MASS OF THE ISOTOPE Pu^{239}

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A measurement of the mass of the plutonium isotope was done in a mass spectrometer[1] with a resolving power of 60,000 — 80,000. To determine the mass of the plutonium isotope we used doublets obtained with the help of organic compounds of different composition. These compounds consisted of the elements H, C^{12}, and O^{16}, whose masses had been measured earlier rather carefully.[1] By determining the isotope's mass by direct comparison with the mass of the organic compounds it was possible to avoid a series of intermediate measurements and thus significantly improve accuracy. We used two organic compounds to produce the doublet pair. In the first case we used alizarin ($C_{14}H_8O_4$, M = 240) giving fragments at mass 239. The second line of the doublet was formed by fragments of the organic compound perylene ($C_{20}H_{12}$, M = 252) having the composition $C_{19}H_{11}$. Ion formation occurred in an arc ion source whose basic discharge was maintained in helium. Pairs of plutonium and organic compounds moved into the discharge by the evaporation of these substances in crucibles of special construction.

The differences ΔM of the masses of the doublets and the corresponding value of mass of the isotope Pu^{239} are shown in the table. The final

Doublet	ΔM, mmu	Mass, Pu^{239}, mu
$Pu^{239}—C_{14}H_7O_4$	18.448±0.082	239.128922±92
$C_{19}H_{11}—Pu^{239}$	33.447±0.067	239.128695±74
		average: 239.128784±165

mass value of the isotope Pu^{239} was calculated taking into account the "weight" of the measurements. For comparison we point out that the value of the Pu^{239} mass obtained from nuclear reactions[2] (there were no mass-spectrometer measurements available up to that time) was 239.126999 ± 150.* The mass of Pu^{239} calculated from data on nuclear reactions with corrections for the more accurate value of isotope Pb^{208},[3] was 239.128025 ± 155.* The disparity between the value of the mass of the isotope Pu^{239} we obtained and the value obtained from calculations on nuclear reaction data is equal to 0.759 amu. This somewhat exceeds double the magnitude of total error of both measurements. It is interesting to note the following fact. The difference between our value and the value obtained by calculation from nuclear reaction data for the isotope U^{238} is equal to 1.035 + 0.120 mmu,[4] and for the isotope Pu^{239} is equal to 0.759 ± 240 mmu. In addition, the deviation for the difference of the masses of Pu^{239} and U^{238} calculated by our data from the corresponding value according to nuclear reaction data is 0.166 ± 0.250 mmu, that is, it is within the limits of experimental error. In our case, the masses of the isotopes Pu^{239} and U^{238} were measured quite independently, but the nuclear measurements are connected by a continuous chain of Q values. Therefore, we may assume that the error ~ 1 mmu was a result of inaccurate values in the Q values that connect the reference isotope Pb^{208} with the isotopes Pu^{239} and U^{238}. This assumption is confirmed by the fact (see references 3 and 4) that deviations of difference values between our values and the nuclear values increase the farther one gets from the standard Pb^{208}, both on the side of an increase in A, and on the side of a decrease in A.

*Error actually equal to ± 1000μ mu.

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SOME CHARACTERISTICS OF THE ANNIHILATION OF AN ANTIPROTON IN THE DEUTERON

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As Pontecorvo has already noted,[1] aside from the usual annihilation of the antiproton in one of the nucleons of the deuterium nucleus, the so-called single-meson annihilation process is also possible, where part of the energy released during annihilation is transmitted directly to the remaining nucleon

$$\bar{p} + d \rightarrow p + \pi^-; \quad (1)$$

$$\bar{p} + d \rightarrow n + \pi^0. \quad (2)$$

Obviously, the relative probability of reactions of this type will be determined not only by statistical factors, but also by the character of the annihilation interaction, of which little is yet known. Not going into the details of the existing models of the annihilation interaction, it would be natural to assume that the relative probability of these processes would be not less than the relative probability of the reaction (taking into account statistical factors)

$$\pi^+ + d \rightarrow p + p, \quad (3)$$

whose cross section for π^+ mesons with momentum ~ 130 Mev/c is ~ 10% of the total π^+d-interaction cross section.[2] At lower bombarding-particle momentum, the contribution of processes of a similar type, which include both nucleons of the deuterium nucleus, will evidently be even greater.

