expected that they would in general be less than those for recombination. Further data on them would be useful.

* On leave from the Department of Mathematics, University College, London.

[1] M. A. Biondi and S. C. Brown, Phys. Rev. **75**, 1700 (1949) and **76**, 1697 (1949); Holt, Richardson, Howland, and McClure, Phys. Rev. **77**, 239 (1950). I wish to take this opportunity of thanking Professors Brown and Holt and their associates for a helpful discussion of their experiments.

[2] D. R. Bates, Phys. Rev. **77**, 718 (1950).

[3] Ta-You Wu, Phys. Rev. **66**, 291 (1944); A. G. Shenstone, Phil. Trans. Roy. Soc. **A241**, 297 (1948).

[4] It is apparent that "stabilization" by the emission of radiation or by collisions of the second kind, are very inefficient by comparison. Thus the time associated with the former cannot be much less than 10^{-8} sec.: and at a pressure of, say, 25 mm Hg, that associated with the latter would still be as long as 10^{-10} sec. even if the deactivation cross section were several orders greater than the gas kinetic.

[5] S. K. Mitra, *The Upper Atmosphere* (Royal Asiatic Society of Bengal, Calcutta, 1948).

[6] H. S. W. Massey, *Negative Ions* (Cambridge University Press, London, 1938).

The Detection of Artificially Produced Photo-Mesons with Counters*

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March 23, 1950

DELAYED coincidences between mesons and their decay electrons, as first observed by Rasetti,[1] have been widely used in cosmic-ray research as a means of counting mesons. A closely related technique in which the delay is timed from a very short proton pulse, has been used by Alvarez *et al.*[2] in the first electronic detection of artificially produced mesons. With the synchrotron the x-ray pulses are not short enough for the use of the latter method; therefore that of Rasetti has been used, with the x-ray pulse widened to about 2 msec. in order to reduce random coincidences.

When a positive π-meson comes to rest, it disintegrates very quickly into a μ-meson, and this in turn into an electron, with the well-known 2.1×10^{-6}-sec. mean-life. The range of the μ-meson is only $\sim$0.2 g, so that when this process takes place in a scintillation crystal with linear dimensions of the order of several centimeters, a large fraction of the decay electrons will also appear in the crystal. The $\pi\rightarrow\mu$-decay is too rapid to be resolved in the electronics of the experiment; instead, the characteristic half-life of the $\mu\rightarrow e$ decay is used to identify the meson. Negative mesons coming to rest in condensed matter do not produce decay electrons and therefore are not counted.

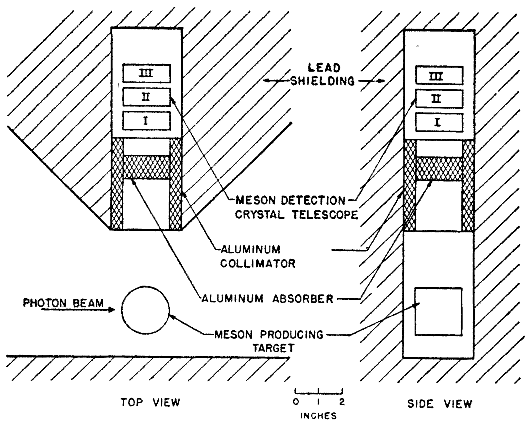

Fig. 1. Arrangement of target, absorbers, and meson detection scintillation counter telescope.

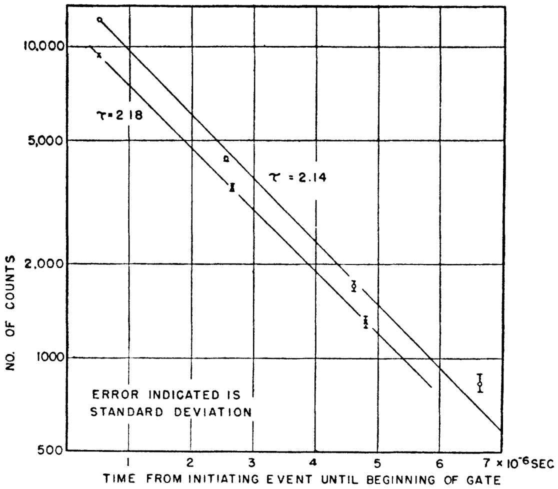

Fig. 2. Relative counting rates in the delayed channels. Two sets of data are shown because three channels were used at first, later four.

