have been performed under pressures lower than

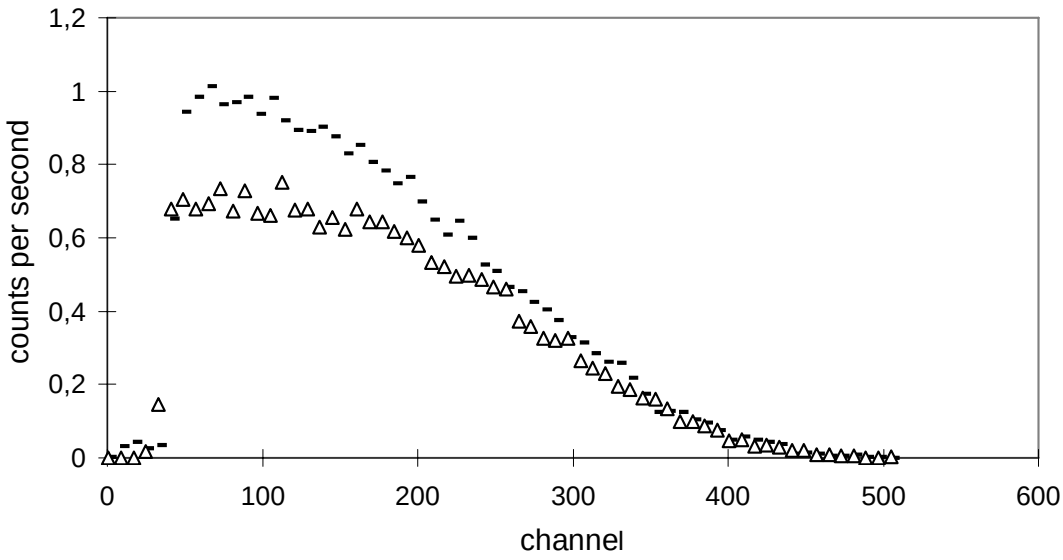
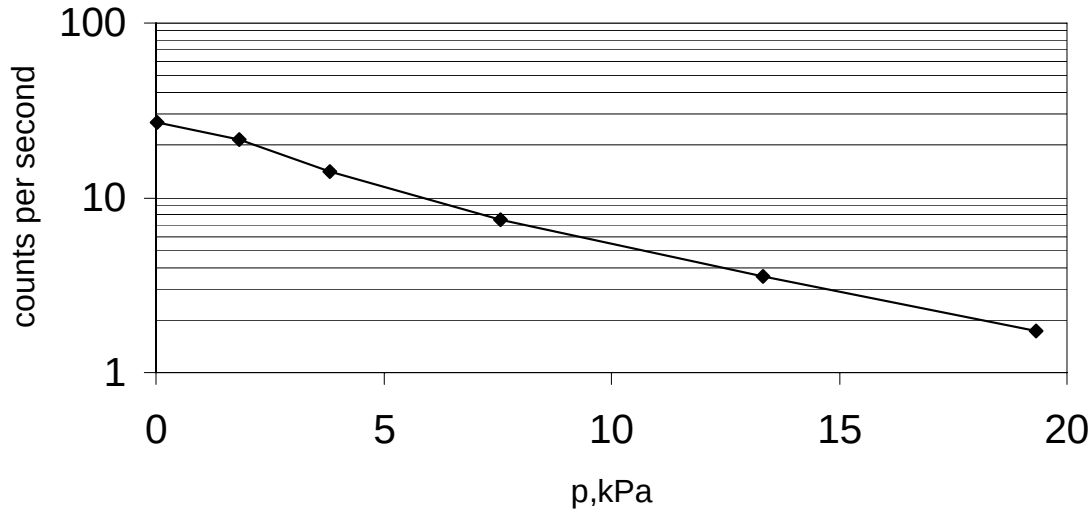


Fig.4. Spectrums of ^{147}Pm under pressures $0{,}026 \quad kPa$ - _ , and $0{,}026 \quad kPa$ - Δ.

20 kPa because the number of the detected particles is negligible for higher pressure.



Fig,5. Dependence of the number of the impulses in logarithmic scale from the pressure in kPa for ^{147}Pm .