It is quite possible that the observable number of "no-meson" annihilation stars in emulsions (~ 5%)* is a result of the fact that in a number of cases the energy of annihilation is transmitted directly to the nucleons. For more solid conclusions we would have to have statistically richer experimental data and also an analysis of the energy distribution of nucleons emitted during annihilation.

It is easy to convince oneself that isotopic spin invariance predicts a quite definite relation between the reaction cross sections for formulas (1) and (2), namely $d\sigma_1/d\sigma_2 = 2$. We point out, however, that a deviation from this relation can be caused not only by a failure of isotopic spin invariance but also by the emission of the hypothetical ρ^0 meson with zero isotopic spin during annihilation:

$$\bar{p} + d \rightarrow n + \rho^0. \quad (4)$$

Moreover, if π^0 and ρ^0 mesons have the same structure as for instance in the Fermi-Yang model, where π^0 and ρ^0 can be described as symmetrical and antisymmetrical functions respectively of the type

$$\pi^0 = (p\bar{p} + n\bar{n})/\sqrt{2},$$

$$\rho^0 = (p\bar{p} - n\bar{n})/\sqrt{2},$$

then, in this case the relation between the reaction cross sections in (1), (2) and (4) will be $d\sigma_1 : d\sigma_2 : d\sigma_4 = 2:1:3$ (with accuracy to the relative mass differences of π^0 and ρ^0 mesons). If in this process the π^0 and ρ^0 mesons actually cannot be distinguished experimentally, then the "neutral" annihilations in formulas (2) and (4) can turn out to be twice as large as for the "charged" annihilations in (1).†

We note that besides reactions (1), (2) and (4) during the annihilation capture of an antiproton by a deuteron, we can also have pair production of strange particles

$$\bar{p} + d \rightarrow \Sigma^- + K^+, \quad (5)$$

$$\bar{p} + d \rightarrow \Sigma^0 + K^0, \quad (6)$$

$$\bar{p} + d \rightarrow \Lambda^0 + K^0. \quad (7)$$

A study of the relative probability of these processes makes it possible to check isotopic spin invariance and also the correctness of the distribution of strange particles in charge multiplets associated with it. Charge independence requires that the ratio of the cross sections for reactions (5) and (6) be $d\sigma_5/d\sigma_6 = 2$. If we accept the Gell-Mann and Pais hypothesis[5] on symmetry in strong interactions, a hypothesis by which all baryons, including hyperons, emerge as isotopic doublets

$$N_1 = \left|\begin{matrix}\Sigma^+ \\ Y^0\end{matrix}\right|, \quad Y^0 = (\Lambda^0 - \Sigma^0)/\sqrt{2} \text{ and } N_2 = \left|\begin{matrix}Z^0 \\ \Sigma^-\end{matrix}\right|,$$

$$Z^0 = (\Lambda^0 + \Sigma^0)/\sqrt{2},$$

then in this case, we have the additional relation $d\sigma_6 \approx d\sigma_7$ [with an accuracy $\delta = (m_\Sigma - m_\Lambda)/m_\Lambda \approx 0.07$]. Reactions (5) – (7) can be easily identified experimentally since in this case the hyperon and the K meson are emitted at an angle of 180° with very definite energies ($E_K \approx 0.7$ Bev, $E_\Lambda \approx 0.5$ Bev, $E_\Sigma \approx 0.44$ Bev).

By similar processes, the production of cascade hyperons is also possible:

$$\bar{p} + d \rightarrow \Xi^- + K^+ + K^0,$$

$$\bar{p} + d \rightarrow \Xi^0 + K^0 + K^0.$$

I take this opportunity to express my gratitude to L. I. Lapidus, B. M. Pontecorvo, and R. M. Ryndin for their suggestions and also to D. Miller who was kind enough to give me experimental results before publication.

