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PROTON INTERNAL STRUCTURE REVEALED BY PION SCATTERING

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Abstract. Analysis of π^+p and π^-p cross-sections allowed getting the pair correlation functions of the proton. The proton structure is expressed as a cluster of subparticles with specific configuration and distances between them, estimated to be in number of 20–30, taking into account the radius of the proton.

Key words: proton, internal structure, pions, scattering, cross section.

1. INTRODUCTION

The elastic and total π^+p and π^-p cross-sections were measured and reported by many authors. A compilation of the data obtained up to the beginning of 1982 was published by Flaminio *et al.* [1]. The experimental data converge to show that the curves giving the total cross-sections *versus* energy, $\sigma_T(E)$, are smoothed curves, with large peaks (resonances) for medium energies and a slow variation with some waving on the high energy side. The curves exhibit striking resemblance to the scattering curves obtained by electron, neutron or X-ray scattering in liquid and amorphous materials. Starting from this observation we have developed, by analogy with the case of solids and liquids, a method to extract structural information on the proton internal structure, in the hypothesis that pions are scattered by unknown internal centres when they knock the proton.

2. THE ENERGY DISPERSIVE METHOD

The energy dispersive method was firstly introduced in X-ray diffractometry by Buras *et al.* [2] and Giessen and Gordon [3] in 1968. In this method a white collimated X-ray beam is scattered by the sample through a fixed optimized angle 2θ and the energy distribution of the scattered photon is analysed by a special detector. The measured energy distribution of the scattered X-rays shows distinct

peaks, exactly as in the case of usual angle dispersive diffraction, providing the information on the material structure. This method became soon a remarkable tool among conventional diffraction techniques for structural analysis of the materials like liquids, solids, and polymers. The method has been applied for all types of "projectiles" (electrons, neutrons), which give diffractive scattering.

3. PION SCATTERING IN THE FRAME OF THE DIFFRACTION THEORY

If one supposes that the total cross-section curve, $\sigma_T(E)$, for pion interaction with the proton is given by the scattering of the pions on the centres that represents the building blocks of the proton, then we can compute the pair correlation function or the so-called radial distribution curve. From this curve one gets the minimum distances between the scattering centres, the positions of the first neighbours, second neighbours, the mean number of the neighbours in the first co-ordination, etc. Thus, an image of the main structure of a cluster of scattering centres can be obtained.

Firstly we have carefully smoothed the experimental curves of π^+p and π^-p cross-sections. Figs. 1 and 2 show the smoothed curves used in our calculations.

Thereafter, the associated de Broglie wavelength for pions was calculated for every pion energy:

$$\lambda_\pi = \frac{h \cdot c}{E^2 - E_\pi^2}, \tag{1}$$

where E_π = 140 MeV.

Using the calculated pion wavelength, λ_π, we transformed the $\sigma_T(E)$ curves into $\sigma_T(2\theta)$ curves, which represent the scattered intensity of the pion beam *versus* the double of the angle of scattering as in the case of the classical geometry of X-ray diffraction in the Debye-/Scherrer method.

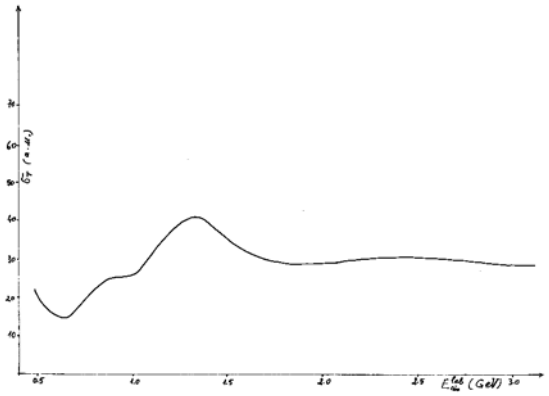
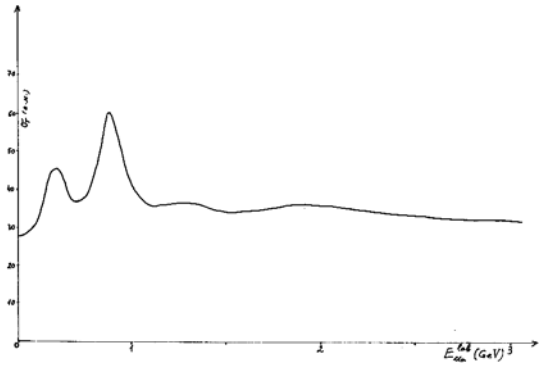


Fig. 1 – $\sigma_T(E)$ for π^+p cross-sections.

Fig. 2 – $\sigma_T(E)$ for π^-p cross-sections.



