ОБЪЕДИНЕННЫЙ ИНСТИТУТ ЯДЕРНЫХ ИССЛЕДОВАНИЙ

ЛАБОРАТОРИЯ ЯДЕРНЫХ ПРОБЛЕМ

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Introduction

The investigation of stopped pion absorption in various hydrogenous substances[1,2] has shown that in this case the following processes occur:

$$\begin{array}{ll} \pi^- + p \to \pi^0 + n & \\ \qquad\qquad\;\; \hookrightarrow 2\gamma & \text{and} \qquad\qquad (1) \\ \pi^- + p \to \gamma + n, & \end{array}$$

which are analogous to those observed earlier for free hydrogen, but their probability W turned out to be essentially suppressed (for instance, for polythene CH_2 by two orders). A sharp dependence of the probability W upon the charge Z of the nucleus of the atom chemically bound with the hydrogen atom (approximately as Z^{-3}) was the most interesting feature of the phenomenon found out. Thus, when passing from LiH to CH the probability W is reduced 8 times, while Z changes only 2 times. The data available for Z - dependence of the value W were obtained in the first investigation by the relative method[2] by measuring the counting rates of γ-quanta pairs from the decay of π^0 mesons emitted from various targets of equal stopping power and in the conditions of the same experiment geometry, which eliminated a possibility of appearing essential systematic errors. Then the data were confirmed in other experiments[3].

The measurements of the absolute value of the probability W were carried out in the first experiments by methods which were not free of systematic errors in the determination of the number of negative pion stops in the target and the efficiency of γ-quanta detection. They provided different results for W_{CH_2} : $4.4\ 10^{-3}$[2], $8.4\ 10^{-3}$[4] x), $5.7\ 10^{-3}$[5] x). Even larger value of W_{CH_2} has been obtained in the experiments performed recently at CERN[3]. In order to refine the results of the first experiments we performed measurements of the value W_{CH_2} by the relative method free of the influence of systematic errors characteristic of the experiments made earlier.

Experimental Procedure

For detecting γ - quanta pairs use was made of a device containing Čerenkov total absorption spectrometers[1]. The value W_{CH_2} was found earlier by comparing the counting rates of γ- quanta pairs formed when negative pion stopped

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x) The above probability has been obtained from the probability W_{CH} found in the experiment and the known ratio W_{CH} / W_{CH_2} (see Table 3 of the present paper).

in liquid hydrogen and polythene targets/1,2/. A correction taking into account the difference in the number of negative pion stops in these targets and various target dimensions was introduced into the obtained ratio of counting rates. The measured probability W is related to the γ-quanta coincidence counting rate by

$$W = N^*_{\gamma\gamma} / N_\pi \Omega \epsilon f k s g \qquad (2)$$

where $N^*_{\gamma\gamma}$ is the number of $\gamma\gamma$ coincidences detected when negative pions stopped in the target, N_π is the number of negative pions detected by monitor counters placed in front of the target, Ω and ϵ is the solid angle and the efficiency of γ-quanta detection with spectrometers, fks is a fraction of negative pions stopped in the target, f is the factor taking into account the dependence of the number of π^- meson stops upon the target form, k - stopping power of the target determined as an integral of π^- meson range distribution $n(R)$ over the thickness of the target, s and g take into account π^- meson scattering and γ - quanta absorption in the target. Since the target densities differed by an order of a magnitude (liquid hydrogen density is only 0.07 gr/ cm^3), the above correction was large, and this was fraught with large sytematic errors.

In order to avoid these errors in the present investigations polythene targets were employed whose density was as small as that of liquid hydrogen. When measuring W_{CH_2} liquid hydrogen and "light" polythene was placed alternatively into one and the same vessel placed between spectrometers. Thus, the comparison of γ-quantum yields was performed in conditions of the same geometry and with the similar number of negative pion stops in the targets. In this case relation (2) is considerably simplified:

$$W_{CH_2} = \frac{(N^*_{\gamma\gamma})_{CH_2}}{(N^*_{\gamma\gamma})_{H_2}} \frac{k_{H_2}}{k_{CH_2}} \frac{s_{H_2}}{s_{CH_2}} \frac{g_{H_2}}{g_{CH_2}} \qquad (3)$$

and includes, besides a directly measured γ-quanta counting rate ratio, the factors which only slightly differ from unity and are determined accurately enough. So, the difference of the values g_{H_2}/g_{CH_2} and S_{H_2}/S_{CH_2} from unity in the described experiments was not larger than 2%.

