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ON THE POSSIBILITIES OF POLARIZED EXPERIMENTS IN PROTON (ANTIPROTON) STORAGE RINGS

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ON THE POSSIBILITIES OF POLARIZED EXPERIMENTS IN PROTON (ANTIPROTON) STORAGE RINGS

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Abstract

The possibilities of carrying out the experiments with the internal gas polarized target in the proton (antiproton) storage ring with electron cooling are discussed. The following two variants have been considered: a) injection of the polarized beam of particles into the storage ring and b) enrichment of the unpolarized beam with the particles of specific polarization, due to spin dependence of the particle loss probability in the interaction with the polarized target. The estimates of optimal operation regimes are given for the second variant.

I. In recent years the interest in the experimental studies dealing with the interactions of polarized particles has been considerably increased. Both the accelerators with polarized particles are being developed and the methods for polarized targets are being worked out in various laboratories /1/. The measurements of the elastic and inelastic interaction cross sections for pure spin states are essential for verifying numerous theoretical predictions. In the case of pp - scattering, the effects of polarization and spin correlation are large and strong dependent on the energy /2/, that may be indicative of the existence of exotic states with the double baryon charge. It would be extremely interesting to conduct similar experiments with antiproton-proton scattering.

A conventional technique of the experiment involving the polarized particle source, the accelerator with the emitted beam and the polarized target faces the serious difficulties in all sections of the facility. The beam intensity available is not sufficiently high;*) the commonly used targets /4/ are not purely hydrogenic; there are undesirable phenomena of the radiation damage and of the target depolarization under action of the beam.

2. In connection with this, it seems to be worthwhile to discuss another possibility; namely, the possibility to perform the experiments with the internal gas polarized target in the proton (antiproton) storage ring. The methodics of polarized gas jets have being intensively worked out by number of experimental groups /5/. In last years the facility with the electron storage ring and internal gas target has been succesfully used in the experiments on electron scattering by the nuclei at the Institute of Nuclear Physics of Siberian Division of the USSR Academy of Sciences /6/.

To estimate the achievable luminosity of the experiment and the degree of polarization we use the notations of the operation regimes with "thin" or "super-thin" internal targets in the charged particle storage ring. Let n be the number of particles injected into the storage ring per second. Let us assume also that just the interaction between the particles and the target is a main reason for the particle losses in the beam, whereas the interaction between the particles and the residual gas can be neglected. If the process under study has the effective cross-section σ, then the observed counting rate will be equal to

$$N = n \cdot \frac{\sigma}{\sigma_t} \qquad (1)$$

where σ_t is the total cross-section of the interaction processes knocking the particle out of the beam. The equality (1) corresponds to the fact that the relative probability for a given particle to undergo the interaction under study is equal to the ratio σ/σ_t, and therefore this is suit to both the single and multiple processes.

Under usual conditions, the particles are lost mostly due to the multiple scattering processes, which lead to increasing the transverse size and (or) energy spread of the beam and their values can exceed the permissible ones. However, if the damping mechanism exists, the damping being shorter than the particle lifetime due to multiple processes, then it proves to be possible to operate in the stationary regime with the beam parameters (size and energy spread) independent on the time. As a damping mechanism one can use the radiation damping for electrons (positrons) and electron cooling /9, 10/ for protons, antiprotons or more heavy particles. Here the total cross-section σ_t will be determined by single processes rather than multiple ones, for example, by inelastic scattering or elastic scattering at the angle exceeding certain maximum value. The maximum scattering angle depends on the cooling kinematics or on the aperture of the vacuum chamber. Such experimental conditions are generally referred to as /7/ the operation in the "super-thin" target regime in contrast to the "thin" target regime, when the multiple processes are not suppressed.

The luminosity of the experiment with the internal target according to (1) is equal to

$$L = \frac{N}{\sigma} = \frac{n}{\sigma_t} \qquad (2)$$

and independent of the target thickness, because, the particle lifetime, i.e. the number of intersections of the target by the particles, as well as the stationary current increase as the thickness is reduced.