The angles θ were calculated with the formula:

$$\theta = \arcsin\left(\lambda_\pi \frac{E^2 - E_\pi^2}{h \cdot c \cdot 2 \cdot \sin\theta_m}\right), \tag{2}$$

where θ_m is the fixed angle measured against the pion beam at which the data are collected. Diddens *et al.* [4] reported a typical experimental value for this angle of $2\theta_m = 15°$. We used this value in calculations. Finally, the scattering curves were processed in order to get the pair correlation function. To this purpose, a curve for independent scattering, similar to the atomic scattering factor in the theory of

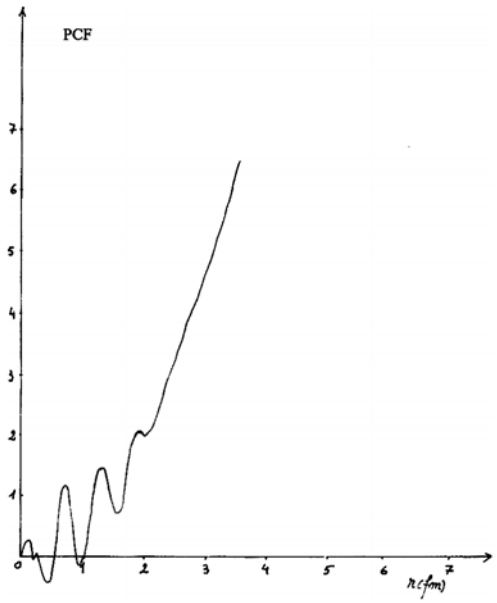


Fig. 3 – Pair correlation function for π^+p scattering.

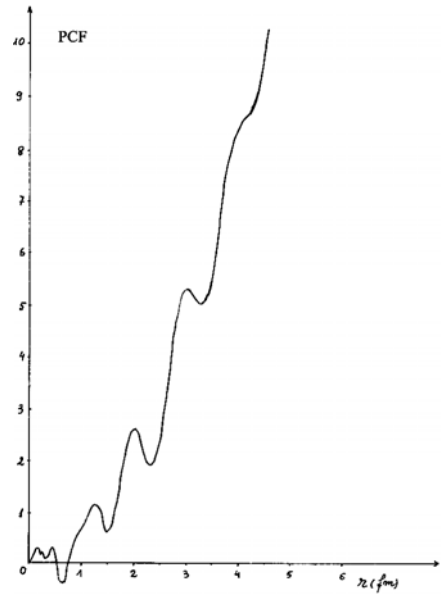


Fig. 4 – Pair correlation function for π^-p scattering.

scattering on atomic centres in solids, was proposed. The Fourier transforms of the pion scattering curves were obtained by a special computer program for X-ray analysis, adapted for these special cases.

The pair correlation functions for π^+p and π^-p scattering are shown in Figs. 3 and 4.

4. RESULTS AND DISCUSSION

The main structural results are presented in Table 1. From the scattering of the positive pions one gets the nearest neighbour distance between the scattering centres in proton: 0.71 fm. From the negative pions scattering the first neighbour sphere is split and the distances between the scattering centres are 0.95 and 1.22 fm, the latter one being prevalent. We suppose that the information given by π^+p scattering is related only to the positively charged centres, while that given by π^-p scattering is due only to negatively charged centres.

Table 1

The structural data of the proton calculated from the pion scattering. The data are compared to those for typical liquids and amorphous solids

Co-ordination spheres	Radial distribution of positive centres		Experim. for liquids			Radial distr. of negative centres			Experim. a-Ge; H_2O
	r_i [fm]	r_i/r_1	He	Ne	Ar	r_i [fm]	r_i/r_1	r_i/r_2	a-Ge
r_1	0.71	1	1	1	1	(0,95)	1	–	–
r_2	1.28	1.80	1.87	1.85	1.81	1.22	1.28	1	1
r_3	1.87	2.63	2.66	2.77	2.64	1.95	2.05	1.60	1.63
r_4			3.58	3.57	3.44	2.91	3.06	2.39	2.45

The sequence of successive peaks in the pair correlation function of positive pions scattering allows concluding that the positive centres in proton are structured very similarly as in liquid He, Ne or Ar (at 4 K). Therefore, the structural ordering of the positive constituents of the proton is that of a quantum fluid with coordination number 8.

As opposite, the negative centres are situated in a tetrahedral configuration and, probably, occupy the interstices of the positive cluster of centres, and are extended beyond this cluster. The tetrahedral disposal of the negative centres was inferred on the basis of the similarity of the negative pion PCF with the PCF of amorphous silicon, germanium and water, well-known tetrahedral structures.

The total number of scattering centers in proton can be only roughly estimated. Taking into account that, for the positive centres, only three distances are revealed on the PCF curve, it results 13 centres. The radius of the proton taken

as the second neighbour distance in the PCF curve (for positive pion scattering) is 1.28 fm, very near to the general accepted value: 1.2 fm [5]. From the PCF of the negative pion scattering one obtains a proton radius of 1.45 fm, a value significantly higher than the usually accepted one. Nevertheless, the radius of the meson cloud supposed to enclose the nucleon core is 1.4 fm in the old models for the proton structure. It is evident that the calculated radius of the proton is affected by errors due to many factors, but especially due to the error in the estimation of the $2\theta_m$ angle. The deviation of this angle from its true value does not influence the conclusion regarding the type of structural configuration of the scattering centres, but the absolute values of the distances between the centres are significantly influenced.

On the basis of the above data, the total number of the scattering centres in the proton can be estimated roughly: 20–30. A simple geometrical modelling suggests a number of 28 centres to be present in the proton.

5. CONCLUSIONS

The application of the energy dispersive method to the interpretation of the experimental curves for the pion scattering cross-section analysis, allowed to get the proton radius in quite a satisfactory agreement with the general accepted value, and gave some insights into the proton structure.

There was revealed that the proton contains positive scattering centres with a network configuration similar to that of quantum liquids (8 first order neighbours) and negative centres in tetrahedral configuration.

A total number of scattering centres in proton was estimated: 20–30. This large number of centres is unfortunately at variance with the number of quarks now supposed to be integrated in the proton.

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