Since the polythene targets had small density, γ-quanta coincidence counting rate was comparatively small. In performing the experiment it was necessary to ultimately reduce the detected background. With this aim for registering

γ-quanta coincidences use was made of a nanosecond circuit on tunnel diodes with a time resolution curve having sharp slopes/6/. In the chosen regime of operation the coincidence counting rate was reduced 50, 000 times on removing a liquid hydrogen target. When an empty glass vessel was put into a negative pion beam the detected $\gamma\gamma$ coincidence counting rate (from the negative pion charge exchange in flight) was 5,000 times smaller than in the case of liquid hydrogen.

Pion Beam, Targets

The accuracy of determination of the value k_{CH_2}/k_{H_2} depends upon the structure of negative pion beam-the higher the accuracy, the smaller the beam range spread. In order to reduce this spread the negative pion beam was formed by means of lead diaphragms placed at the exit of the accelerator chamber. The negative pion range distribution $n(R)$ measured with a telescope of scintillation counters the last of which was switched in anticoincidence, is shown in Fig. 1 (along with the negative pions, as is seen from Fig. 1, the beam has also μ^--meson admixture which was not essential in our experiments). The obtained distribution coincides with the distribution $n(R)$ found in the experiments where the dependence of $\gamma\gamma$-coincidence counting rate upon the thickness R of the filter slowing down negative pions was measured with a thin lithium hydride plate used as a target. (Fig. 1).

In measuring W_{CH_2} polythene targets of various density were employed. In order to prepare targets use was made of small thinwalled polythene cylinders fastened on 0.01 gr/ cm^3 styrofoam rods. The relative stopping power of the targets $q = k_{CH_2}/k_{H_2}$ was varied from 0.5 to 2. In the most unfavourable case ($q = 2$) the error in W_{CH_2} caused by the inaccuracy in the determination of the range curve $n(R)$ was as small as 3%. The accuracy of determination of q was 4%.

Substances used as target material, according to certified data, did not contain noticeable contamination. For additional checking of their purity test experiments were carried out in which the values of W' for targets made by pressing polythene of small density and styrofoam (CH) were compared directly with the value W_{CH_2} for a target of polythene the chemical composition of which was exactly known. All the targets had similar stopping power, their sizes practically coincided. The obtained results, $W'_{CH_2}/W_{CH_2} = 1.02 \pm 0.06$ and $W'_{CH}/W_{CH} = 1.2 \pm 0.2$, show that materials used for making targets of small density were of sufficient purity.