3. Two variants for producing the polarized beam in the storage ring are possible. First, one can to inject the polarized particles from the accelerator into the storage ring. Second, it is possible to "enrich" the beam with the particles of specific polarization (faster extinction of the opposite polarization), due to the spin-dependent scattering of the particles by the polarized target /11/. Let us make some remarks

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*) Though, there exists a possibility /3/ to increase the intensity with the beams of negative H^- ions.

concerning the first variant. To this end we cite a typical quantitative example.

Let us assume that we have the internal gas target in the proton storage ring. The target is supposed to be superthin (section 2) with the 100% polarization. The polarized proton beam whose momentum, for the sake of clarity, is assumed to be equal to $p \approx 2\frac{GeV}{c}$, is injected into the storage ring. At this energy one may expect a sufficiently high efficiency of the electron cooling /3/.

The particle lifetime is determined by the total cross-section of elastic (Coulomb and nuclear) and inelastic interactions. The electron cooling mechanism becomes ineffective /12/ for the particles scattered to the angles $\theta \gtrsim (2\text{-}3) \cdot 10^{-3}$. These things may be substantially improved, if one places the target within the region of small values for β - function ($\beta = \beta_t$), while the cooling electron beam within the large β-insertion ($\beta = \beta_c$). One may have deliberately the increase factor to be equal to 10, thereby increasing a limiting value of the scattering angle up to $\theta_m \approx (2\text{-}3) \cdot 10^{-2}$. At such angles the Coulomb scattering can be neglected for the proton energy under consideration.

Assuming that cross-section, determining the lifetime of the particles, is equal to $\sigma_{el} + \sigma_{in} \approx 50_{mb}$, one obtains the luminosity $L \approx 2 \cdot 10^{25} cm^{-2} \cdot n$.

At the target thickness $10^{14} cm^{-2}$ the stationary current proves to be equal to $3.3 \cdot 10^{-8} n$ A. If one assumes that it is possible to cool the currents accumulated to 1 A, then the required injection rate is $n = 3 \cdot 10^{7} s^{-1}$, therefore the luminosity $\sim 10^{33} cm^{-2} s^{-1}$ is achieved.

In the case, when the storage ring size equals to several tens of meters and one has 1 sec injection repetition period. the time necessary for the transition to the stationary regime seems to be equal to a few hours. This time can be essentially decreased, using a higher rate of injection, which, on the present-day knowledge, may achieve 10^{10} sec^{-1}.

4. A high density of the polarized gas target ($10^{14} cm^{-2}$) is needed for the second variant, to the discussion of which we are proceeding. The point is that the polarization process calls for the time intervals exceeding the lifetime, whereas the lifetime at a high target density constitutes several hours. A large effective thickness of the target may be obtained with the facility with several gas jets along the storage ring. It should bear in mind that this will allow a simultaneous performation of some independent experiments. Moreover, a large target thickness reduces the demands made to the residual vacuum in the storage ring. Since under our conditions the particle lifetime is determined by the combination of the Coulomb and nuclear interactions, then the requirement for the effective vacuum must include a certain factor depending on Z^2 and the atomic number of residual gas nuclei. If this factor is taken to be equal to 20 (nitrogen), then in order that the residual gas influence on the particle lifetime. may be negligibly small the pressure must be much more less than 10^{-8} mm Hg. This restriction is not strong, but one needs to take into account that with decrease of the target thickness the vacuum must be improved correspondingly.

The second variant of the method is based on the injection of unpolarized particles, after that the polarization must be accumulated, due to the spin dependence of the scattering by the polarized target.

The total luminosity may be estimated just as above. In order to estimate the polarization obtained, it is necessary to know the interaction cross-sections of the projectile in certain spin states and the target possessing a specific polarization. Inelastic scattering removes the particles from the beam immediately. As to the elastic scattering, this results in the particle loss, if the scattering angle exceeds the maximum value. The experimental data on the pp - scattering at the momentum $p = 2$ GeV/c show that the elastic cross section at the angles $\theta > \theta_m = 10^{-2}$ is equal practically to the total cross-section, and the Coulomb scattering can be ignored. Then one can estimate the stationary beam polarization in terms of the total cross-sections in pure spin states:

$$\mathcal{P} = \frac{\sigma_{\uparrow\downarrow} - \sigma_{\downarrow\downarrow}}{\sigma_{\uparrow\downarrow} + \sigma_{\downarrow\downarrow}} = \frac{\sigma_{\uparrow\downarrow} - \sigma_{\downarrow\downarrow}}{2 \langle \sigma \rangle} . \qquad (3)$$

This formula follows from the obvious expression for particle number n_s for each polarization at the stationary regime

$$n_s = n \cdot \tau \propto \frac{n}{\sigma_t} \qquad (4)$$

where τ is the beam lifetime.

