The Dependence of the 33-Mev π^+ Production Cross Section on Atomic Number

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A PRELIMINARY result has been obtained on the variation of the ($T_\pi = 33$ Mev) positive pion-production cross section with atomic number which results from the interaction of a ($T_p = 340$ Mev) proton beam with target nuclei. The chief concern is the functional behavior with atomic number of pion-production cross sections at different pion energies.

For this experiment the targets consisted of six elements (Be, C, Al, Cu, Ag, and Pb). These targets were in tubular form having the following dimensions: (a) for the light elements (Be, C, Al) ¾ in. o.d., ½ in. i.d., and 1½ in. long; (b) for the heavy elements (Cu, Ag, Pb) ¾ in. o.d., ½ in. i.d., and ½ in. long. A ½ in. long tubular carbon target was used to determine the normalization factor necessary for the difference in target geometry between the light and heavy elements.

The targets were mounted on the axis of a 22-in. (pole-diameter) spiral orbit spectrometer. They were bombarded by a (1-in. diameter) collimated proton beam which was electrically deflected out from the 184-inch synchro-cyclotron, integrated by an argon-

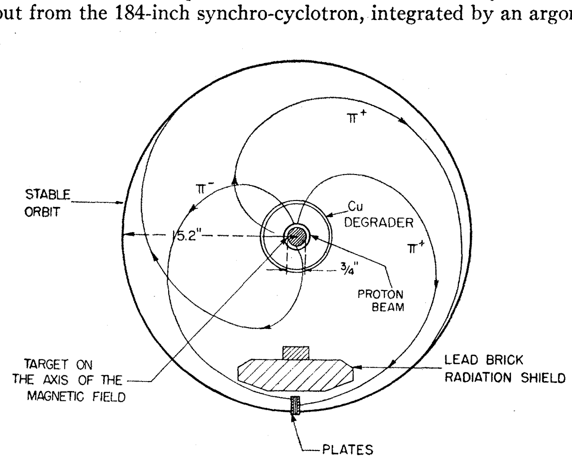

FIG. 1. Schematic diagram of experimental arrangement illustrating the charged pion trajectories in the median plane of the spiral-orbit spectrometer.

filled ion chamber, and then passed through the (1½-in. i.d.) axial hole of the magnet.

The principle of "the sprial-orbit spectrometer"[1] was used to focus pions of known energy which were emitted at 90° to the incoming proton beam. The pions were detected by means of C–2 Ilford (200μ) nuclear emulsions which were placed in the region of the "stable orbit" as is shown schematically in Fig. 1. Since pions of $T_\pi = 9.2$ Mev were being focussed at the "stable orbit," a 4 in. o.d. tubular copper degrader of appropriate thickness permitted the selection of pions of $T_\pi = 33 \pm 3$ Mev created in the target.

The same volume of emulsion was scanned for each of the seven exposures. The relative π^+ production cross section per target nucleus was determined and is presented in Fig. 2. The uncertainties indicated in the spectral data are statistical probable errors involved in the counting of pions. Shown also in Fig. 2 are (a) Z^1 variation normalized at the Ag point, (b) $Z^{\frac{2}{3}}$ variation normalized at the Ag point, (c) $Z^{\frac{2}{3}}$ variation normalized at the Al point.

The experimental results for the six elements indicate clearly a better fit to a $Z^{\frac{2}{3}}$ variation. This is quite similar to the results obtained by one of the authors for pions of $T_\pi = 42$ Mev.[2] Furthermore the data are in accord with those reported by Hamlin *et al.*[3]

