The action of the *C-neutrons* on rhodium gives an unexpected result. Within the thermal region, the ratio of activities varies from 10.38±0.12 to 9.23±0.10 for paraffin-distances from 2 to 10 cm. This shows the existence of different capture levels in the *C*-neutron band, which seems to be due to resonances within the thermal region. Such resonances have already been proposed by others[7] and seem to be the more probable for Rh as this element has a resonance level at 1.33 ev which is close to the thermal region.

In this part of the experiments too, the ground state is favored by the higher energies, which is the same as observed in the resonance region.

The existence of different *C*-neutron capture levels seems to be confirmed by the different values obtained for the mean square distance of each isomer

$\langle r^2\rangle_{\mathrm{Av}}=267.0$ cm^2 for the 4.2-min Rh isomer,
$\langle r^2\rangle_{\mathrm{Av}}=263.1$ cm^2 for the 44-sec Rh isomer,

this value corresponding to the highest energy.

Finally we may notice that for fast neutrons (source without paraffin) the ratio of the isomer activities for bromine[6] was found to be 2.1 and for rhodium[5] about 6. The latter value was confirmed by us.

IV. CONCLUSIONS

If there is a single neutron capture level for nuclear isomers, this single level can but form both isomers in a invariable proportion.

As the ratio of the isomers varies with the distance from the source, there is evidence for the existence of *more than one* capture level. This is true for the resonance neutrons in bromine and perhaps in rhodium, whereas for rhodium, resonance levels seem to extend within the region defined by the *C*-neutrons. These views are confirmed by the fact that: (a) corresponding migration distances differ and (b) the ratio of the isomers certainly is different for resonance and for *C*-neutrons.

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An Experiment on the Anomalous Scattering of μ-Mesons by Nucleons

E. AMALDI AND G. FIDECARO
Istituto di Fisica della Università, Centro di Studio per la Fisica Nucleare del C.N.R., Rome, Italy

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Large angle scattering of fast μ-mesons by an iron plate, 6 cm thick, has been investigated by means of a counter-hodoscope which recorded separately two energy bands: from 200 Mev to 320 Mev kinetic energy, and from 320 Mev to infinity. About half a million incident μ-mesons were counted. Upper limits for the cross sections for anomalous scattering were obtained: about 4.5×10^{-29} cm^2/nucleon for the low energy band; about 2.3×10^{-30} cm^2/nucleon for the high energy band. Also an upper limit for the cross section for production of penetrating showers by μ-mesons at sea level is given. We found a cross section of 10^{-30} cm^2/nucleon for showers of at least two particles of which at least one is emitted at an angle larger than 20° with a range of at least 7 cm Fe+5 cm Pb.

I. INTRODUCTION

In a previous paper[1] we pointed out that the investigation of anomalous scattering of μ-mesons by nucleons seems unnecessary because of the well known experiment of Conversi, Pancini, and Piccioni, which showed that μ-mesons at rest interact very weakly with nucleons. However, it is not evident that the conclusions regarding the nuclear interactions between μ-mesons almost at rest and nucleons can be extrapolated to the case of μ-mesons with kinetic energy around several hundred Mev. In fact, Evans and George, and George and Trent,[2] working at sea level, under a clay thickness equivalent to 60 m water, found a local production of stars and penetrating showers which had to be due to μ-mesons. The corresponding cross section for these effects turned out to be of the order of 10^{-29} cm^2/nucleon; i.e., a value enormously larger than that expected according to the calculations of Fermi, Teller, and Weisskopf[3] on the capture of slow mesons by light nuclei. It is still smaller, however, than the lowest value yet obtained by means of direct observation of the anomalous scattering.[4] For these reasons we thought the anomalous scattering of mesons at sea level to be worthy of investigation. Some of the results reported here have already been published elsewhere.[1]

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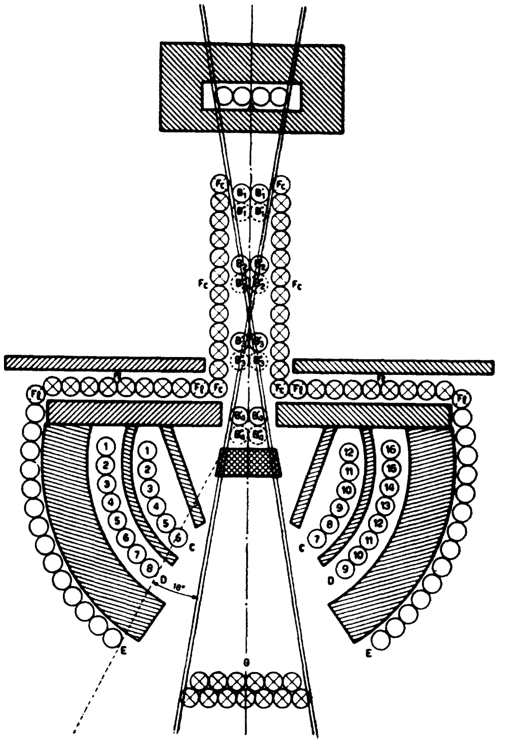

FIG. 1. A scale diagram of the experimental setup.