The apparatus is sketched in Fig. 1. The 330-Mev (max.) x-ray beam is collimated to $1\frac{1}{2}$ in. diameter and allowed to strike a target. The mesons produced at the target are detected in a telescope of three anthracene scintillation crystals after traversing variable amounts of aluminum absorber. The telescope can be rotated about the target in the plane of the beam. A meson is counted if it comes to rest in crystal II and its decay electron appears in the same crystal. That is, we require a pulse simultaneously in crystals I and II, but no pulse in crystal III. This coincidence starts several successive delay gates of two microsecond time width and if a pulse appears in crystal II during the gate time, it is recorded in that channel. There is an appreciable number of accidental delayed coincidences. These can be calculated from the known single counting rates, gate width, and duty cycle, and are then subtracted. The accidental rate is usually about 10 to 20 percent of the counting rate in the first channel. When the target is removed, both accidental and real coincidences are smaller by a factor of several hundred.

After the background subtraction the counting rates in the several delay channels should reproduce the exponential $\mu\rightarrow e$ decay. The lifetime data so far obtained are plotted in Fig. 2. When the x-ray energy is reduced below threshold no mesons are observed.

Since the crystals are proportional counting devices, the counting rates are functions of the amplitudes required for those pulses

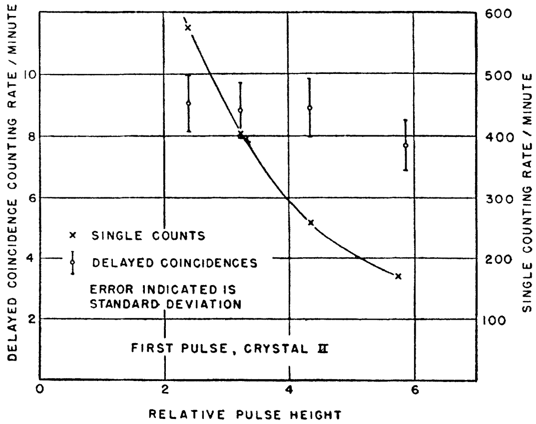

Fig. 3. Counting rate in crystal II (points without statistical error) and meson counting rate (with mean statistical error indicated) as a function of the minimum voltage required of the first pulse in crystal II.

entering into a delayed coincidence. The stability of the detecting system depends on the sensitivity of the meson counting rate to the minimum amplitudes required of the pulses. Such a plateau curve (counting rate *vs.* minimum pulse amplitude) is shown in Fig. 3.

With a synchrotron beam intensity of about 10^{10} Mev/sec. and the geometry of Fig. 1, a target of 4 g/cm^2 of carbon, and 1 in. of aluminum absorber, corresponding to a meson energy of 54 Mev, the meson counting rate is about 15 counts/min. This makes it possible to do experiments more quickly than with photographic emulsions. On the other hand, only positive mesons can be counted in this manner, and absolute cross-section measurements have a large error, since the detection efficiency is not known with precision.

We should like to express our thanks to Professor E. McMillan for his support of this research, and to the operating crew of the synchrotron, especially to Mr. W. Gibbins, for their able cooperation.

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* This work was sponsored under the auspices of the AEC.

[1] F. Rasetti, Phys. Rev. **60**, 198 (1941).

[2] Alvarez, Longacre, Ogren, and Thomas, Phys. Rev. **77**, 752 (1950).

Preliminary Results on the Production of Mesons by Photons on Carbon and Hydrogen*

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March 23, 1950

The method of meson detection described in the preceding letter[1] is being applied to the study of the production of positive mesons by x-rays on hydrogen and heavier nuclei. We report here some preliminary results in which the hydrogen cross sections are obtained by subtracting the yields on carbon from those on paraffin. All the measurements reported here are being continued, and hydrogen cross section measurements with a liquid hydrogen target are in progress.