*The estimate of this quantity, made on the basis of available data,[3] includes corrections for $\pi^\pm$ self absorption in the emulsion nuclei, and excludes the cases when only neutron mesons are emitted (based on data on annihilation of antiprotons by hydrogen; D. Miller, private communication).

†The existing experimental data of D. Miller and others (which are still skimpy statistically) give no grounds as yet

for assuming that a noticeable number of hypothetical ρ^0 mesons is emitted, in addition to π^0 mesons, in the annihilation of the antiproton by the proton.[4]

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RESULTS OF A MODEL OF THE p-p INTERACTION AT 10 Bev

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EARLIER we developed an idea for a model of the process of multiple production.[1,2] To check the efficiency of the proposed model we made up a table of 200 random stars formed in p-p interactions at 10 Bev.[3] The table included the processes of multiple production of from 1 to 6 mesons according to statistical theory with the assumption of the existence of isobars. We are now publishing some results on the formation of stars from the table.

Figure 1 shows the obtained momentum spectrum of nucleons and mesons in the c.m. system (for comparison the smooth curve shows the same spectrum calculated in the usual way).[4] Figure 2 shows the momentum spectra of protons, π^+ and π^- mesons in the laboratory system.

The table of random stars allowed us to obtain theoretical values of the quantities for which calculation using the usual methods is difficult. Figure 3 shows the distribution of angular divergence between the charged particles in the stars in both systems (in plotting the distribution we included all $m(m-1)/2$ angles between m rays of the star). We also obtained the angular distribution between projections of rays onto a plane normal to the axis of interaction (Figure 3). This distribution is convenient because it does not change under a transformation from one system to the other. We note that with peripheral interactions, the angles $\sim 0°$ and $\sim 180°$ must occur more often than in the distribution obtained in reference 5.

Gramenitskiĭ and others[6] measured the corre-

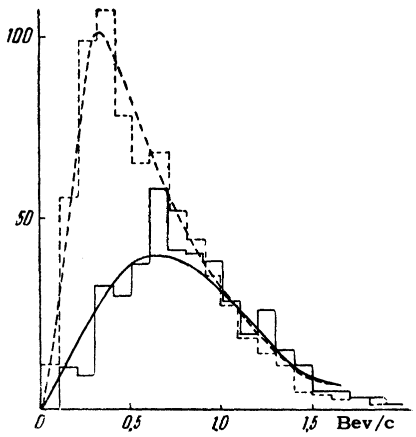

FIG. 1. Solid lines denote nucleons, broken lines denote mesons.

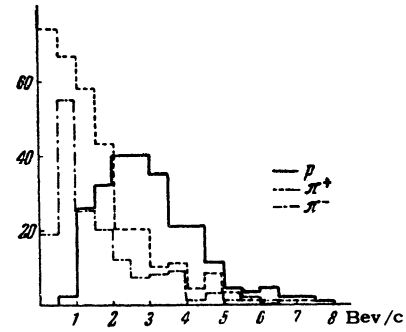

FIG. 2

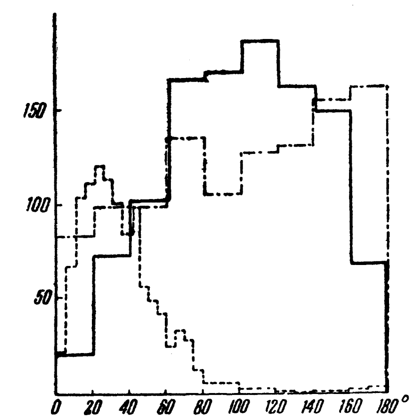

FIG. 3. Dot-and-dash lines show the spectrum of angles between projections of rays onto the plane normal to the axis of interaction; solid line shows the spectrum of angles between rays in the c.m. system; dotted line shows the same in the laboratory system.