II. PROCEDURE

The equipment used is shown in Fig. 1. The solid angle of the incident particles was defined by either of two telescopes, B' or B'', placed one behind the other. These trays were mounted in this way in order to increase the intensity without increasing too much the lack of angular definition in the direction perpendicular to the plane of the figure. Counters A were in parallel and were placed under 15 cm Pb and above 5 cm Pb, so that the soft component was eliminated. F_c+F_l was an anticoincidence set of counters for lateral protection. The 6-cm thick scatterer covered almost exactly the solid angle defined by the two telescopes B' and B''. The counters of C and D were connected to a hodoscope of neon lamps which gave some rough information concerning the direction of motion of the scattered particles. A layer of Pb 2.5 cm thick was placed in front of counters C and a second layer of 2.5-cm Pb was placed between counters C and D. Counters E were all in parallel and separated from counters D by 10 cm of Pb. Counters G were connected in parallel.

By means of suitable circuits we counted the following types of events:

$$N_1 \rightarrow A+B' \text{ (or } B'')+(C+D)-F-G.$$
$$N_2 \rightarrow A+B' \text{ (or } B'')+G+(C+D)-F.$$
$$N_3 \rightarrow A+B' \text{ (or } B'')+G-F.$$
$$N_4 \rightarrow A+B' \text{ (or } B'')+(C+D)+E-F-G.$$

Pictures of the neon lamps of the hodoscope were taken for all events of types N_1, N_2, and N_4. N_3 represents the total number of particles crossing either of the telescopes B' or B'', and the scatterer. N_1 and N_4 are the numbers of particles scattered at angles larger than 18°, N_1 including all particles that had a minimum range of $\sim$7 cm Fe+5 cm Pb after the collision, N_4 including those that had a minimum range of $\sim$7 cm Fe+15 cm Pb. If the scattered particles were μ-mesons, the corresponding minimum kinetic energies before the collision are $T_\mu \simeq 200$ Mev and $T_\mu \simeq 320$ Mev.

III. RESULTS

The results of three sets of measurements are given in Table I. In the first set we used a Pb scatterer in order to have an appreciable multiple Coulomb scattering. In the third set of measurements the incident mesons were filtered with a brick layer about 200 g/cm^2 thick, sufficiently wide to insure that the solid angle defined by the two telescopes B' and B'' was completely covered.

Before trying to use the data of Table I to give an upper limit to the anomalous scattering cross section of μ-mesons by nucleons, we must consider several other effects which could contribute to the number of scattered particles (Table II). The geometry of the equipment was so chosen that the multiple Coulomb scattering[5] was quite appreciable in the case of Pb but negligible in the case of Fe. The single Coulomb scattering has been calculated under two assumptions: we considered, first, Fe and Pb nuclei of finite size,[5] and second, individual point charge protons as scatterers. The number of scattered protons is rather uncertain, because its calculation involves the number[6] and energy spectrum[7] of protons present in the cosmic radiation at sea level, and their differential cross section for elastic collisions against nucleons.[8]

TABLE I. Experimental results.

Set of measurements	Absorber	Scatterer 6 cm thick	Total time, t, in hours	Number of incident particles per min, N_3/t	Total number of incident particles, N_3	Total number of scattered particles $200 \leq T_\mu \leq 320$ Mev N_1-N_4	$T_\mu \geq 320$ Mev N_4
1	...	Pb	230 hr 16 min	5.33 ± 0.02	73,769	13	0
2	...	Fe	765 hr 10 min	5.44 ± 0.01	249,168	3	3
3	200 g/cm^2	Fe	706 hr 23 min	4.84 ± 0.01	204,914	1	0

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[6] Adams, Anderson, Lloyd, Rau, and Saxena, Rev. Mod. Phys. **20**, 334 (1948); B. Rossi, Rev. Mod. Phys. **20**, 537 (1948).

[7] B. Ferretti, Nuovo Cimento **6**, 379 (1949).

[8] Hadley, Kelly, Leith, Segrè, Wiegand, and York, Phys. Rev. **75**, 351 (1949); F. Rohrlich and J. Eisenstein, Phys. Rev. **75**, 705 (1949).