Exposures have also been obtained (for $T_\pi = 25$ Mev and

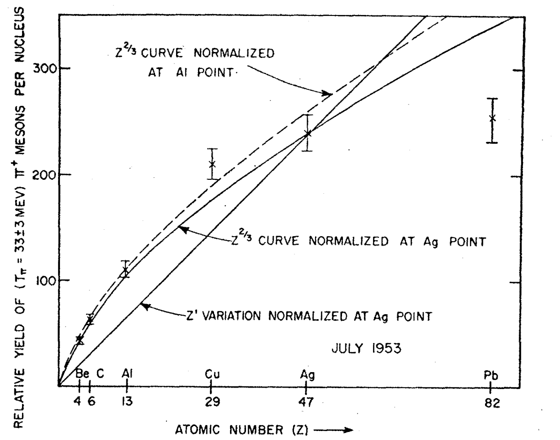

FIG. 2. Relative ($T_\pi = 33 \pm 3$ Mev) π^+ production cross sections as a function of atomic number, illustrating the variation of experimental data from a Z^1 and $Z^{2/3}$ dependence.

$T_\pi = 11$ Mev) for negative and positive pions. These results will be reported soon.

We are grateful to Professor E. Lawrence, Professor R. Thornton, Professor W. Barkas, and Professor C. Richman for their aid in obtaining the funds for the spiral-orbit spectrometer as well as their continued interest. We would like to acknowledge the cooperation of Mr. James Vale and the cyclotron crew in making the exposures.

[1] G. Miyamoto, Proc. Phys. Math. Soc. (Japan) **17**, 587 (1943); R. Sagane and W. Gardner, University of California Radiation Laboratory Report UCRL, Translation 111, 1951 (unpublished); R. Sagane, University of California Radiation Laboratory Report UCRL-2161, 1953 (unpublished).
[2] R. Sagane, Phys. Rev. **90**, 1003 (1953); University of California Radiation Laboratory Report UCRL-2161, 1953 (unpublished).
[3] Hamlin, Jakobson, Merritt, and Schultz, Phys. Rev. **84**, 957 (1951).

Polarization of Nuclear Spins in Metals*

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WHEN a metal such as lithium is placed in a static magnetic field, two set of Zeeman levels are produced associated with the nuclear spins[1,2] and the conduction electron spins,[3,4] respectively. The corresponding resonance transitions have been observed. With magnetic resonances in general it is found that when the amplitude of the alternating magnetic field is increased, the population difference between the Zeeman levels decreases, a phenomenon known as saturation. For example, we have found previously[4] that for the conduction electrons in lithium, an alternating field of some 5 gauss produces saturation. On the basis of a detailed calculation of the nucleus-electron interaction, Overhauser[5] has predicted that for metals the saturation of the conduction electrons should simultaneously *increase* the population difference between the nuclear Zeeman levels by a factor of several thousand, and has proposed this as a method of polarizing nuclear spins. Since the strength of the nuclear resonance absorption is proportional to the population difference between adjacent nuclear Zeeman levels, the nuclear resonance forms a convenient method of measuring the degree of nuclear alignment. We have verified Overhauser's theory by observing the enhancement of the nuclear resonance in metallic lithium produced by electron saturation.

The experiment was performed in a static magnetic field of 30.3 gauss provided by a small end-corrected solenoid. The sample containing 5 cm³ of lithium dispersed in oil was placed in the tank coil of a 50-watt oscillator operating at 84 Mc/sec, the Larmor frequency for the electrons in the magnetic field. Measurements

