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Berkeley, California

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Ilford C-2 emulsions, 200 microns thick, were exposed in the collimated x-ray beam from the Berkeley 322 Mev synchrotron. Exposures were made at synchrotron energies of 322, 242, and 161 Mev, and the monitor ionization chamber was calibrated relative to pair production cross sections at each of the three energies by the method described by Blocker, Kenney, and Panofsky.[1]

The complete area covered by the beam (3/8 in. circle) on each plate has been scanned for two and more prong stars. Because of the impossibility of distinguishing between a two prong star and a scatter in the track of a single particle in a large number of cases, two prong stars were classified as either possible or probable. Because of the arbitrariness and the difficulty of setting sufficiently precise criteria for this distinction, the two prong data is regarded as essentially qualitative. All events within 5.5 microns of either surface of the emulsion after processing were discarded, and the minimum prong range counted was 3 microns.

The yields of stars with various numbers of prongs are shown in Table I. The 322 Mev yields are normalized to an emulsion thickness before processing of 200 microns and an exposure of 10^8 "equivalent quanta," or 322×10^8 Mev total energy in the complete bremsstrahlung spectrum. The yields at the other energies are normalized to the same thickness and to exposures that contain the same number of quanta per Mev interval at 32 Mev. The uncertainties indicated in the table are the standard deviations due to counting statistics only.

The prong spectrum of the 322 Mev yield is similar to that reported by Kikuchi;[2] the difference in the minimum prong length counted probably accounts for the discrepancies.

Using the nominal partial densities of emulsion elements given by the manufacturer, and assuming that star production cross sections are proportional to mass number, the 322 Mev yield of 3 and more prong stars gives a cross section of silver, integrated over the bremsstrahlung spectrum, of 6.5×10^{-27} cm^2 per "equivalent quantum." This figure is reduced to 5.6×10^{-27} if cross section is assumed proportional to $A^{2/3}$.

The energy distribution of the quanta responsible for the differences in yields from the different energy exposures is shown in Fig. 1. Also shown at one tenth the scale for the difference spectra is the spectrum of 161 Mev bremsstrahlung. Because most of the difference quanta are in the energy range between the two upper limits of the bremsstrahlung spectra, it is possible to calculate a cross section averaged over this energy interval. Estimating that that part of the yield due to the low energy tail in the 161 to 242 Mev difference spectrum is 10 percent of the 161 Mev yield, and making similar corrections for the yield from the tail in the 242 to 322 Mev difference spectrum, the average cross sections of silver for the production of three or more prong stars are

$$\frac{\int_{242}^{322} \sigma(E)\, N_{322}(E)dE}{\int_{242}^{322} N_{322}(E)dE} = (8 \pm 1) \times 10^{-27}\ \mathrm{cm}^2$$

$$\frac{\int_{161}^{242} \sigma(E)\, N_{242}(E)dE}{\int_{161}^{242} N_{242}(E)dE} = (7 \pm 1) \times 10^{-27}\ \mathrm{cm}^2$$

where $N_{322}(E)$ is the number of quanta per Mev in 322 Mev bremsstrahlung, etc.

The integrated meson production cross sections of silver listed in Table II have been calculated from the measured carbon cross sections,[3,4], assuming the $A^{-1/3}$ dependence of yield per nucleon found for π^+ meson production.[5] It seems likely that part of the stars observed are associated with meson production. The star yield is probably too large to be accounted for by this process alone, however, since only about 1/4 of the low energy π^- mesons found which were produced in the emulsion had as many as 3 other prongs associated with their production.

Another possible mechanism for star production by high energy photons is suggested by the π^+ meson relative yield data of Mozley.[5] The implication of the $A^{-1/3}$ dependence of yield per nucleon is that only the surface nucleons are effective in producing mesons. Since none of the known photonuclear reactions have cross sections comparable to nuclear area at these energies, this effect is probably not due to nuclear opacity to photons. If, however, this effect is due to nuclear opacity to mesons, one might expect that there should be stars produced by meson production and reabsorption in the same nucleus with cross sections several times that for meson production.

I wish to thank Prof. E. M. McMillan for suggesting this problem and for his helpful discussions, Mrs. W. R. Gaffey for assistance in scanning the plates, and Dr. R. S. Christian for calculations of the bremsstrahlung spectra, Mr. R. Kenney and Mr. W. Blocker for the use of equipment and assistance in calibration of the ionization chamber, and to Mr. G. C. McFarland and the synchrotron crew for assistance in making the exposures.

