High-Energy Proton Scattering from Carbon and Deuterium

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The momentum spectra of protons scattered from carbon and deuterium at angles close to 60 mrad and for incident proton momenta between 12 and 27 Gev/c have been measured. The data show good agreement with calculations based on plural quasi-elastic proton-nucleon scattering within the nucleus.

THE momentum spectra of protons scattered from CH_2, CD_2, and C targets in the internal beam of the CERN proton synchrotron have been measured, and a subtraction method has been used to obtain the p-p and p-d spectra. Details of the experimental arrangement and the information obtained on elastic and inelastic p-p cross sections are contained in separate publications.[1,2] This paper describes the information gathered on proton scattering from carbon and deuterium. The measurements were taken at laboratory scattering angles close to 60 mrad and the incident protons had momenta, P_0, between 12 and 27 Gev/c.

Figure 1 shows the momentum spectra obtained from p-C and p-p scattering at three different bombarding momenta and the p-d and p-p spectra at one momentum. The points shown were obtained by averaging the observed data over small momentum intervals. Several features are immediately clear. For all incident momenta studied, the peak in the momentum spectrum obtained for the protons scattered from the C target is broader and at a higher momentum than that for elastic p-p scattering.[3] With increasing bombarding momentum, the separation between the peak from carbon and the p-p elastic peak increases. At $P_0=26.02$ Gev/c the p-C spectrum shows two peaks, the lower one occurring at approximately the momentum of the p-p peak and the upper one half-way between this and P_0. (P_0 is indicated by the arrow in Fig. 1.)

The observed values of the differential cross section of the peak or peaks in the p-C momentum spectrum and of $\langle\Delta P\rangle_H-\langle\Delta P\rangle_C$ are given in Table I for all momenta and angles studied. $\langle\Delta P\rangle$ is the average recoil loss.

Since the momentum transfers involved in these experiments are of the order of 1 Gev/c, the scattering from carbon is expected to be the result of proton-nucleon collisions. An explanation for the peak shift and double peaks observed in carbon has been suggested by Karplus and Yamaguchi[4] in terms of plural quasi-elastic proton-nucleon scattering within the carbon nucleus. Small angles of scattering are strongly favored by the steep angular dependence of the proton-nucleon cross section. As the momentum loss for elastic scattering is proportional to Θ^2, the momentum of the outgoing proton is higher for plural scattering through small angles than it is for single scattering through the full angle. The calculations indicate that double scattering is of importance for carbon, when the momentum

TABLE I. Proton-carbon scattering. Θ and P_0 are the laboratory scattering angle and the incoming momentum, respectively. The quantity $\langle\Delta P\rangle_H-\langle\Delta P\rangle_C$ is the momentum difference between the peaks for (p-C) scattering and (p-p) scattering. The statistical errors on the carbon cross sections are in all cases less than 5%, the systematic absolute errors could be ~50%, and the systematic relative errors could be ~40%.

Θ (mrad)	P_0 (Gev/c)	$P_0\Theta$ (Gev/c)	Carbon $(d\sigma/d\Omega)_{lab}$ (mb/sr)	$\langle\Delta P\rangle_H-\langle\Delta P\rangle_C$ (Gev/c)
56.5	12.99	0.734	373	0.03
56.5	15.89	0.898	98	0.06
56.5	17.30	0.927	64.5	0.13
56.5	17.75	1.003	54	0.17
56.5	18.69	1.056	31	0.20
56.5	19.56	1.105	14.5	0.22
56.5	19.75	1.116	17	0.20
56.5	19.91	1.125	16.6	0.26
56.5	21.88	1.236	6.4	0.31
56.5	22.74	1.285	4.3	0.33
56.5	26.02	1.470	0.93	0.37[a]
60.5	18.29	1.107	25	0.23

[a] The average of the single and double scattering peaks has been taken.

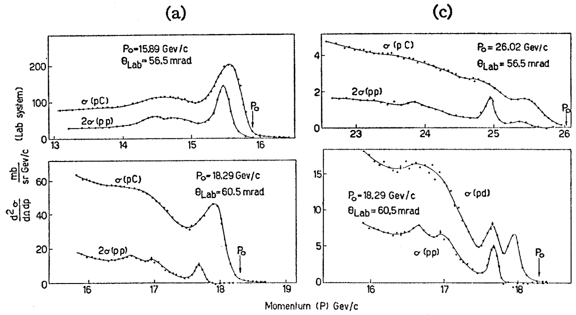

FIG. 1. (a), (b), and (c) show the proton momentum spectra obtained from p-C and p-p scattering at three different incoming proton momenta, P_0. (d) shows the spectra for p-d and p-p scattering at one momentum.