Using the same experimental data for $p = 2\frac{GeV}{c}$, we find $\mathcal{P} \approx 10\%$ for the transverse polarization. In the case of longitudinal polarization /2/ the information on the cross-section difference $\sigma_{\rightleftarrows} - \sigma_{\rightrightarrows}$ leads to a 16-20% polarization. This situation may be carried out with a special magnetic field configuration which must convert the longitudinal beam polarization at the point of its interaction with the target into the transverse polarization on the basic section of the storage ring /13/.

Alongside the considerations connected with the electron cooling efficiency, the proton momentum value seems favourable for the proton polarization accumulation due to the presence of noticeable peaks in cross-section differences $\sigma_{\rightleftarrows} - \sigma_{\rightrightarrows}$ and $\sigma_{\uparrow\downarrow} - \sigma_{\downarrow\downarrow}$, in this energy region. The regime, where after the processes of accumulation and polarization the energy changes so that the measurement is carried out in the desirable energy region, must be, most probably, the main operating regime. Here the target on which the scattering under study occurs may be different from that used for obtaining the polarized beam. However, the luminosity in this case becomes smaller due to the decreasing of the average injection rate (an additional duty factor arises).

5. Of course, a direct acceleration of the polarized protons and their utilization in the study of interactions with the superthin polarized target gives a higher luminosity of the experiment, compared to the polarization accumulation due to the difference of the interaction cross-sections in various spin states. At present only the second variant allows, however, to hope for performing the polarized experiments of sufficient luminosity with antiprotons /11/.

Application of this approach to antiprotons seems to be highly valuable in connection with the recently proposed schemes for antiproton accumulation at an energy of about 2 GeV and an injection rate of 10^8 particles/sec /14, 15/. In the stationary operation regime with the super-thin target the accessible luminosity may be 10^{33} cm^{-2} sec^{-1}, just as in the case of polarized protons.

Unfortunately, the presently available experimental information on the interaction of antiprotons with polarized protons is extremely poor. Within the experimental errors the difference in the cross-sections of the elastic scattering of different polarization antiproton beams by the polarized proton target may be actually considered to equal to zero. Neglecting the difference between these cross-sections in the elastic $\bar{p}p$ - scattering and assuming that for the inelastic $\bar{p}p$ - collisions this quantity has approximately the same value as for the pp - collision, we would find the estimate 4 ÷ 6 % for the resulting antiproton polarization. Practically, the difference between the spin effects in inelastic $\bar{p}p$ - and pp - collisions may prove, however, significant due to a large number of resonant reaction channels opened in the $\bar{p}p$ - collisions at $p \approx 2$ GeV/c.

6. It should be noted, that there is evidence /16/ on the nuclear enhancement of the spin asymmetry in the inelastic proton scattering. Therefore, the experiments with super-thin nuclear targets must be very useful as from the view point of the study of the nuclear effects themselves, so for the selection of nuclear targets making possible to obtain a higher stationary polarization. In particular, it is reasonable to test as a target the nuclei with a high ground state spin.

7. Let us consider in more detail the regime where one operates at the same energy at which the polarization is obtained. Up to now, the question was to obtain a maximum luminosity L. Here it is possible to calculate the stationary polarization $\mathcal{P}$. The requirements for the obtaining of highest

difference of the interaction cross-sections for various spin states is small, so that the change of the beam polarization after the transition to the count energy can be neglected. Then, similar to (6), we have

$$\Lambda = \frac{L\overline{P}^2}{L_0} = \frac{1-e^{-x_c}}{x_p+x_c}\,\frac{1}{2}\left[\frac{e^{-x_p(1+\delta)}}{1+\delta} + \frac{e^{-x_p(1-\delta)}}{1-\delta}\right]\tanh^2(\delta x_p)\ . \tag{9}$$

