related many-body forces, even without repulsive cores, might account roughly for nuclear binding energies and radii.

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[1] F. Bitter and H. Feshbach, Phys. Rev. **92**, 837 (1953).
[2] D. Frisch, Phys. Rev. **84**, 1169 (1951).

Charged Pion Production from Carbon by Protons*

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A STUDY has been made with nuclear emulsions of the cross sections for production of positive and negative pions from carbon at 0° and 90° to a 340-Mev proton beam. For the 0° experiment and the 90° π^+ spectrum a uniform magnetic field was used. The 90° π^- spectrum was obtained with the aid of a symmetric heterogeneous magnetic field of a 22-inch spiral orbit spectrometer. The proton source was the external electrically deflected beam of the 184-inch synchrocyclotron. From this study[1] the following conclusions are drawn.

(a) The peak of the cross section for π^- production at these laboratory angles occurs much earlier than the corresponding peak for π^+ production.

(b) The maximum pion energy cutoff for π^- production is smaller than the corresponding pion energy cutoff for π^+ production.

(c) The shapes of the π^- production spectrum disagree with the previously reported spectrum shapes,[2] particularly in the low-pion-energy region.

(d) In the low-energy region the $\pi^\pm$ spectrum shapes when plotted against pion energy qualitatively resemble the corresponding shapes in $\beta^\pm$ decay.

(e) These spectra when integrated over the pion energy give the following results per carbon nucleus:

Laboratory angle θ	$\frac{d\sigma^+}{d\Omega}\times 10^{28}$ cm² sterad⁻¹	$\frac{d\sigma^-}{d\Omega}\times 10^{28}$ cm² sterad⁻¹	$\frac{\pi^+}{\pi^-}$	$\frac{\pi^+(0°)}{\pi^+(90°)}$	$\frac{\pi^-(0°)}{\pi^-(90°)}$
0°	21.0 ±0.5	0.71 ±0.02	29.5 ±1.2	6.3 ±0.2	1.67 ±0.09
90°	3.35 ±0.07	0.43 ±0.02	7.8 ±0.04		

(f) An estimate can be made of the total production cross section per carbon nucleus from the following data:

(1) Leonard's 180° results[3] on charged-pion production from carbon, which are $d\sigma^+/d\Omega=(1.77\pm0.40)\times10^{-28}$ cm²/sterad; $d\sigma^-/d\Omega=(1.90\pm0.56)\times10^{-29}$ cm²/sterad;

(2) the preliminary results at 30° on π^+ production which show that the π^+ peak occurs at a pion energy $T_\pi>55$ Mev; and

(3) the assumption that the angular dependence of the π^+ production cross section at each angle when integrated over pion energies can be represented by

$$\frac{d\sigma^+}{d\Omega}(\theta)=A+B\cos\theta+C\cos^2\theta,$$

and the corresponding π^- production cross section by

$$\frac{d\sigma^-}{d\Omega}(\theta)=A'+B'\sin^2\theta+C'\cos\theta.$$

This estimate gives

$$\sigma_T{}^+=(7.6\pm0.7)\times10^{-27}\text{ cm}^2,$$
$$\sigma_T{}^-=(0.55\pm0.09)\times10^{-27}\text{ cm}^2,$$
$$\pi^+/\pi^-=14\pm4.$$

(g) The disagreements between previously published data[2] on π^+ production at 90° can be resolved so that all results on π^+ production at this angle are in good agreement for pion energies above 25 Mev.

(h) For the calculation of the π^- production cross section a more appropriate zero-prong correction that is based on 4883 negative pions in clean C-2 Ilford nuclear emulsions is 1.35.

(i) The spiral-orbit principle[4] is especially suited for the study of charged pion production at 90° to the proton beam.

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[1] W. F. Dudziak, University of California Radiation Laboratory Report UCRL-2564 (unpublished).
[2] C. Richman and H. Wilcox, Phys. Rev. **78**, 496 (1950); Block, Passman, and Havens, *ibid.* **88**, 1243 (1952); Passman, Block, and Havens, *ibid.* **88**, 1247 (1952).
[3] S. Leonard, Phys. Rev. **93**, 1380 (1954).
[4] G. Miyamoto, Proc. Phys.-Math. Soc. (Japan) **24**, 676 (1942).

Natural Radioactivity of Rhenium*

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THE natural radioactivity of rhenium[1] was characterized by an aluminum absorption curve as having an energy of some 43 kilovolts. We have had occasion to attempt a better measurement of the energy and have been surprised to find that the energy is much lower than was originally deduced. In fact an aluminum foil of only 270 micrograms per cm² transmits less than 6 percent of the radiation, whereas the earlier result corresponded to a half-thickness of about 400 micrograms per cm². It seems likely that the earlier result was due either to a small amount of impurity or