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[3] As described in reference 2 the justification for identifying the peak in the p-p momentum spectrum with elastic scattering is the agreement, within the experimental accuracy of about 100 Mev, between the calculated and observed recoil loss, $\langle\Delta P\rangle_H$.
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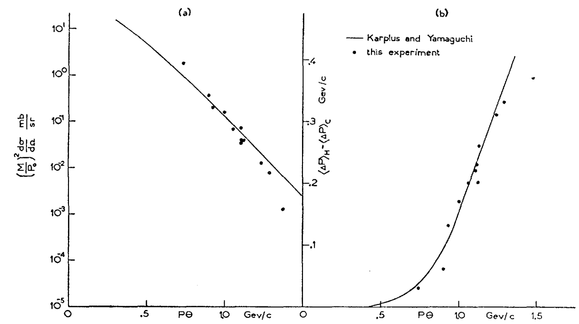

FIG. 2. Comparison between the results of this experiment and calculations of Karplus and Yamaguchi[4] on plural quasi-elastic scattering. (a) compares the laboratory differential cross sections, and (b) the separation between the laboratory momentum of the peak from p-C scattering and that of p-p elastic scattering.

transfer is about 1 Gev/c. The result is two peaks, one from single scattering at the same momentum as for elastic p-p scattering and the other, from double scattering, at half the momentum loss. These two peaks are broadened by the fermi motion and, in general, merge into a single peak. The spectrum at 26.02 Gev/c, where the highest momentum transfer is involved, shows the two peaks resolved.

Figure 2 shows a comparison between the experimental results and the calculations of Karplus and Yamaguchi; Fig. 2(b) compares the values of $\langle\Delta P\rangle_H - \langle\Delta P\rangle_C$, and Fig. 2(a) shows the p-C differential cross section as a function of the momentum transfer. The agreement is good.

Figure 1(d) shows the momentum spectra for p-d and p-p scattering. The p-d spectrum shows two clearly resolved peaks, one at the same momentum as the elastic p-p peak, the other at half the momentum loss. There are two obvious possible explanations of the higher momentum peak, double quasi-elastic scattering, and single coherent scattering from the deuteron as a whole. The latter seems unlikely as the momentum transfer (1.1 Gev/c) is large compared to the deuteron binding energy.

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π^-–p Interactions at 1.3 Bev*†

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A study has been made of the interactions of 1.3-Bev π^- mesons from the Cosmotron in the Columbia 12-in. propane bubble chamber. Out of a total of 1401 two-prong interactions measured and analyzed, 587 were classified as hydrogen interactions. Techniques used in scanning, measurement, and analysis, and the uncertainties involved in these techniques are discussed with special reference to the problem of carbon contamination. Corrections to the data are calculated. Best values for cross sections at this energy are: $\sigma_{el}=10.5\pm0.8$ mb, $\sigma_{\pi^-\pi^+n}=9.2\pm1.4$ mb, $\sigma_{\pi^-\pi^0p}=6.2\pm0.9$ mb, $\sigma_{neutral}=5.2\pm0.2$ mb, and $\sigma_{\pi^-\pi^-\pi^+p}=1.0_{-0.3}^{+0.5}$ mb, normalized to $\sigma_{total}=34.7\pm1.2$ mb. A study of $\pi^-+n\rightarrow\pi^-+\pi^-+p$ events in carbon is used to provide evidence on carbon contamination in single pion production. The data on single pion production processes are compared in detail with the predictions of the statistical model, the isobar model, and pion-pion interaction theory. The extended isobar model gives qualitative agreement with some features of the c.m. momentum spectra, but quantitative agreement is poor. Evidence is found for a resonance in $\sigma_{\pi\pi}(\omega)$ between 700 and 800 Mev total energy for the dipion system. The data are consistent with a resonance in the $T=J=1$ $\pi-\pi$ state. A rise in the $\pi-\pi$ cross section at low energies appears to occur. Differences in results for (π^-,π^+,n) and (π^-,π^0,p) events are considered. Evidence for final-state pion-nucleon interactions in conjunction with pion-pion interactions is presented.

I. INTRODUCTION

AT the present time there is considerable interest in the interactions of pions with nucleons at energies in the Bev region. Total and elastic cross sections have been measured in detail in several experiments for energies ranging from a few hundred Mev to about 1.5 Bev.[1–7] A summary of many of the

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