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Calculations on Meson Production by Photons. M. L. Goldberger.

Calculations have been made by the speaker and K. Brueckner on the meson production by photons. The calculations are based on the present rather uncertain meson theories and therefore blind credence should not be given the numerical results that are presented.

When photons of sufficient energy impinge on nucleons, mesons are produced. The threshold energy for the production of mesons is

$$E_\gamma = \mu c^2 \ (1 + \mu/2M) \cong 157 \text{ Mev.}$$

where μ represents the mass of the meson, μ = 286 electron masses, and M, the mass of the nucleon involved.

One must consider two possibilities for the production of mesons; a photon may interact with a neutron to expel a negative meson and a proton:

$$\gamma + n \Rightarrow p^+ + \mu^-,$$

or else a photon may interact with a proton with the subsequent emission of a neutron and a positive meson

$$\gamma + p^+ \Rightarrow n + \mu^+.$$

In each case two mechanisms must be considered. First one considers the possibility that the nucleon is in a tentative state of dissociation, the neutron into a proton and a negative meson, and the proton into a neutron and a positive meson, that is made final by the addition of the photon energy which compels a complete separation of the particles. By analogy this mechanism might be termed the photoelectric process. It is pictorialized in Figs. 1a and 2a.

The second manner of interaction between photon and nucleon is described by the name "shaking off". In Fig. 1b, the shaking off of a proton is diagrammed and in Fig. 2b a positive meson is shaken off by the action of the photon.

In the situations illustrated by Fig. 1 the existence of two charge concentrations of opposite polarity imply a non-zero dipole moment. In Fig. 2, however, one deals in general with a spherical distribution of positive charge and therefore, the dipole moment vanishes. Since the proton in Fig. 2b is regarded as being at rest, its momentum vanishes and this distinguishes this case from the others.

By calculation and experiment it is found that the number of negative mesons exceeds that of positive mesons when the meson energy is less than 40 Mev. The only place in the calculations where an asymmetry between the two processes for the production of mesons might find an expression is in the interaction of the photons with the nucleon charge. The two terms of the Hamiltonian (non-relativistic form) that are affected are

$$\frac{\vec{P} \cdot \vec{A}}{Mc} + \mu \vec{\sigma} \cdot \vec{H}$$

where $\vec{P}$ is the momentum vector, $\vec{A}$ is the vector potential, μ is the magnetic moment, $\vec{\sigma}$ the Pauli spin matrix and $\vec{H}$ the magnetic field vector.

In the case $\gamma + M \Rightarrow p^+ + \mu^-$, both terms contribute to the Hamiltonian whereas in the case $\gamma + p^+ \Rightarrow n + \mu^+$ both terms vanish since $\vec{P}$, the momentum vector, is zero for a proton at rest and μ, the magnetic moment, is also zero.

The numerical results of the calculations are briefly summarized as follows:

		Scalar Meson Theory	Pseudo Scalar Theory	Vector Theory
no. μ^-/no. μ^+	E = 157 Mev	1.34	1.34	.97
	E = 300 Mev		1.60	

(These values do not depend on the unknown coupling constant g between nucleons and mesons. However, to obtain the following results it was necessary to make a guess as to the value of g.)

The Cross Section for the Production of Mesons

	Scalar Theory	Pseudo Scalar Theory	Vector Theory
σ_t for 300 Mev monochromatic γ rays	4×10^{-29}	18×10^{-29}	
$\int \frac{\sigma_t}{E}\, dE$ Bremsstrahlung spectrum	1.7×10^{-29}	11×10^{-29}	

The angular distribution was calculated on the basis of scalar meson theory and was found to vary roughly as $\sin^2\theta$ in the center of mass system. The graph of Fig. 3 shows a comparison of the total cross section for monochromatic x-rays as a function of the energy of the quanta for the scalar and pseudo scalar theories. Fig. 4 gives a similar comparison of the differential cross section for monochromatic photons.

Recent Work on Element 87. Earl Hyde.

Element 87, francium, is one of the four "missing elements" of the periodic table which had not been discovered in nature until recently. The other elements that fall into this category are those with atomic number 43, 61, and 85.

Element 87 was first isolated by M. Perey in 1939 as a short lived isotope with a half life of 21 minutes. It was discovered as a member of the decay chain of U^{235} by 1 percent α branching from Ac^{227} in the reaction ${}_{89}Ac^{227}\ (\alpha)\ {}_{87}Fr^{223}$ and is therefore present in nature.

Workers on the Manhattan Project in their studies of the decay of U^{233} found ${}_{87}Fr^{221}$. The isotopes that had been found at the time that the present research began are compiled in the table below.