5. DISCUSSION

For the both sources the influence of the geometry of the experiment – the supercollimators and the scattering caused by the air, however smaller in comparison with other

absorbers, causes strongly expressed reduction of intensity of the electron stream. The shielding of the scattering atomic nuclei from the atomic electrons about relativistic velocities of the falling β-electron influences in cases of lower angles in comparison with nonrelativistic electrons. In general the influence of the shielding about any angle of scattering reduces with the increase of the energy of the falling electron and with the diminution of the atomic number of the scattering atom. The difference cross section of scattering obtained with the help of the relativistic theory of the electron by Dirac, neglecting the shielding in case of scattering of an electron upon a nucleus with charge

$$d\Phi = \frac{2\pi e^4 Z^2}{4m^2 v^4}\left(1-\beta\right)\frac{\sin\theta}{\sin^4\frac{\theta}{2}}\left\{1-\beta^2\sin^2\frac{\theta}{2}+\frac{Z\pi\beta}{137}\left(\sin^2\frac{\theta}{2}-1\right)\right\}d\theta \qquad (3)$$

Z is:

where m_e is the mass of the electron at rest, v – its velocity, e - elementary charge, Z – the atomic number of the scattering center, $\beta = v/c$, c - light velocity. When $v \langle\langle c$, β tends to zero and the expression (3) becomes the classic formula of Ruderford.

The lower limit of the scattering angle in case of interaction between an electron and a scattering atom is defined from $\theta_{\min} = \lambda/2\pi a$, where $\lambda = h/p$ and $a = a_0 Z^{1/3}$ ($a_0 = h/2\pi m_e e^2$ Bohr's radius) [7]. Concerning the so defined $\theta_{\min}$ it is required the Born's approximation $2\pi Zze^2/hv \langle\langle 1$, to be fulfilled. It is valid about the β-radiation of the used radioactive isotop and the scattering centers – the atomic nuclei of nitrogen and oxygen. Only about high-energy end of $^{90}Sr(Y)$ the relation is smaller than one. When the relation L/d of supercollimators is big enough and the energy of the β-particles is small enough it will turn out that $\theta_{\min}$ is bigger than the collimation angle and all scattered particles from the center of the tube fall on its walls. The minimum angle of scattering $\theta_{\min}$ about $E_{\max} = 2{,}27 Mev$ of ^{90}Y is $0{,}24^0$ and about $E_{\max} = 0{,}224 Mev$ of ^{147}Pm is $1{,}24^0$. The collimation angle $0{,}95^0$ is greater than $\theta_{\min}$ about the maximum energy of emission of ^{90}Y, therefore the electrons with this energy leave from the middle of the tube, while the collimation angle about ^{147}Pm is greater than $\theta_{\min}$, i.e. the electrons can't leave from the middle of the tube. Therefore scattered and gone out electrons from ^{147}Pm source are just those electrons, which are scattered near enough the

end of the tube. The minimum angles of scattering and the collimation angle influence in addition the mass coefficients of absorption. This effect, together with the effect of scattering explain the difference between the mass coefficients of absorption for ^{147}Pm and $^{90}Sr(Y)$.

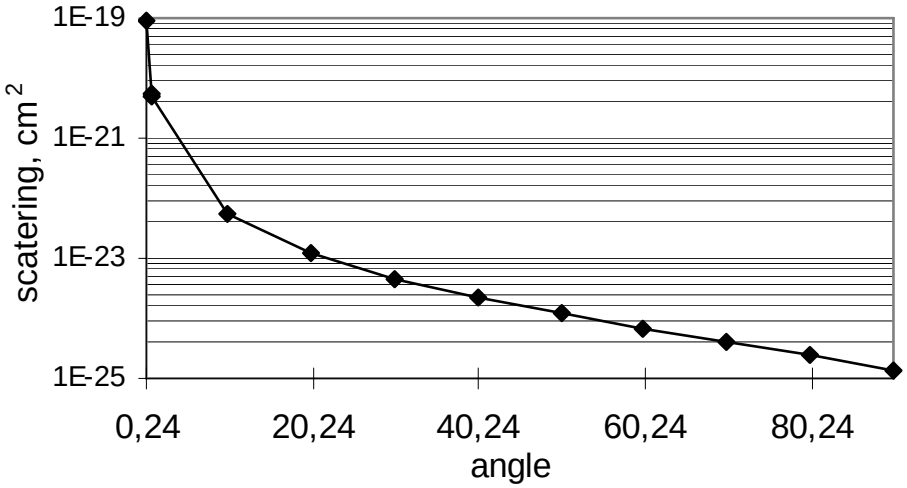


Fig.6a. The integral cross section for ^{90}Y in cases of different down integration limits, starting from $\theta_{\min} = 0{,}24^0$ to the maximum angle π for $E_{\max} = 2{,}27 Mev$.