In interpreting these results it should be kept in mind that both energy and angle of production of the meson are measured, and these determine the incident x-ray energy by momentum and energy conservation in the case of production on hydrogen. This means, for instance, that a knowledge of the energy distribution of the mesons at a fixed angle of production and of the energy distribution of the incident x-ray beam allows a determination of the excitation function for photo-meson production. We feel however that the energy, angular and statistical accuracies of the data reported here do not yet warrant such an analysis.

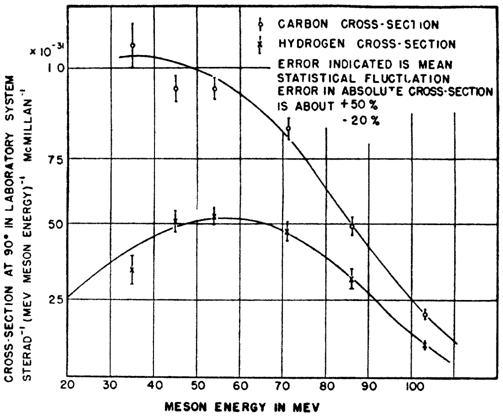

Fig. 1. Production of mesons by photons on carbon and hydrogen at 90°. The photons have a bremsstrahlung spectrum with a 330-Mev maximum energy. The number of McMillans in a bremsstrahlung beam is defined as the total energy in the beam divided by the maximum photon energy.

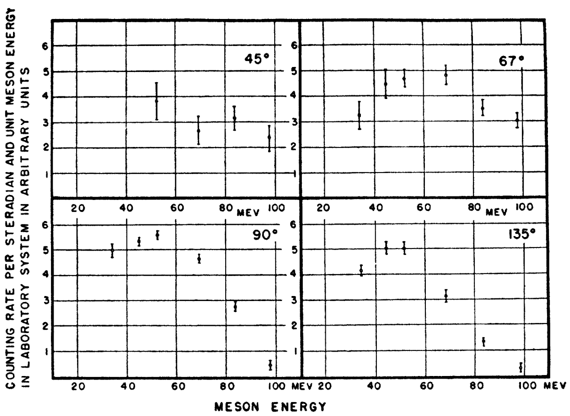

Fig. 2. The production of mesons in $C_{17}H_{14}$ at various angles as a function of the meson energy.

Figure 1 shows the relative number of mesons produced by carbon atoms and hydrogen atoms at 90° in the laboratory system as a function of energy. The incident photons have a bremsstrahlung spectrum of 330-Mev maximum energy. The meson energy is determined from the energy-range relationship, and it is assumed that the nuclear absorption of mesons is zero.[2] The carbon cross sections have already been determined by photographic detection methods,[3] and the two results agree within the statistical inaccuracies. The most startling fact shown in Fig. 1 (and also in Fig. 3) is that the cross section of the six bound protons in a carbon atom is only about twice as large as that of a single free proton. It is perhaps surprising that the effects of nuclear binding are so pronounced. However, a more detailed analysis[4] shows that since the energy of the recoil nucleons is not very much greater than the Fermi energy, this inhibition of the reaction in the case of complex nuclei may be no more than a manifestation of the exclusion principle.

Figure 2 shows an attempt at obtaining similar information at several other angles. However, the statistical accuracies are not great enough to make the subtraction meaningful. So the data

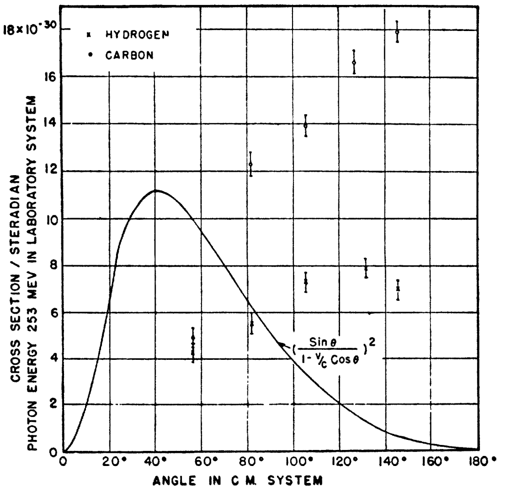

Fig. 3. The angular distribution of the mesons produced by 250-Mev (laboratory system) photons on hydrogen and carbon. The theoretical curve is that for an electric dipole photo-effect, $\{\sin\theta/[1-(v/c)\cos\theta]\}^2$.