Considering expression (9) as a function of x_c and of the total time $x=x_p+x_c$ it is easily to see that an optimal time share connected to the counting is equal to $\frac{x_c^{opt}}{x}=\frac{\ln(x+1)}{x}$ at a fixed x. This dependence and the function $[\Lambda(x)]_{x_c=x_c^{opt}(x)}$, derived from it, are presented in Fig. 3 for $\delta=\frac{1}{6}$. At $x=3$, that approximately corresponds to equal times x_c and x_p, the curve $\Lambda(x)$ has a sharp maximum. A value Λ in the point of maximum is equal to 0.0038. The account of the accumulation time somewhat decreases this quantity. However, this loss may be reduced, carrying out the particle accumulation simultaneously with the enrichment of the beam with the particles of definite polarization.

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FIGURE CAPTIONS

Fig. 1 Dependence of the polarization experiment effectiveness Λ on a relative count rate for various values of spin interaction asymmetry.

Fig. 2 Dependence of the maximum effectiveness Λ_{max} on the spin interaction asymmetry.

Fig. 3 Optimum share x_c^{opt}/x of the counting time and corresponding effectiveness $[\Lambda(x)]_{x_c=x_c^{opt}(x)}$ of the experiment for the operation at the energy different from the polarization energy.

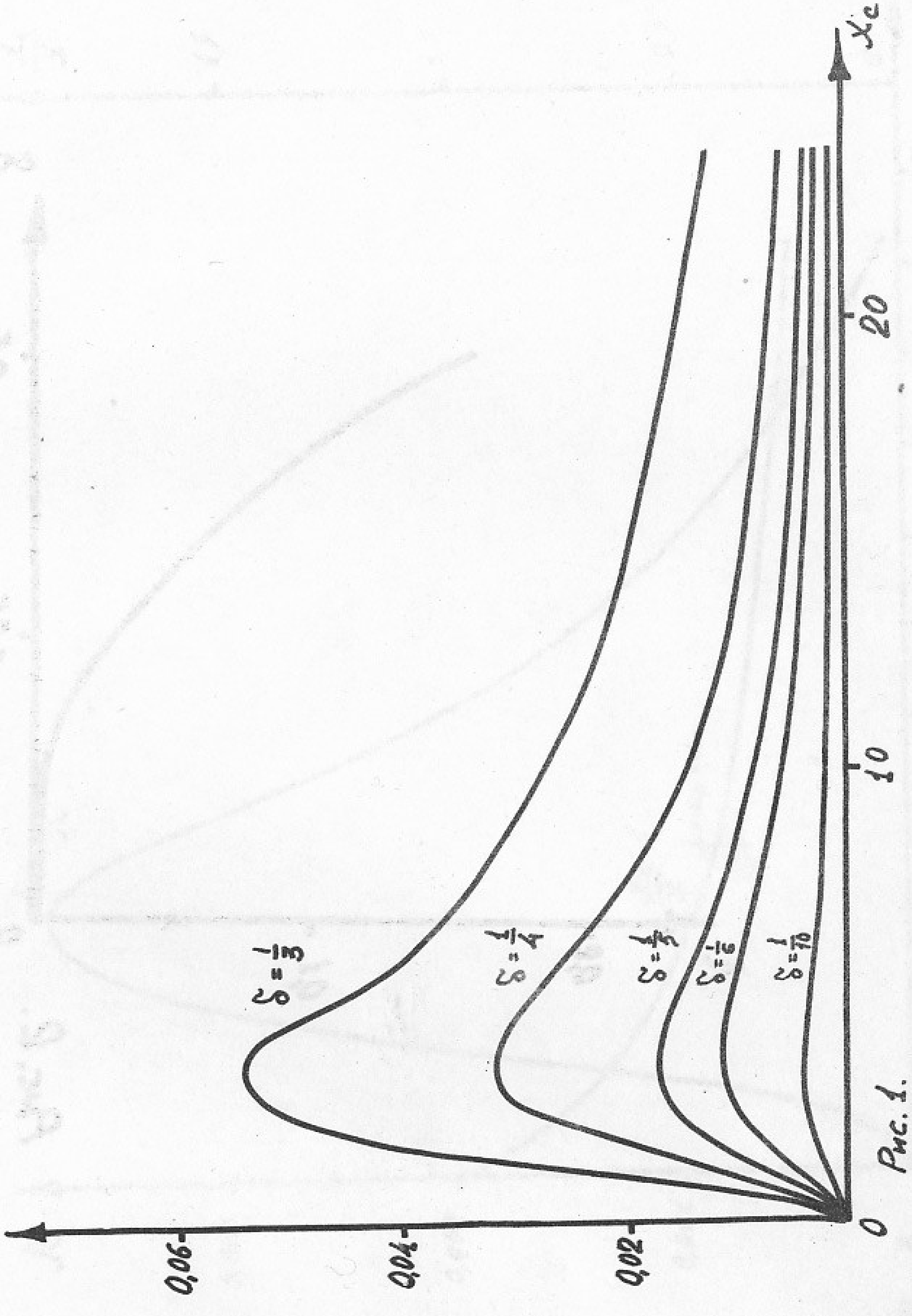
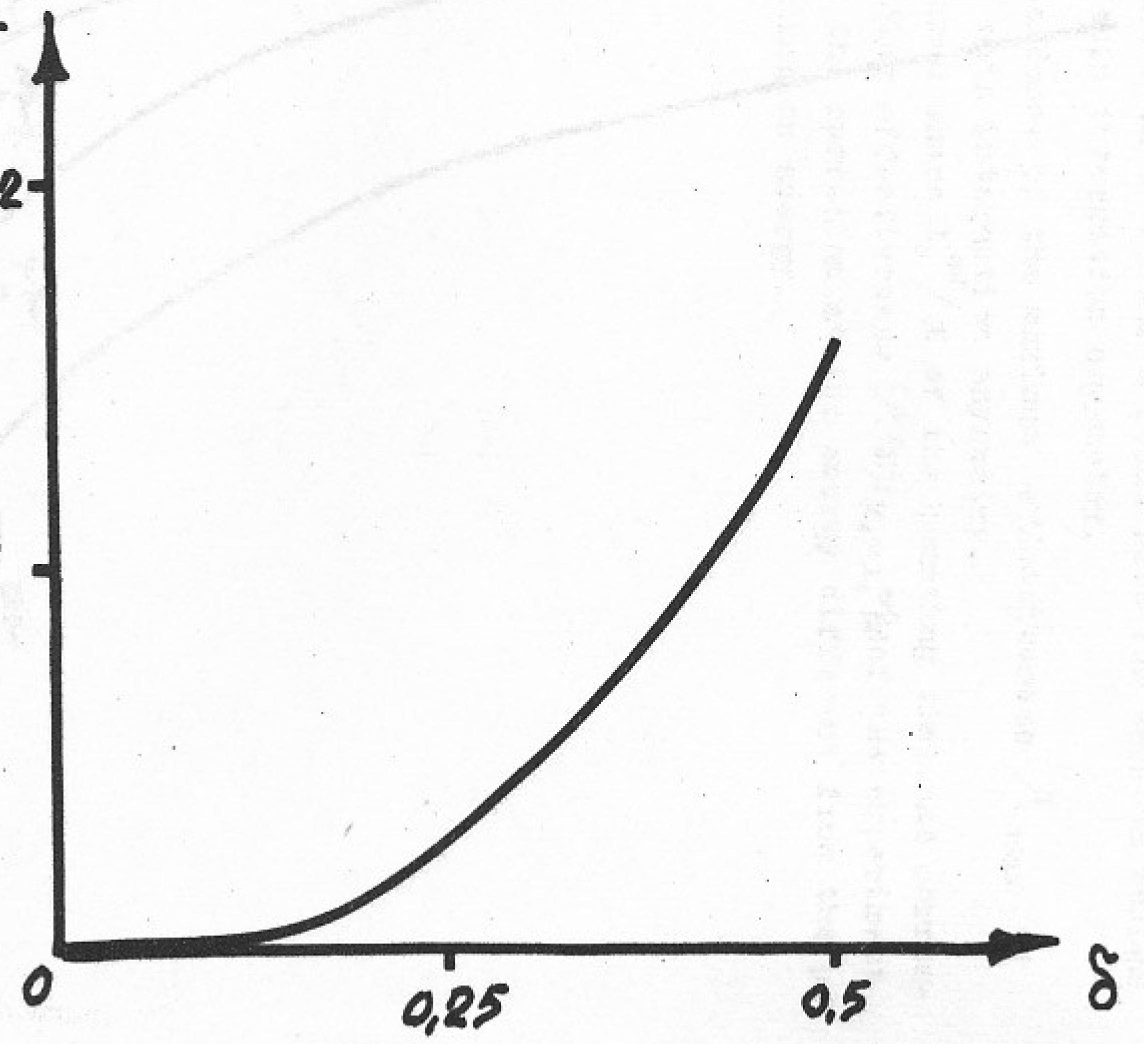