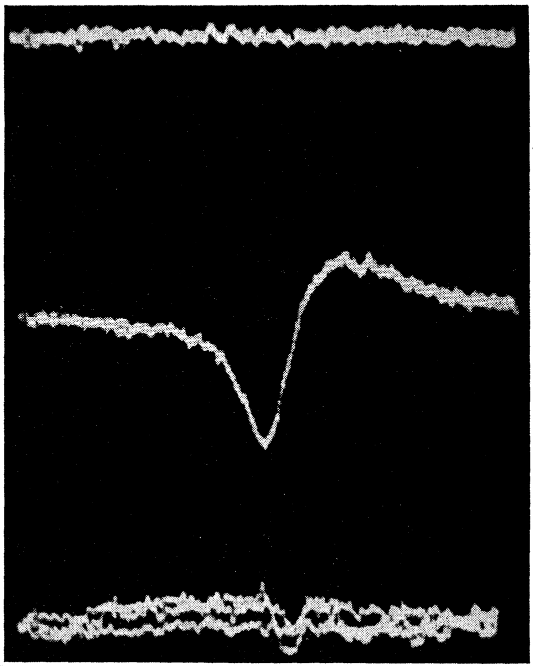

FIG. 1. Oscilloscope pictures of 50-kc/sec nuclear resonance absorption *vs* static magnetic field. Field excursion 0.2 gauss. Top line: Li^7 resonance (lost in noise). Middle line: Li^7 resonance enhanced by electron saturation. Bottom line: Proton resonance in glycerin sample.

indicated an alternating field of about 4 gauss. The nuclear resonance was detected using a 50-kc/sec crystal controlled oscillator and a twin-*T* bridge, the 50-kc/sec signal being converted to 600 kc/sec and detected in a communications receiver. The signal was observed on an oscilloscope or with a 30-cps lock-in amplifier. The rf tank coil of 1 turn, the 270-turn nuclear resonance coil, and the solenoid were oriented mutually perpendicular, and the array was placed in a copper box to shield the detection apparatus from rf radiation. The 84-Mc/sec oscillator could be switched on or off without disturbing the bridge balance.

The accompanying oscilloscope photographs (Fig. 1) summarize the results. The top line shows the appearance of the ordinary lithium nuclear resonance, which is so weak at these frequencies as to be completely lost in noise. The second line was photographed after the electron saturating oscillator was turned on. The Li^7 resonance now appears strongly. For comparison, the proton line in glycerin (also at 50 kc/sec) is shown in line three. In all three cases the amplifier gain settings and degree of bridge balance were identical. The very weak glycerin resonance, however, is produced by a sample of eight times the number of nuclei as the lithium. The enhancement of the lithium resonance, therefore, confirms Overhauser's theory strikingly.

On the basis of comparison with the glycerin resonance, we estimate the nuclear population difference to be increased nearly 100-fold in our experiment. This figure is somewhat smaller than the maximum amount predicted, showing that either complete saturation was not achieved, or that other nuclear relaxation processes short-circuit the alignment partially. One process we believe to be important is the relaxation produced by self-diffusion of the nuclei.[2] We have also observed a small enhancement in sodium under conditions of incomplete saturation. With both metals the saturating fields produced intense heating of the samples.

We are indebted to Dr. Overhauser for interesting discussions and a most stimulating association during his stay at Illinois. Mr. Robert Schumacher assisted in construction of the equipment. The results of Mr. Donald Holcomb and Dr. Richard Norberg on nuclear relaxation times in lithium were helpful in searching for the nuclear resonance. We wish to thank Dr. Richard M. Brown for several useful suggestions concerning low-frequency nuclear resonance.

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† National Science Foundation Predoctoral Fellow.

[1] H. S. Gutowsky and B. R. McGarvey, J. Chem. Phys. **20**, 1472 (1952).
[2] D. F. Holcomb and R. E. Norberg (to be published).
[3] Griswold, Kip, and Kittel, Phys. Rev. **88**, 951 (1952).
[4] Carver, Holcomb, and Slichter (to be published).
[5] A. W. Overhauser, Phys. Rev. **89**, 689 (1953); **91**, 476 (1953); Phys. Rev. (to be published).