From Table II we see that it is possible that none of the very few particles scattered by Fe were μ-mesons; rather, all were protons. In order to state an upper limit for the anomalous scattering cross section of μ-mesons by nucleons it would be necessary to know the expected number, $\bar{N}_p$, of scattered protons for each of the two bands of energy. We think that a conservative evaluation of such an upper limit is obtained if we assume for $\bar{N}_p$ the values given in Table III. With this assumption and from the observed number of incident μ-mesons, one can conclude that it is very improbable that the anomalous scattering cross section is larger than the following values:

$$\begin{aligned}\text{for } 200 \leq T_\mu \leq 320 \text{ Mev} &= 4.5\times 10^{-29} \text{ cm}^2/\text{nucleon},\\ \text{for } 320 \leq T_\mu \qquad &= 2.3\times 10^{-30} \text{ cm}^2/\text{nucleon}.\end{aligned}$$

Such a conclusion is correct provided that the hypothetical anomalous scattering of μ-mesons does not deviate too strongly from an isotropic distribution in the center-of-mass system.

TABLE II. Number of counts expected as a result of events which are different from anomalous scattering of μ-mesons by nucleons.

	Pb, first set of measurements		Fe, second set of measurements		Fe, third set of measurements	
	Low energy band	High energy band	Low energy band	High energy band	Low energy band	High energy band
Observed counts	13	0	3	3	1	0
Expected counts due to: (calculated)						
Chance coincidences	0.01	0.04	0.04	0.13	0.04	0.10
Multiple Coulomb scattering	7	0	<0.04	0	0	0
Single Coulomb scattering by nuclei	0.07	0.007	0.26	0.026	0.21	0.021
Single Coulomb scattering by protons	0.18	0.23	0.48	0.62	0.39	0.51
Scattered protons	1.3	0.6	3	1.5	0.9	0.4

We now consider the events of type N_2, which have not yet been discussed. An event N_2 is recorded when one or more particles cross the telescope $A+B$ (or B') $+G$ and not the anticoincidence F, and give rise in the scatterer to at least one particle crossing the hodoscope $C+D$. The particle crossing the hodoscope must be emitted at an angle of at least 20° with an energy large enough to cross at least 5 cm Pb.

Three types of events contribute to N_2; electronic secondaries of single penetrating particles, penetrating showers generated by protons, and penetrating showers generated by μ-mesons. Adding together the results of the second and third sets of measurements, we have $N_2=39$ for about 4.5×10^5 incident mesons of $T_{0\mu}\geqslant 100$ Mev.

While the correction for chance coincidence is quite small for events of type N_1 and N_4 (Table II), in the case of events of type N_2 such a correction reduces the observed value of N_2 by about one-half. An upper limit of the value of the cross section for the production of penetrating showers by μ-mesons can be obtained by assuming that the contribution to N_2 from secondary electrons and penetrating showers generated by fast protons is negligible. Under this assumption one obtains $\sigma \sim 10^{-30}$ cm²/nucleon for production, by μ-mesons, of penetrating showers with at least two particles of which at least one is emitted at an angle larger than ~20° with a range larger than ~7 cm Fe+5 cm Pb.

TABLE III. Numbers used for the mean values of the scattered protons.

	$\bar{N}_p$	
	Low energy band	High energy band
Second set of measurements	2	1
Third set of measurements	0	0

In this calculation we have used the total number of incident mesons, i.e., all mesons for which $T_\mu\geqslant 100$ Mev. It is evident that mesons of this low energy cannot produce events of the type N_2. We note, however, that the μ-meson spectrum is flat in the region of a few hundred Mev and that a shift of 100 Mev of the minimum kinetic energy, $T_{0\mu}$, corresponds to an increase in the given cross section of only 5 percent. Thus the upper limits for the cross sections would have to be increased by perhaps 20 percent. This correction would be beyond our limits of accuracy.

The cross sections for anomalous scattering and for the production of showers by μ-mesons can be compared with the results of Evans and George, and of George and Trent.[2] Our cross sections are appreciably lower than those given by these authors. The difference, however, could be due to the much higher energy of the incident μ-meson in the experimental conditions of these authors. Under a layer equivalent to 60 m of water, the mean energy of μ-mesons is about 1.4×10^{10} ev while at sea level it is of the order of 0.9×10^9 ev.

George and Evans[2] interpret their results as due to the electromagnetic interaction of the incident μ-meson with the nuclear meson field. According to this scheme one would expect a cross section for μ-mesons at sea level at least 10 times smaller than at 60 m water equivalent.

A more detailed account of the experimental arrangement and of the evaluation of the measurements will be published elsewhere.[9]

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[9] E. Amaldi and G. Fidecaro, Nuovo Cimento (1950) (in press).