Рис. 1.


Λ
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0,1
0
0,25
0,5
δ

Рис. 2.

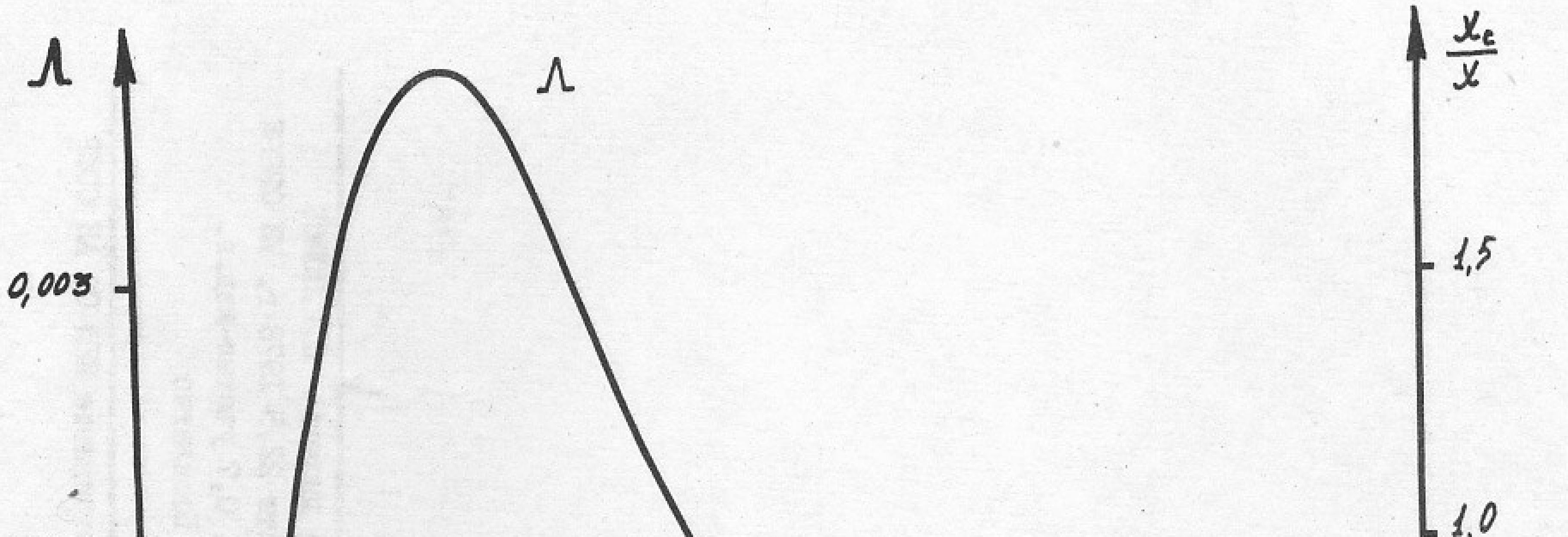
Λ
0,003
0,002
0,001
Λ
$\frac{\varkappa_e}{\varkappa}$
$\varkappa = \varkappa_p + \varkappa_e$
$\frac{\varkappa_e}{\varkappa}$
1,5
1,0
0,5
0
0
1
2
3
4
5
6
7
8
9
10
11
$\varkappa$

Рис. 3.

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