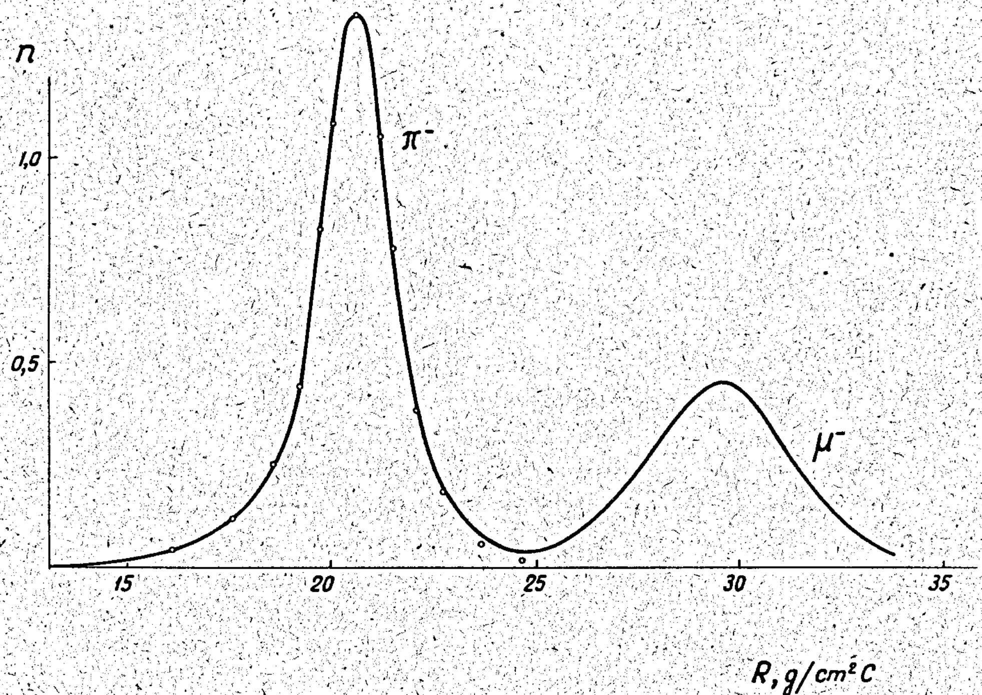

Fig.1. Meson range distribution. Curve – the dependence $n(R)$ measured with a telescope. o– π^- meson stops in a thin lithium hydride target.

Determination of W_{CH_2} by the Relative Method

In order to determine the values of $N^*_{\gamma\gamma}$ the $\gamma\gamma$ coincidence counting rates $N_{\gamma\gamma}$ were measured with various thickness of R of the filter slowing down negative pions (Fig. 2). Some experiments were repeated at sharply reduced negative pion beam intensity, which allowed to be convinced in the absence of nonlinear instrumental effects. The values of $N^*_{\gamma\gamma}$ were found by taking into account a small contribution from negative pion charge exchange in flight /2/. The obtained dependences $N^*_{\gamma\gamma}(R)$ are shown in Fig. 3. The comparison of these dependences with the curves calculated basing on the measured pion range distribution and on the distribution of pion stop points in the target /2/ makes it possible to additionally check the validity of the determination of the factor $q = k_{CH_2}/k_{H_2}$ in formula (3). With increasing the density of the polythene target the maximum of the curve $N^*_{\gamma\gamma}(R)$ is shifted to smaller values of R, and the curve width δ is increased. As is seen from Table 1, the measured and calculated widths δ and the maximum shifts ΔR_{max} are well consistent.

Table 1

Target	q	ΔR_{max}, gr/cm^{2}C		δ, gr/cm^{2}C	
		Experim.	Calculated	Experim.	Calculated
Polythene	1.80	-0.43 ± 0.08	-0.46 ± 0.05	3.1 ± 0.3	3.2 ± 0.1
Polythene	1.40	-0.26 ± 0.08	-0.22 ± 0.05	2.8 ± 0.3	2.7 ± 0.1
Polythene	1.15	-0.30 ± 0.10	-0.08 ± 0.05	2.7 ± 0.3	2.5 ± 0.1
Hydrogen	1	0	0	2.5 ± 0.2	2.3 ± 0.1
Polythene	0.96	-0.01 ± 0.08	$+0.02 \pm 0.05$	2.5 ± 0.2	2.3 ± 0.1
Polythene	0.62	$+0.20 \pm 0.10$	$+0.18 \pm 0.05$	2.1 ± 0.2	2.1 ± 0.1
Styrofoam	0.07	$+0.25 \pm 0.15$	$+0.35 \pm 0.05$	–	2.0 ± 0.1

In determining the values q and $N^*_{\gamma\gamma}$ from the measured values a small con-