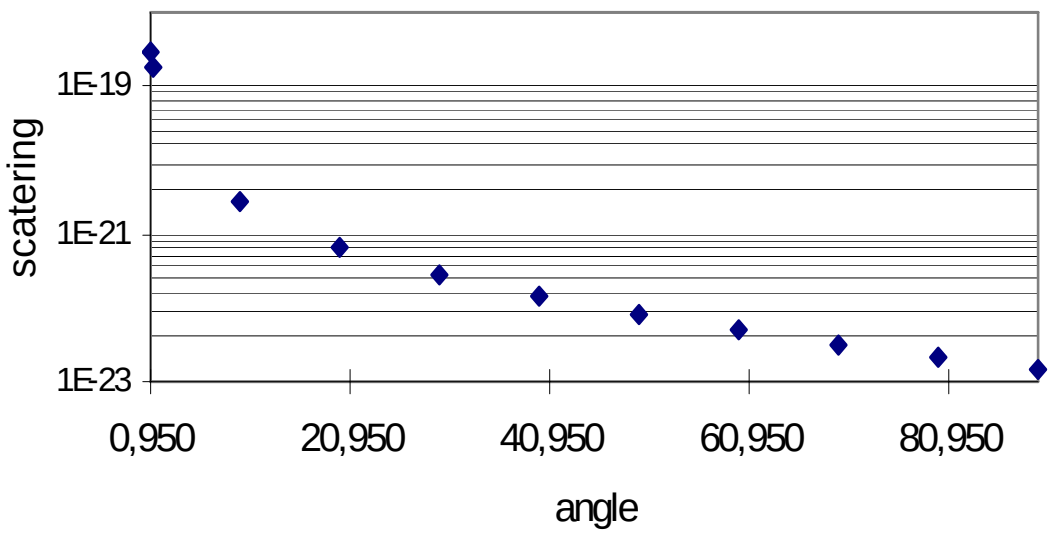


Fig.6b. The integral cross section for ^{147}Pm in cases of different down integration limits, starting from $\theta_{\min} = 0{,}95^0$ to the maximum angle π for $E_{\max} = 0{,}224 Mev$.

The integration of expression (3) is not possible about the whole angle interval from 0^0 to π for defining of the common integral cross section, but this is not necessary. The integration in the range from angle θ to the maximum angle of scattering π is enough. The dependence of the integral cross section of scattering for the maximum en-

ergy of ^{90}Y about different lower integration limits beginning from $\theta_{\min} = 0{,}24^0$ to the maximum angle π is shown on Fig.6a). The same dependence about maximum energy of ^{147}Pm is shown on Fig.6b). The collimation angle $0{,}95^0$ is included for comparison. The integral cross section of scattering includes small angles and has great values as the two charts show. It decreases quickly with the increase of the down integration limit. Having in mind the values of $\theta_{\min}$, one may conclude about the maximum values of the energies of ^{90}Y and ^{147}Pm that the decrease in the number of the β-particles is due to the scattering on low angles. As a result of it the scattered β-particles direct towards the walls of the supercollimators and they do not influence the process of transmission any more.

6. CONCLUSION

The obtained above experimental data reveal, that the change of the air pressure within the indicated interval do not influence the number of the β-particles measured without supercollimators, while their use within the same interval of the air pressure exercises considerable influence. The decrease of β-particles is due to the scattering by the air on small angles. This process directs a considerable part of the radiation towards the walls. The particles directed towards the walls reduce the number of the particles leaving the tube.

The number of the transmitted particles is described by the equations (1) and (2). The mass absorption coefficient depends on the geometry of experiment, the energy of source, the supercollimators, the detector and the geometric scales of the tubes. Besides, it depends on the kind of the gas in the tubes. Investigations on the energetic spectrum and the radial distribution of the transmitted particles are able to give additional information about their behaviour in supercollimators.

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