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Table I

Relative Yields of Stars

No. prongs \ X-ray energy	322 Mev	242 Mev	161 Mev
possible 2	73 ± 7	81 ± 8	34 ± 5
probable 2	91 ± 8	70 ± 7	36 ± 5
3	137 ± 6	109 ± 9	39 ± 5
4	88 ± 5	57 ± 6	29 ± 4
5	37 ± 3	14 ± 3	8 ± 2
6	13 ± 2	3.6 ± 1.6	0.6 ± 0.6
7	3 ± 1		
8	0.9 ± 0.5		
≥ 3	280 ± 9	184 ± 12	77 ± 9
≥ 5	54 ± 4	18 ± 4	9 ± 2

Table II

Meson photo-production cross sections of silver, integrated over 322 Mev bremsstrahlung, in units of 10^{-27} cm^2 per equivalent quantum

π^+	0.7
π^-	1.1
π^0	4.0
sum	5.8

References

[1] Blocker, Kenney, and Panofsky, Phys. Rev. 79, 419 (1950)

[2] Kikuchi, Phys. Rev. 80, 492 (1950)

[3] Peterson, Gilbert, and White, Phys. Rev., in press

[4] Steinberger, Panofsky, and Steller, Phys. Rev. 78, 802 (1950)

[5] Mozley, Phys. Rev. 80, 493 (1950)

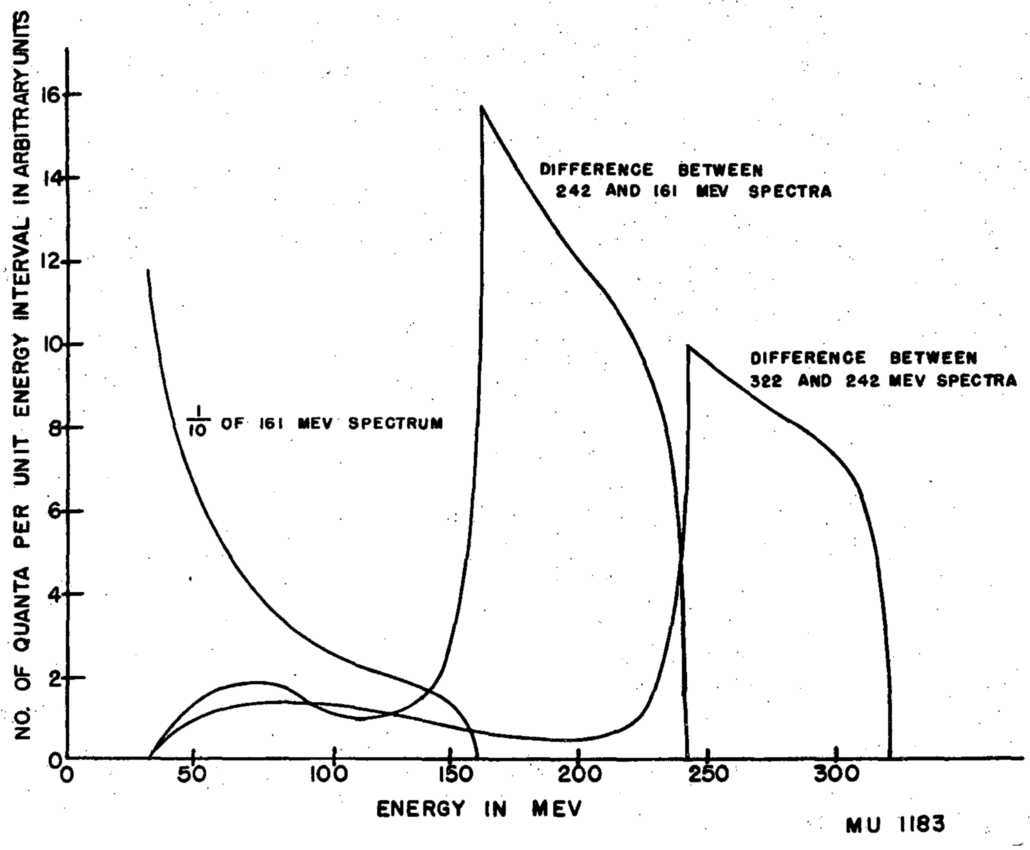
NO. OF QUANTA PER UNIT ENERGY INTERVAL IN ARBITRARY UNITS
16
14
12
10
8
6
4
2
0
0
50
100
150
200
250
300
ENERGY IN MEV
DIFFERENCE BETWEEN 242 AND 161 MEV SPECTRA
DIFFERENCE BETWEEN 322 AND 242 MEV SPECTRA
$\frac{1}{10}$ OF 161 MEV SPECTRUM
MU 1183

Fig. 1