Mean Free Path of the Particles Produced in Nuclear Explosions and Comparison between Explosions in C and Pb

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We give here the preliminary results of a cloud-chamber research made during the spring and summer of this year at the Laboratorio della Testa Grigia (3500 meters above sea level). There were two aims of our research: (a) Measurement of the mean free path in Pb for nuclear interaction of the penetrating particles of nuclear explosions; (b) comparison of the nuclear explosions produced in nuclei of different size (C and Pb) so as to have an experimental choice between the different theories of meson production.[1]

Our experimental disposition is given in Fig. 1. The cloud-chamber expansions were controlled with G-M counters. At least one counter in the tray *A* and at least two counters in each of the trays *B*, *C*, and *D* had to be discharged. In the cloud chamber (32 cm in diameter and 10 cm of illuminated depth) there are seven Pb and C plates, of the thicknesses indicated in the figure. Present results were obtained from a total of 1980 photographs taken in 570 hours of measurement.

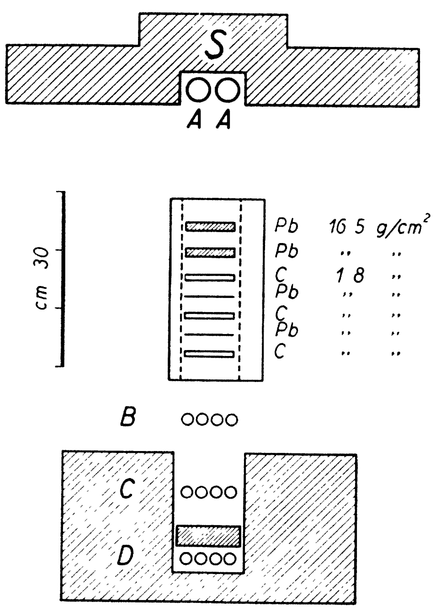

Fig. 1. Arrangement of apparatus.

(A) In the 223 nuclear explosions produced in the lead *S* above the cloud chamber (so-called penetrating and mixed showers) we counted 614 penetrating particles which traversed the Pb plates of the cloud chamber for a total of 23,300 g/cm². On the other hand, we counted 29 nuclear explosions produced by these penetrating particles in the Pb plates of the cloud chamber, and 7 scatterings with a projected angle $\geqslant 10°$. Hence we obtained an uncorrected mean free path $\lambda_{unc}=650$ g/cm².

The nuclear explosions produced inside the cloud chamber were recognized (i) by the emission of at least two particles, one of them at least heavily ionizing, (ii) by the emission of at least four relativistic particles from a thin plate, (iii) by the emission of two penetrating particles at least from the first thick plate. The events (i) are by far the highest percentage. Our λ_{unc} is certainly larger than the true value, for the larger part of the nuclear explosions were produced in the thick plates, but a part of them were not revealed because they did not emerge with heavily ionizing particles. The simultaneous presence in the cloud chamber of 16.5 and 1.8 g/cm² Pb plates enabled us to correct the above value of the mean free path. Let us consider only the nuclear explosions revealed on the basis of criterion (i). The probability p_t to reveal a nuclear explosion in the thin plates by criterion (i) is rather close to unity; on the basis of previous works[2] we have estimated it at about 0.85. To estimate the probability p_T of revealing a nuclear explosion in the thick plates on basis of criterion (i) we have assumed (as appeared directly) that all the nuclear explosions observed in the cloud chamber and produced by ionizing particles in the thick and thin plates (55 and 17 nuclear explosions respectively) are of the same type as those produced by the penetrating particles of a preceding nuclear event in the Pb *S*. Thus it resulted:

$$p_T=0.85(55\times 1.8):(17\times 16.5)=0.3.$$

On the basis of the above values of p_T and p_t, and introducing a further small correction to take into account the instrumental selection in favor of the nuclear explosions with successive production, we could calculate $\lambda=300$ g/cm², with a possible error of ± 30 percent. This value is in a good accord with that which we estimated (350 g/cm²) by a less direct correction in a preceding work.[3] Later, Fretter[4] published a maximum mean free path of 750 g/cm², in agreement with our uncorrected value.

Fretter too, in his measurements, revealed the nuclear explosions with criteria (i) and (iii). On the basis of the

[1] W. Heitler and L. Jànossy, Congress of Como (1949); W. Heisenberg, Congress of Como (1949); G. Wataghin, Phys. Rev. **74**, 975 (1948), and **75**, 693 (1949).

[2] Harding, Lattimore, and Perkins, Proc. Roy. Soc. **A196**, 325 (1949); Bridge, Hazen, Rossi, and Williams, Phys. Rev. **74**, 1083 (1948).

[3] Lovati, Mura, Salvini, and Tagliaferri, Nuovo Cimento **6**, 207 (1949) and Nature **163**, 1004 (1949).

[4] W. B. Fretter, Phys. Rev. **76**, 511 (1949).

TABLE I. Number of nuclear explosions observed in the thin C and Pb plates, distributed according to the number of relativistic particles.

$\diagdown n$	0	1	2	3	4	5	6	7	8	9	10
C	8	11	5	3	6	3	2	2	1	—	—
Pb	1	5	12	9	10	7	5	—	—	—	1

results of Powell and co-workers[5] we evaluated the number of the events of type (i) observed by Fretter. Then we estimated his probability corresponding to our p, finally obtaining for him $\lambda = 360$ g/cm^2, which is rather consistent with our value of λ.

It is rather probable that the penetrating particles of the nuclear explosions be mainly π-mesons and protons. If we should admit, on basis of Piccioni's result,[6] a mean free path for the π-mesons larger than the geometrical at least by a factor say 4, it could be deduced that about $\frac{1}{3}$ of the penetrating particles emitted in the nuclear explosions at 3500 meters above sea level are protons.

(B) In Table I the distribution is given of the nuclear explosions produced in the three C and in the two Pb thin plates, according to the number of relativistic particles. Our statistics are still insufficient, and the theories are too qualitative. We only note here that we obtained an experimental ratio,

$$\frac{\text{nuclear explosions with } n \geqslant 4 \text{ relativistic particles in C}}{\text{nuclear explosions with } n \geqslant 4 \text{ relativistic particles in Pb}} = 0.6 \pm 0.3.$$

(For $n \geqslant 4$, the numbers of nuclear explosions in C and Pb may be directly compared, for their revelation (criterion ii) is independent of the presence of the heavy ionizing particles.) This result seems to indicate that many nucleons may be accelerated to a relativistic velocity in a nuclear explosion, eventually giving rise to mesons, at least in the nucleus of Pb. In fact, should the nuclear explosions be a single nucleon-nucleon impact inside a nucleus, than we should have, assuming geometrical cross sections for the production of nuclear explosions, a value of 3.5 for the above ratio. This value might vary from 3.5 to 2, owing to the transparency of the C nucleus.

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[5] Brown, Camerini, Fowler, Heitler, King, and Powell, Phil. Mag. **40**, 862 (1949).

[6] O. Piccioni, Congress of Como (1949).