Isotope	Half-life	Activity
Fr^{223}	21 min.	β^-
Fr^{221}	4.8 min.	α
Fr^{220}	30 sec.	α
Fr^{219}	.02 sec.	α
Fr^{218}	extremely short	α

The speaker has set himself the task of isolating the francium isotope of mass number 222.

At first an attempt was made to produce ${}_{87}Fr^{222}$ by utilizing the 10^{-4} α branching of ${}_{89}Ac^{226}$. ${}_{89}Ac^{226}$ was obtained by the (p,n) reaction from the bombardment with protons of Ra^{226}. This attempt however was unsuccessful since by the same means Ac^{225} was produced. The reaction $Ac^{225}(\alpha)Fr^{221}$ is so much more prolific that it completely masked the desired Fr^{222}.

The procedure was changed and Fr^{222} was successfully obtained directly from the bombardment of Th^{232} with 100 Mev protons. The resulting Fr was isolated with Cs carrier and identified by observing the following decay chain with A. Ghiorso's pulse analyzer:

$$Fr^{222} \xrightarrow[14 \pm 3 \text{ min.}]{\beta^-} {}_{88}Ra^{222}$$
$$\downarrow$$
$${}_{86}Em^{218} \quad 38 \text{ sec. } \alpha$$
$$\downarrow$$
$${}_{84}RacI \quad 19\ \mu \text{ sec. } \alpha$$

The possibility of detecting other isotopes of francium was investigated. By looking at a plot of the energy of α emission versus mass number (Fig. 3) for different elements in this region one observes that for each element the emission energy increases with increasing mass number, reaches a maximum, and then decreases again. The maximum of α emission energy indicates a neighborhood of instability and is accompanied by extremely short half-lives. The francium isotopes that have been discovered thus far lie to the right of this unstable range of mass numbers. The regularity exhibited by some elements led to a search for francium isotopes on the other side of the range of extreme instability.

Th^{232} was bombarded with 350 Mev protons and a 30 min. 6.25 Mev α Fr isotope was seen. The mass assignment is not as yet complete but it is known that the mass number is less than 213. After an active sample known to contain 30 min. Fr had decayed, a residual 1.68 h 5.6 Mev α At isotope was observed. This may be a daughter by α decay of the Fr isotope, and thus may be the basis for a mass assignment.

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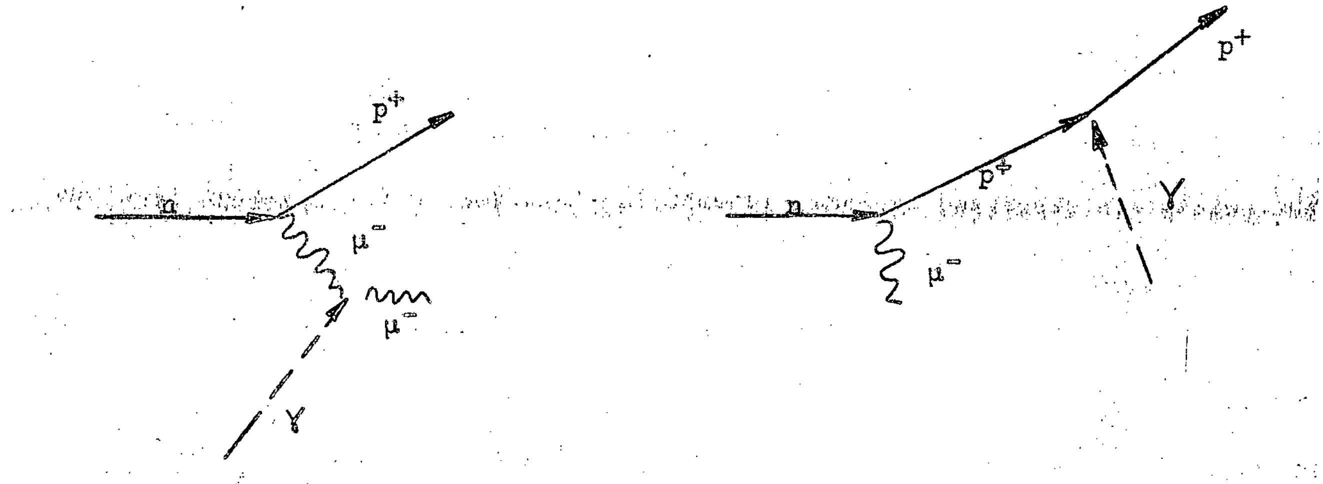