Phase-Shift Analysis of High-Energy *p-p* Scattering Experiments*

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IT has often been suggested[1] that the isotropy of the differential cross section for *p-p* scattering up to 350 Mev[2,3] as well as its magnitude (at 240 Mev this is 4.97 ± 0.43 mb/sterad,[2] and σ is fairly constant with energy from 150–350 Mev[3]) might be fitted with *s* and *p* waves only.[4] Wolfenstein and Ashkin[5] have proposed including in such an analysis the left-right asymmetry, observed at Rochester, of $2e=9.8\pm5$ percent in the final angular distribution of 240-Mev protons scattered successively by two (effective) hydrogen targets.[6] Such a fit can in fact be made for the 240-Mev data with a number of different combinations of phase shifts, as will be shown.

In terms of the phase shifts $\delta_L{}^J$ the above facts mean the following, if we neglect all phase shifts for $L>1$:

(1) The isotropy of the angular distribution requires that the coefficient of $\cos^2\theta$ in $\sigma(\theta)$ vanish:

$$0=\sin^2\delta_1{}^0+3\sin^2\delta_1{}^1+5\sin^2\delta_1{}^2-\sin^2(\delta_1{}^0-\delta_1{}^2)-(9/4)\sin^2(\delta_1{}^1-\delta_1{}^2). \quad (1)$$

(2) In this case, the differential cross section in the center-of-mass system is given by

$$k^2\sigma(k,\theta)=\sin^2\delta_0{}^0+\sin^2\delta_1{}^0+3\sin^2\delta_1{}^1+5\sin^2\delta_1{}^2. \quad (2)$$

(3) The general theory of polarization effects in scattering problems has been discussed by Wolfenstein and Ashkin,[7] and the application to the double scattering experiment has been considered by Goldfarb and Feldman,[8] and by Swanson.[9] One finds that the observed asymmetry,

$$2e=[I(\phi=0)-I(\phi=\pi)]/I(\phi=\pi/2),$$

where I is the proton intensity from the second target at azimuthal angle ϕ, is[7]

$$2e=2P(k_A,\theta_A)P(k_B,\theta_B). \quad (3)$$

Here $P(k,\theta)$ is the percentage polarization[7] of one of the scattered protons induced by the collision of two initially unpolarized proton

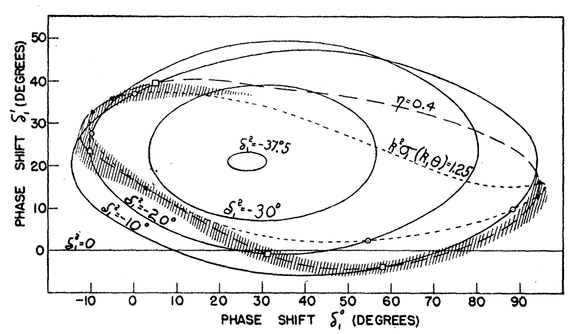
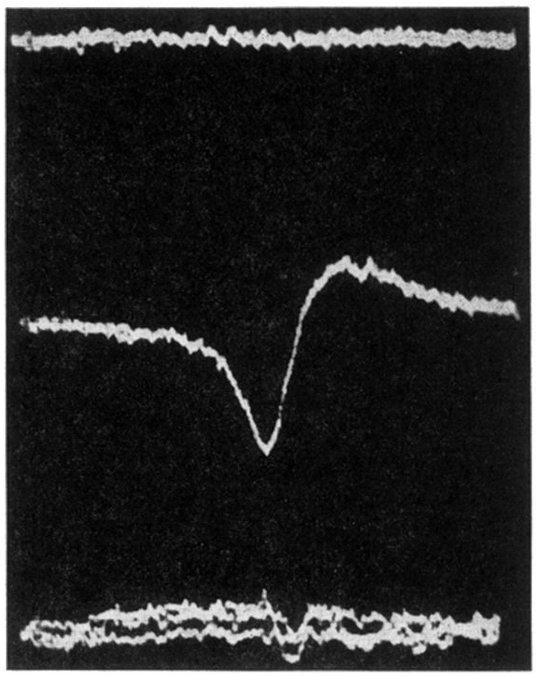


FIG. 1. Phase-shift diagram.



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