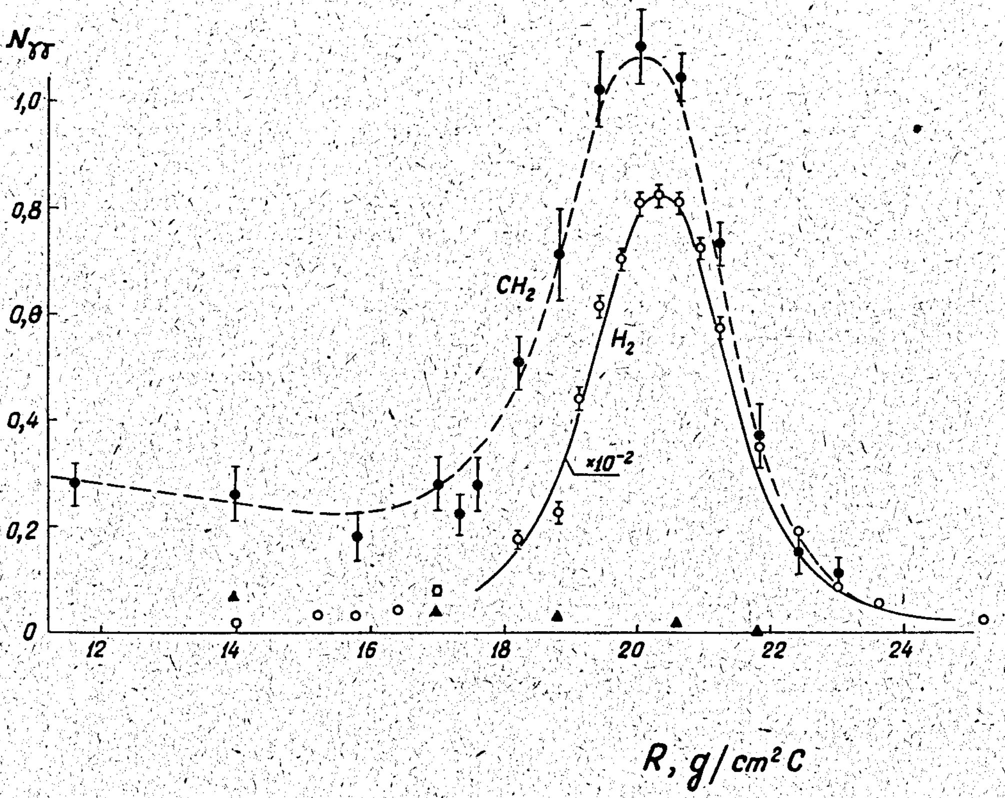

Fig.2. $\gamma\gamma$ -coincidence counting rate $N_{\gamma\gamma}$ with various thicknesses R of a filter slowing π^- mesons down.
o - a liquid hydrogen target (scale: 1:100).
● - a polythene target with q=1.15,
▲ - an empty vessel. Curves - the calculated dependences $N_{\gamma\gamma}$ (R).

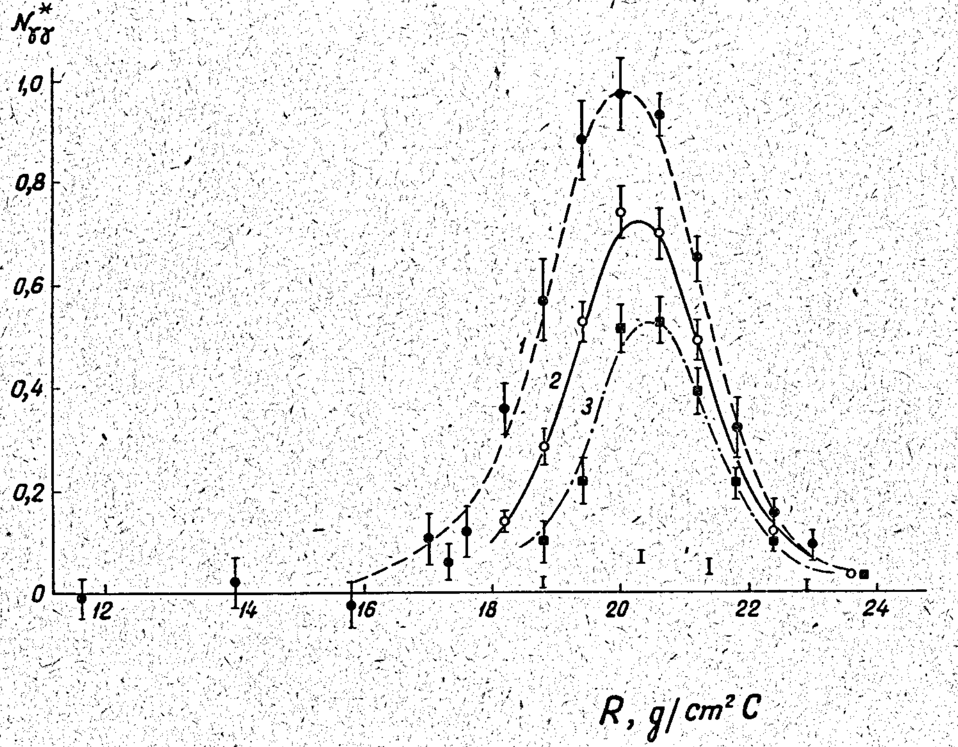

Fig.3. Gamma-quanta yield from negative pion stops in polythene targets with q=1.15 (●), 0.96 (o) and 0.62(■). Curves 1-3 - the calculated dependences $N^*_{\gamma\gamma}$ (R), I - a styrofoam target, q=0.07.