a b

Fig. 1

$\gamma + n \Rightarrow p^{+} + \mu^{-}$

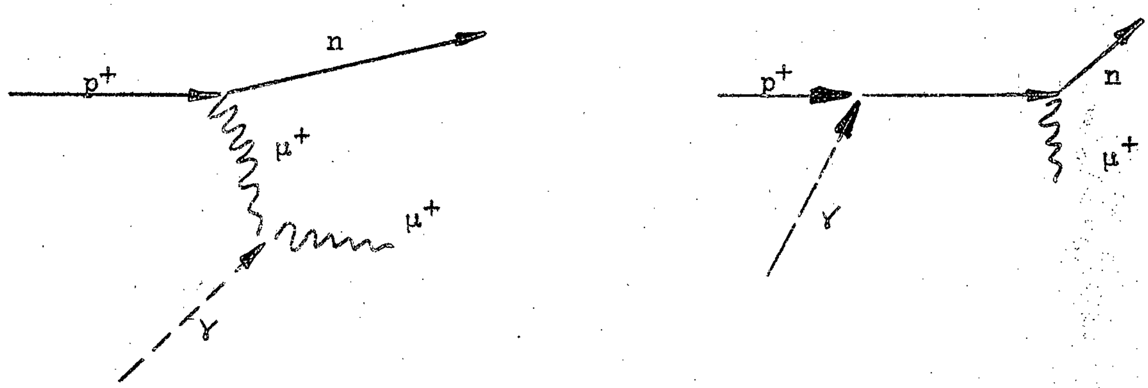

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Fig. 2

$\gamma + p^{+} \Rightarrow n + \mu^{+}$

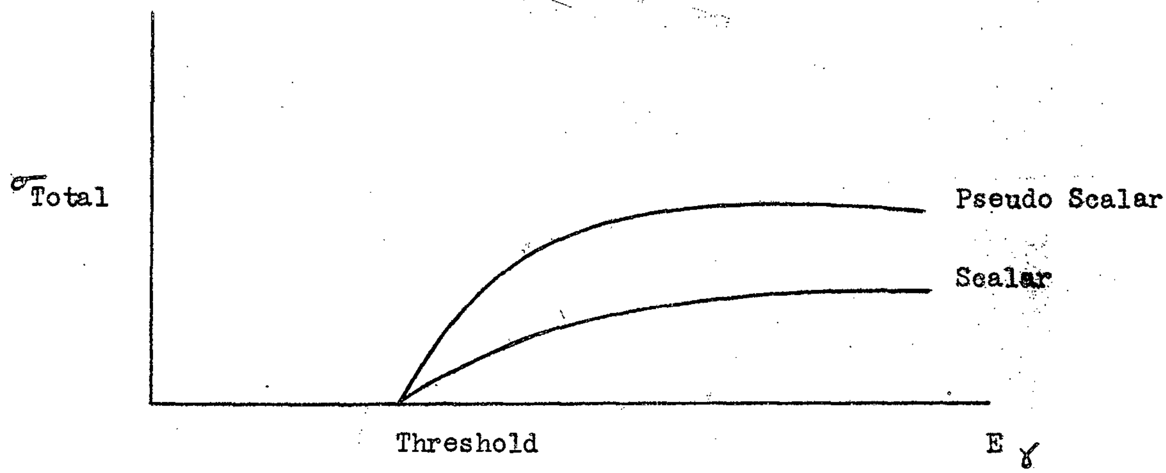

σ_{Total}
Pseudo Scalar
Scalar
Threshold
E_γ

Fig. 3

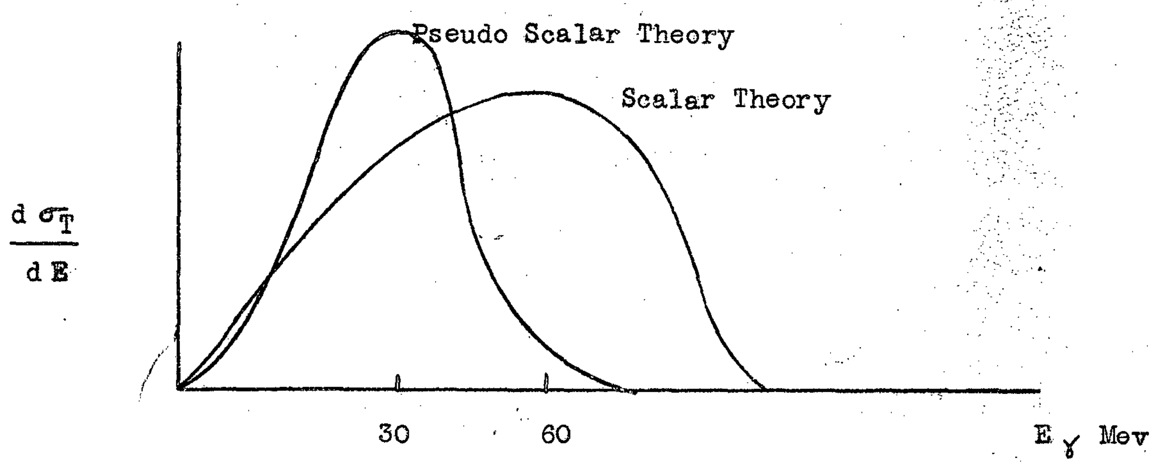
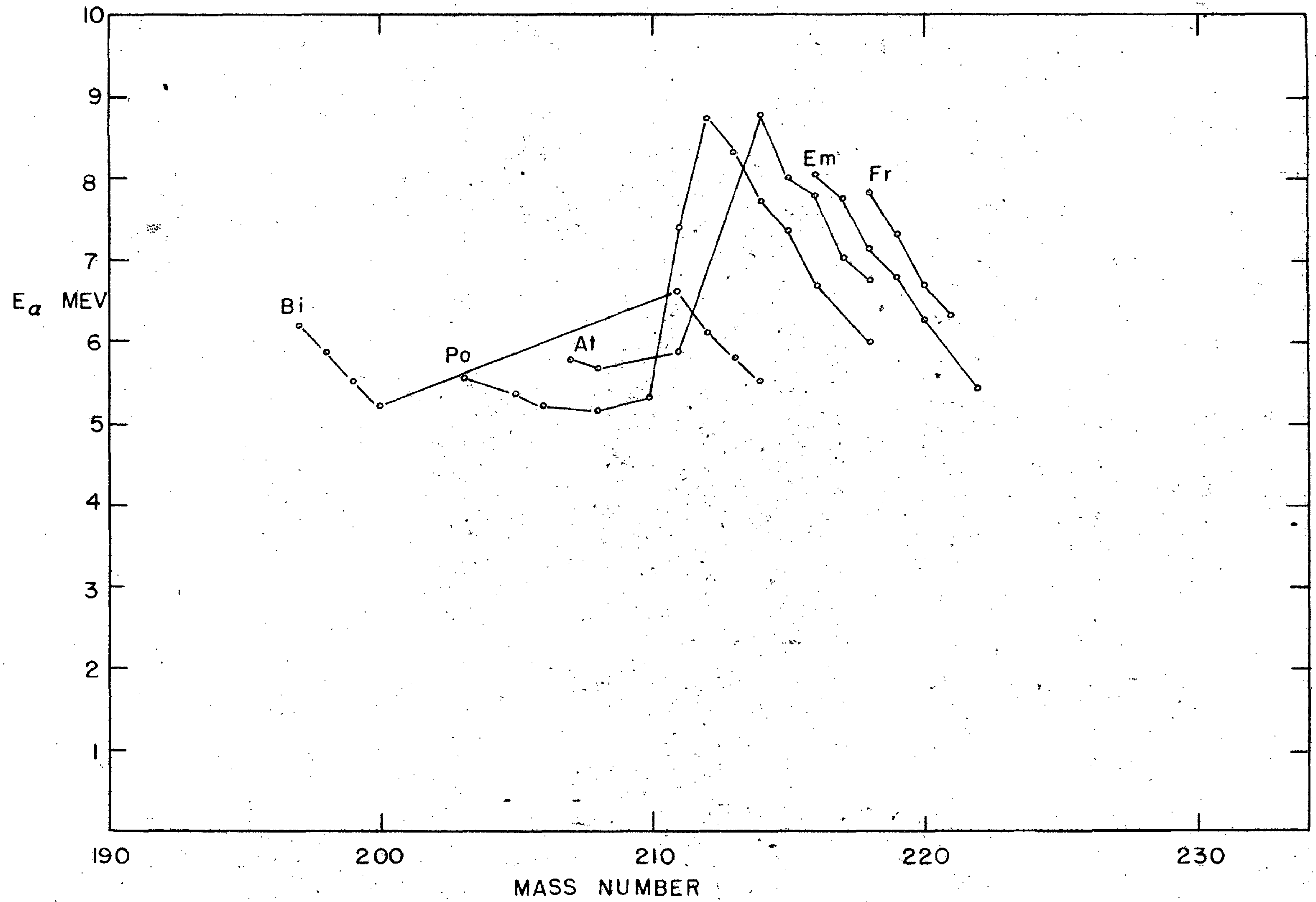

Pseudo Scalar Theory
Scalar Theory
$\frac{d\sigma_T}{dE}$
30
60
E_γ Mev

Fig. 4



10
9
8
7
6
5
4
3
2
1
E_α MEV
Bi
Po
At
Em
Fr
190
200
210
220
230
MASS NUMBER

FIG. 5

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