tribution due to styrofoam rods was subtracted. The corresponding correction to W_{CH_2} was from 1.5 to 5%. W_{CH_2} found with various values of q turned out to be equal to each other (Fig. 4). The probability of negative pion absorption by hydrogen nuclei bound in polythene was found to be

$$W_{CH_2} = (9.6 \pm 0.9)\ 10^{-3}.$$

Side by side with the determination of W_{CH_2} by the relative method the measurements of W_{CH_2} were carried out which were analogous to the earlier ones/2/. In this case the ratios of the yields of γ - quanta from liquid hydrogen and "normal" polythene targets were compared. With the account of the measured target formfactors f and other factors entering into formula (2), the value W_{CH_2} was obtained to be

$$W_{CH_2} = (9.2 \pm 1.3)\ 10^{-3}.$$

The last value is two times larger than the value of W_{CH_2} obtained earlier by the same method/2/. The reason for this was an arithmetic error made in calculating the ratio of the number of π^- meson stops in liquid hydrogen and polythene targets. The use of the correct π^- meson range curves changes the earlier obtained results by $W_{CH_2} = (7.7 + 1.3)\ 10^{-3}$, which is in agreement with the data of the present paper.

Simultaneously with the measurements of W_{CH_2} the relative measurements of the probability W for lithium hydride (LiH), styrole (CH) and water were performed. The values W_{LiH}/W_{CH_2} and W_{CH}/W_{CH_2} coincided with those found earlier/2/, the value W for water turned out to be somewhat larger

$$W_{H_2O}/W_{CH_2} = 0.25 \pm 0.04.$$

Measurements with a γ - Telescope

Along with the above-described measurements the experiments have been performed in which the value W was determined on the basis of measurements of the γ -quantum flux from the target by means of a γ - telescope with a known efficiency. γ - quanta produced in the lithium hydride target when negative pions stopped in it were collimated with a lead diaphragm and hit the lead convertor. Electron-positron pairs produced in the convertor were detected with a scintillation counter and a Čerenkov spectrometer placed behind the convertor and connected to a fast coincidence circuit together with counters registering

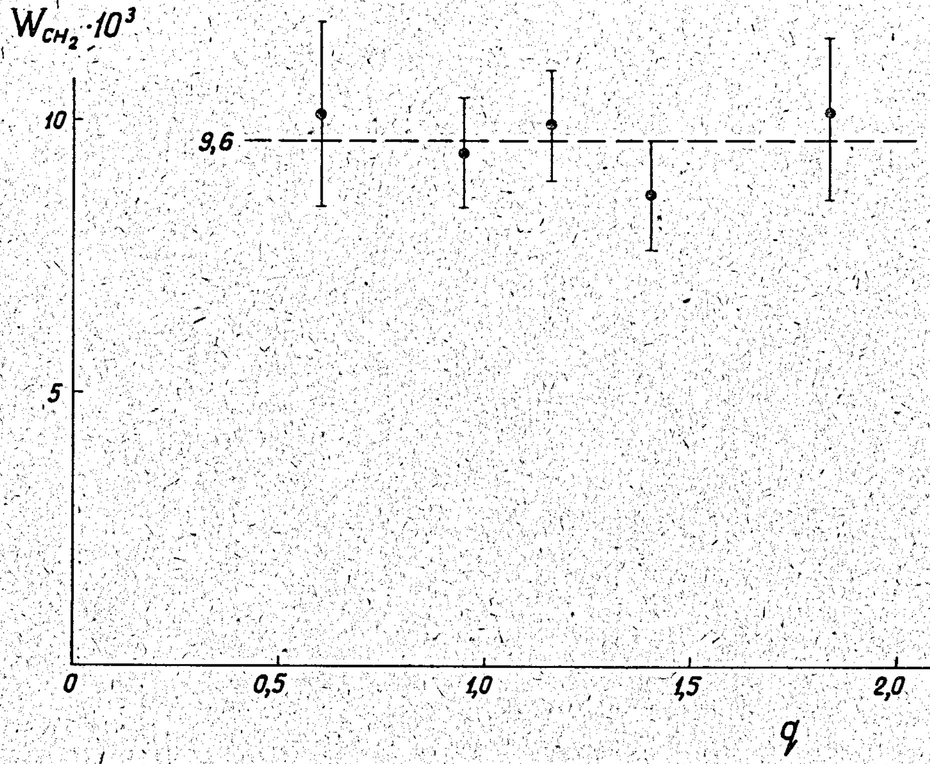

Fig.4. The values W_{CH_2} found with various values of q.

negative pion stops. In order to reduce the background between the convertor and the diaphragm an anticoincidence scintillation counter was placed. The adjustment of the γ-telescope and test measurements were made with a liquid hydrogen target. On removing the target from the beam the γ-telescope counting rate was reduced 500 times; "convertor in / convertor out" ratio was 15-20. The measurements were carried out with convertors 3 and 5 mm thick.

The γ-telescope efficiency ϵ was determined basing on the experiments performed with a monoenergetic electrons. For $d = 3$ mm it turned out to be 0.24 ± 0.01. The γ-telescope efficiency ratios found experimentally for convertor thicknesses $d = 3$ and 5 mm proved to be the same in the case of lithium hydride and liquid hydrogen targets and were as follows:

$$\epsilon(d=5\,mm)/\epsilon(d=3\,mm)\Big|_{experim.} = 1.35 \pm 0.05,$$

which coincides with the calculated ratio

$$\epsilon(d=5\,mm)/\epsilon(d=3\,mm)\Big|_{calcul.} = 1.33 \pm 0.02.$$

The number of π^- meson stops in the target was determined by the same method as in measuring the range curve (see above).

Test experiments confirmed the validity of the determination of the apparatus efficiency and the absence of noticeable systematic errors: the measured value W_{H_2} turned out to be

$$W_{H_2} = 1.07 \pm 0.14 .$$

The value W_{LiH} was determined by the subtraction method basing on the measurements of γ-quanta yields from targets made of lithium hydride and lithium. It was found to be $(3.0 \pm 0.4).10^{-2}$. For the targets employed $W_{CH_2}/W_{LiH} = 0.35 \pm 0.02$, hence

$$W_{CH_2} = (10.4 \pm 1.5).10^{-3},$$

which is in good agreement with the value W_{CH_2} obtained by the relative method.

Discussion

The value obtained in the present experiment by various methods for the probability

$$W_{CH_2} = (9.6 \pm 0.8).10^{-3}$$

differs one and a half time from that obtained at CERN/3/ (see Table 2). The reason for this discrepancy is, probably, the overestimation of the accuracy of the efficiency determination/3/ which was obtained by calculations.

Table 2

Paper	W_{CH_2}, 10^{-3}
Nuovo Cimento 28, 99, 1963	$(4.4 \pm 0.4) \rightarrow 7.7 \pm 1.3$ x)
Phys. Letters 2, 23, 1962	8.4 xx)
Phys. Rev. Lett. 9, 400, 1962	5.7 xx)
Phys. Lett. 5, 67, 1963	13.9 ± 1.5
The present paper:	
a) measurements by the relative method	9.6 ± 0.9
b) measurements by the method/2/	9.2 ± 1.3
c) measurements with a γ-telescope	10.4 ± 1.5

x) A corrected value (see above).

xx) See a footnote on page 1.

The probability W ratios for various substances obtained earlier/2/, in the present paper and in the experiments at CERN/3/ are in good agreement (Table 3).

Table 3

Target	LiH		CH_2	CH	H_2O	$C_4O_2H_8$
JINR x) W, 10^{-3}	25 ± 3	29 ± 4 xx)	9.6 ± 0.8	3.8 ± 0.5	2.4 ± 0.4	3.0 ± 0.4
JINR/2/ W, rel. units	2.6 ± 0.2	3.1 ± 0.3 xx)	1	0.39 ± 0.04	0.25 ± 0.04 x)	0.31 ± 0.04
CERN/3/ -"-	2.8 ± 0.3	-	1	0.39 ± 0.05	-	-

x) Data of the present paper.

xx) With the account of a small admixture of absorbed water.

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